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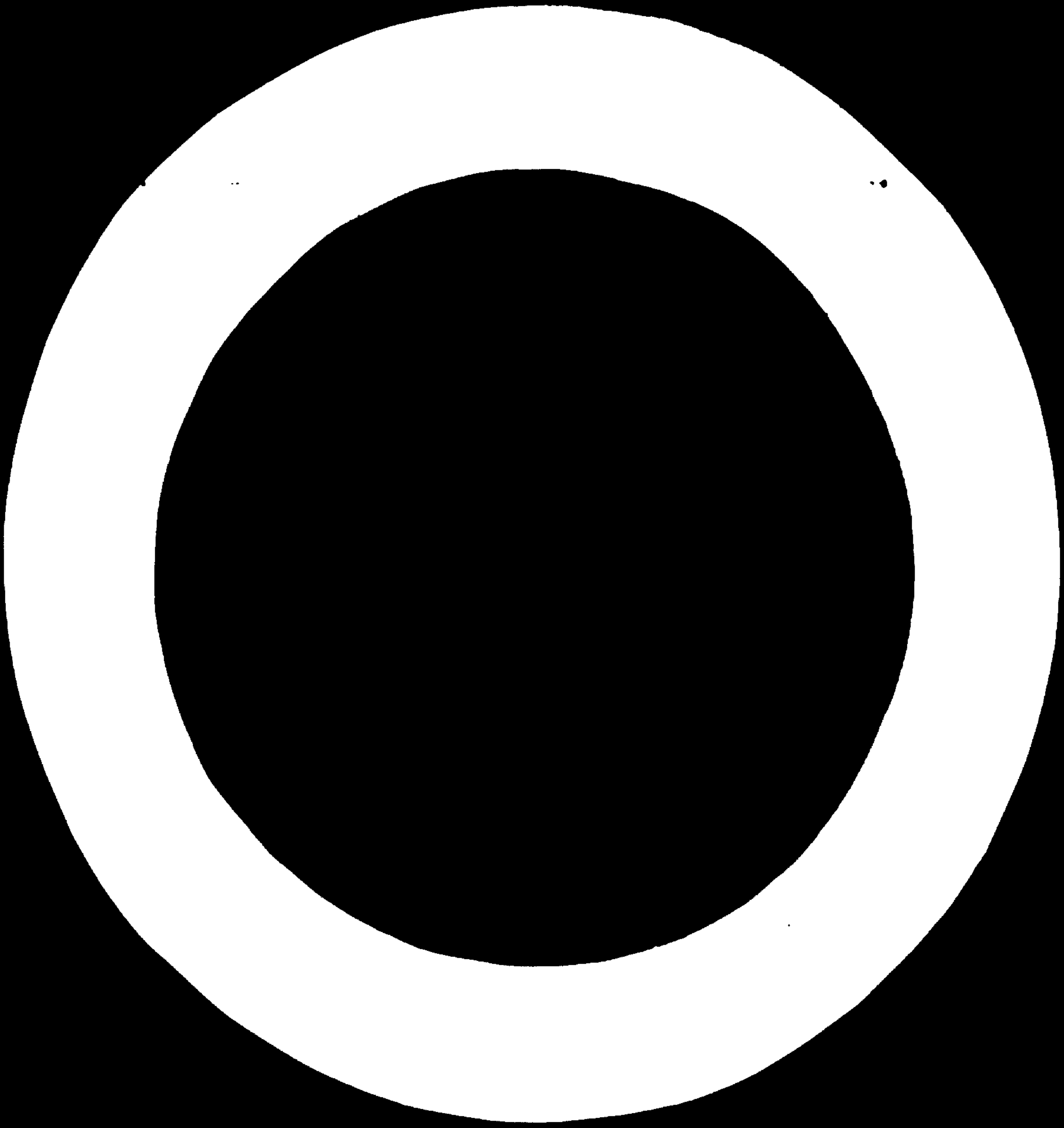
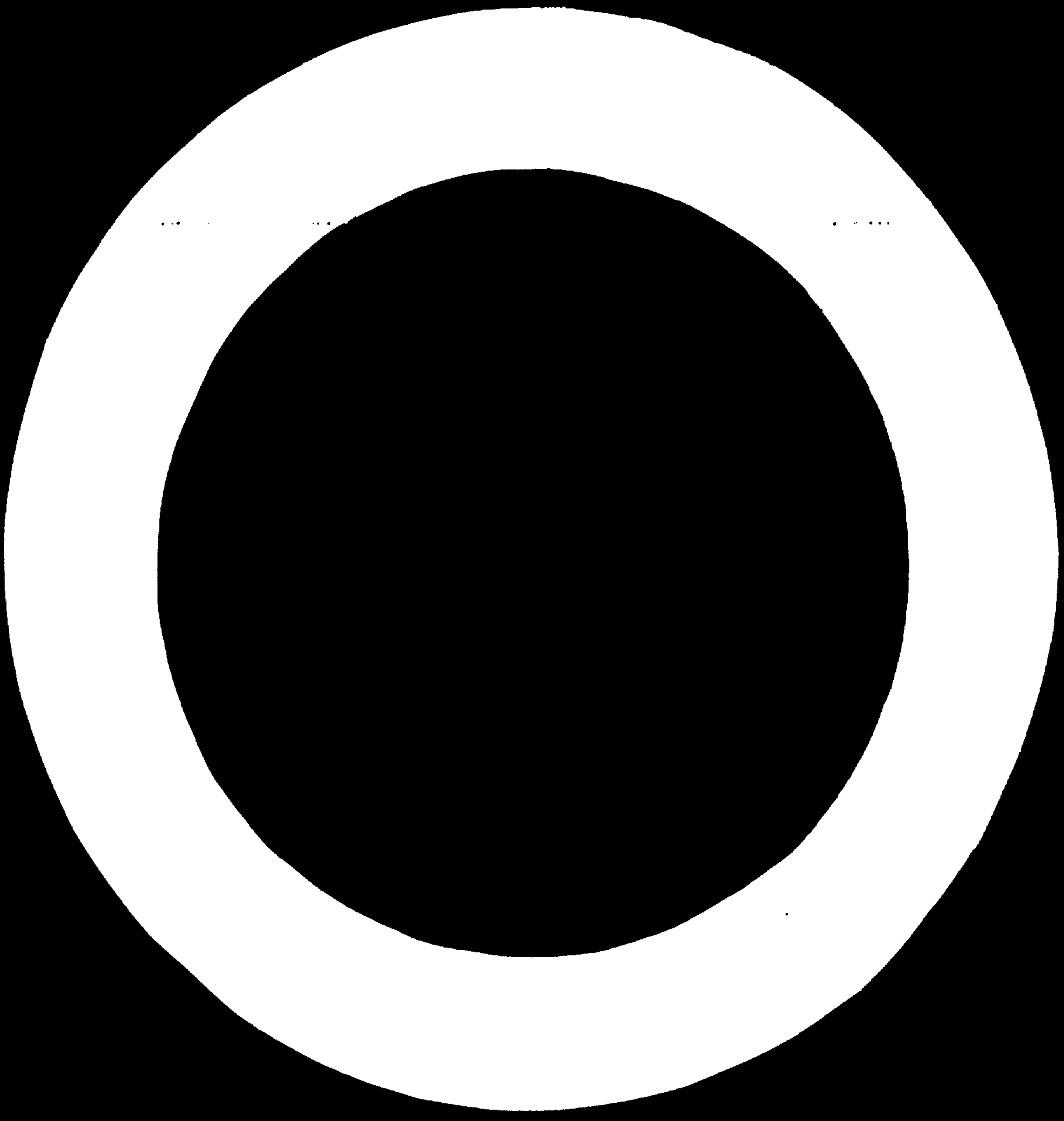
STUDIES IN PETROCHEMICALS

UNITED NATIONS





Volume II

STUDIES IN PETROCHEMICALS

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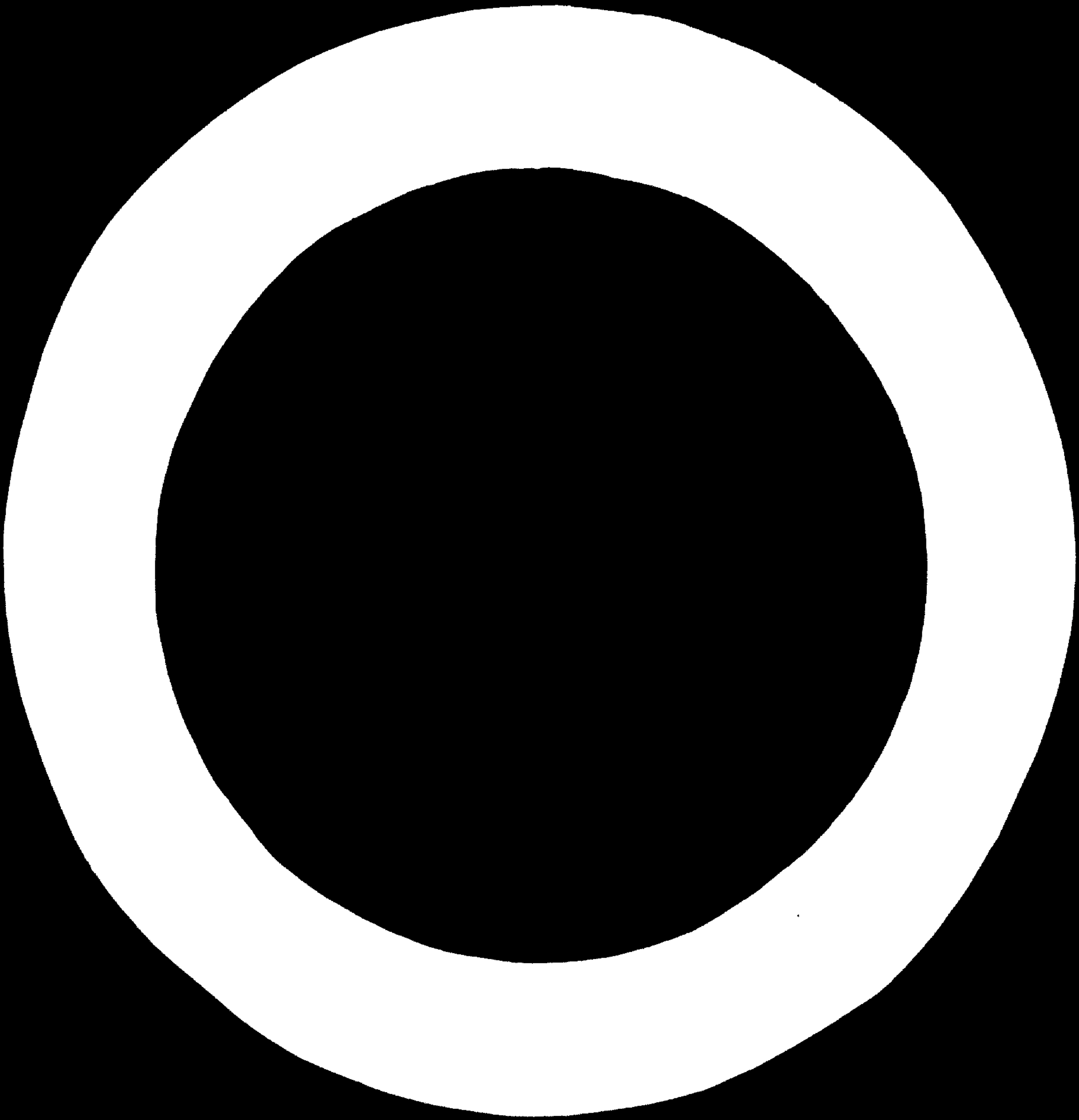


D. Synthetic fibres

INTRODUCTORY SUMMARY

The synthetic-fibre journey of a petroleum extraction from its source to the consumer's home proceeds in a series of transformations effected by various chemical processes. This journey which is technically described as the "process route" may be described in non-technical terms as follows: first, there is petroleum extraction which is followed, in order, by refinery operation, production of aromatics and olefins, production of petrochemical raw materials, production of synthetic fabrics and, finally, the shipment of these fabrics to the consumers.

The most important synthetic fibres manufactured from petroleum intermediates are polyamides (nylon), polyesters (dacron, terylene, fortrel etc.) acrylic fibres, (orlon, acrilan etc.). Of the total world output of synthetic fibres, approximately 51 per cent are polyamides, 20 per cent polyesters and 19 per cent acrylic fibres.

Polyamides and polyesters differ in elasticity and chemical resistance. The former are largely based on benzene. In particular, nylon 66—a brand of polyamide—may be based on propylene, butadiene or cyclohexane A reaction of acid with amine, followed by condensation polymerization (elimination of water), yields a polyamide (nylon). At each stage in the process route, that is, before the final product is manufactured, one or two raw materials may turn out to be the most important. An example of this is caprolactam which is the relevant monomer for the production of polyamides. An important point to note is that the cost of producing such intermediate raw materials largely determines the commercial feasibility of producing the final product.

Caprolactam may be produced from cyclohexane, benzene, phenol or toluene as primary raw materials. For the manufacture of nylon 6, the cyclohexane method is considered the least expensive. But, the economy of a process should be conceived as varying not only with the price of the most important intermediate raw material used in the process, but also the size, location of the plant and the by-products generated. The production of caprolactam forms an important basis not only for the synthetic fibre under discussion, but also for nutrition industries. It is known that lysine, an amino-acid which is a constitutent of proteins, can be produced from caprolactam. The alternative uses of caprolactam, as well as of any other important raw material, should influence the decision on its use in any specific channel.

A reaction of acids and alcohols, the most important of which are terephthalic acid and ethylene glycol, results in the production of polyester fibres. In the United States, polyester fabrics are sold under the trade name of "dacron", and in Britain under "terylene". In Japan, Italy and the Federal Republic of Germany, different trade names are also in use. For the production of terephthalic acid, p-xylene, a product of petroleum refining, is the major raw material, while ethylene glycol is based on ethylene production. The other synthetic fibres, namely acrylics and polyacrylonitrile are, respectively, based on acetylene-cum-hydrogen cyanide and propylene. Acrylics can also be manufactured by a direct synthesis of ammonia and propylene.

The main issues that emerge from thinking about the prospects for the establishment of synthetic fibre production in developing countries are whether the intermediate raw materials should be imported or manufactured domestically and, if this decision can be easily made, which technical processes had better be used. To develop the production of synthetic fibres, in developing countries, it is suggested that production should start from the last stage and develop backwards to the manufacture of petroleum intermediates. This means that importing the intermediate raw materials might be more economical initially.

The successful establishment of a synthetic fibre production depends not only on the prospects of cost minimization, but to a large degree on the extent of the market and its fashion-taste orientation. A thorough investigation of the customer's acceptance of the end-product would be advisable. Consideration should be given to the fact that urban-dwellers are generally more disposed to accept synthetic fibres than the country-dwellers who prefer natural fabrics, notably cotton, especially in less developed countries.

1. THE PETROCHEMICAL INDUSTRIES

Synthetic fibres

Prepared for the United Nations Centre for Industrial Development by l'Institut français du pétrole

I. Introduction

Synthetic and artificial fibres constitute approximately 23 per cent of the total world consumption of natural and chemical fibres, of which synthetics are about 25 per cent and artificials 75 per cent. Synthetics and artificials are estimated to be equally divided in the United States of America for 1965.

The field of synthetic fibres is only little more than twenty years old. First-comer was nylon, a polyamide based on adipic acid and hexamethylene diamine. To-day nylon fibres, including the caprolactam-based types still make up some 50 per cent of the synthetic fibres market. In the second place, both chronologically and in terms of present importance, it is the acrylic fibres which have been introduced largely at the expense of markets for wool. A strong market growth is shown by polyesters, notably types based on condensation compounds of dimethyl terephthalate and ethylene glycol. Still other fibres which are being introduced include products based on vinyl chloride and polyvinyl alcohol.

II. Role of petrochemicals in synthetic fibres manufacture

If petrochemicals play a relatively minor role as to the supply of intermediate products (acetic acid and acetic anhydride) as feedstocks for the cellulosics manufacture (viscose rayon and acetate rayon), synthetics constitute both the most significant and the fastest growing market for petrochemicals in the textile field.

It will be the purpose of the following sections to consider for the most important synthetic fibres as: nylons, acrylics, and polyesters

(*a*) The manufacture of the principal monomers, which are supplied by the petrochemical industry and which find their principal outlets in the manufacture of wholly man-made fibres;

(*b*) The manufacture of polymers derivatives;

(*c*) The spinning and drawing of polymers into synthetic fibres.

III. Nylon-type fibres

Two types of nylon make up almost the entire market: nylon 66 which is a copolymer of adipic acid and hexamethylene diamine; and nylon 6 which is formed by polymerization of caprolactam. Nylon 6 was not introduced to the American market until 1954 (it had previously been produced in Europe); but since its introduction this fibre has grown rapidly and if it accounted only for 12 per cent of the United States market for nylon, everywhere else it has the first position.

A. MANUFACTURE OF MONOMERS

Three intermediates constitute the bulk of raw material requirements in nylon production: adipic acid and hexamethylene diamine for nylon 66; and caprolactam for nylon 6.

1. ADIPIC ACID

Adipic acid is not only one of the monomers for nylon 66, it is also an intermediate in one route to hexamethylene diamine, the other monomer. Two routes are used in the commercial synthesis of adipic acid. The older approach employs phenol as raw material, while the alternative method starts from cyclohexane. In both instances, the key intermediate is cyclohexanol.

(a) *Phenol route*

Cyclohexanol is obtained by the hydrogenation of phenol and converted to adipic acid, using nitric acid as oxidizing agent.

(b) *Cyclohexane route*

Conversion of cyclohexane to adipic acid is effected in two steps: air oxidation to a mixture of cyclohexanol and cyclohexanone, followed by nitric acid oxidation of these intermediates to adipic acid.

2. HEXAMETHYLENE DIAMINE

Hexamethylene diamine is the second key intermediate in the manufacture of nylon 66. The compound may be produced by the hydrogenation of adiponitrile which is obtained commercially by one of two routes which start from adipic acid and from 1,4-butadiene, respectively.

(a) *Adiponitrile* via *adipic acid*

Adipic acid is reacted with ammonia. The resulting ammonium adipate and adipamide are dehydrated to adiponitrile.

(b) *Butadiene route to adiponitrile*

This conversion is carried out in three successive steps: (*a*) chlorination of butadiene to dichlorobutene; (*b*) nitrilation of dichlorobutene with hydrogen cyanide; (*c*) hydrogenation of dicyanobutene into adiponitrile.

3. CAPROLACTAM

This material offers a potentially lower-cost raw materials base than hexamethylene diamine and thus provides a long-term competitive advantage for nylon 6 over the more firmly established nylon 66.

Caprolactam may be produced from cyclohexane, benzene or toluene as primary raw materials. In the case of cyclohexane and benzene, the routes of synthesis lead via cyclohexanone oxime and the synthesis of this intermediate is the key to the manufacture of caprolactam.

Thus, cyclohexanone oxime may be produced from cyclohexylamine, derived either from aniline or from cyclohexanol. Alternatively, cyclohexanone oxime can be produced from phenol via the cyclohexanone. Both cyclohexanol and cyclohexanone thus figure as intermediates in the synthesis of both caprolactam (for nylon 6) and adipic acid (for nylon 66), emphasizing the close chemical relationship between the two types of nylon (see figure I below).

Synthesis of caprolactam from cyclohexanone consists of two steps:

(*a*) Reaction of cyclohexanone with hydroxylamine sulfate, producing ammonium sulfate as co-product;

(*b*) Beckmann rearrangement to convert cyclohexanone oxime into caprolactam.

Synthesis of caprolactam from aniline is also carried out via cyclohexanol oxime. The route involves intermediate production of cyclohexylamine.

(a) *Economics of caprolactam manufacture*

Elements of the operating cost for a 15,000 tons/year caprolactam plant based, respectively, on phenol and benzene-cyclohexane feedstocks are presented in the tables 1 and 2 below.

TABLE 1. 15,000 TONS/YEAR CAPROLACTAM PRODUCTION BASED ON BENZENE-CYCLOHEXANE ROUTE[a]

Operating cost elements

Investment	
Process units (MM $)	13.5
Raw-material consumption	
Benzene (tons/year)	16,600
Hydrogen (10^3 m^3/year)	17,200
Ammonia (tons/year)	28,500
Oleum at 20 % (tons/year)	20,300
Sulfur (tons/year)	14,300
CO_2 (tons/year)	9,300
By-product ammonium sulfate (tons/year)	75,000
Utilities requirements	
Electricity (10^3 kWh/year)	23,000
Steam (10^3 tons/year)	280
Fuel (10^6 kcal/year)	1,000
Refrigeration[b] (10^3 kFrigories/year)	45,000
Cooling water (10^3 m^3/year)	30,000
Demineralized water (10^3 m^3/year)	150
Chemicals and catalyst consumption (10^3 $/year)	16
Labour	
Men/shift[c]	30
Men/day	6

[a] Hydroxylamine sulfate production is included.

[b] At — 15 °C (NH_3).

[c] Including chemists.

The benzene cyclohexane process is carried out in five steps:

(*a*) Benzene hydrogenation;

(*b*) Oxydation of cyclohexane;

(*c*) Production of cycohexanone oxime;

(*d*) Conversion of the oxime to caprolactam;

(*e*) Extraction of caprolactam.

The phenol-based process consists of:

(*a*) Phenol hydrogenation into cyclohexanol-cyclohexanone mixture;

(*b*) See steps (*b*), (*c*), (*d*) and (*e*) of benzene-based process.

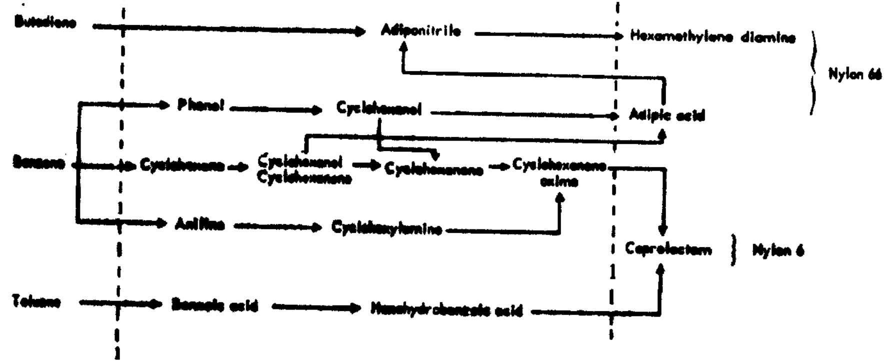


Figure I. Relationship between nylon 6 and nylon 66 intermediates

TABLE 2. 15,000 TONS/YEAR CAPROLACTAM PRODUCTION BASED ON PHENOL FEED-STOCK

Operating cost elements

Investment	
Process units (MM $)	12.4
Raw materials	
Phenol (tons/year)	14,700
Hydrogen (tons/year)	1,320
Ammonia (tons/year)	28,500
CO_2 (tons/year)	10,500
Sulfur (tons/year)	14,300
Oleum (20-25 %) (tons/year)	22,500
By-product ammonium sulfate (tons/year)	81,000
Utilities	
Electricity (10^3 kWh/year)	24,800
Steam (10^3 tons/year)	400
Fuel oil (10^3 tons/year)	0.6
Refrigeration [a] (10^6 kFrigories/year)	45,000
Cooling water (10^3 m^3/year)	16,500
Demineralized water (10^3 m^3/year)	150
Labour	
Men/shift [b]	30
Men/day	6

[a] At −15°C (NH_3).

[b] Including chemists.

B. POLYMERIZATION

1. NYLON 6 PRODUCTION

The polymerization of caprolactam to nylon 6 can be realized batch-wise, but it is more usually carried out continuously at atmospheric pressure, in a tubular reactor.

Solid caprolactam is melted and passed into a mixer with the catalyst and the chain terminator. The mixture is introduced into the reactor, the tubes are heated to 250°C; the residence time is about twenty hours.

The polymer leaves the reactor in a molten state; the impurities are removed by distillation. The polymer may be either cast into ribbon form, quenched and cut, or sent directly to the spinnerets.

2. NYLON 66 PRODUCTION

This manufacture is carried out in two phases which are explained in (*a*) and (*b*).

(a) *Polycondensation of adipic acid and hexamethylene diamine*

In order to obtain large molecules, we have to introduce into the polymerization reactor an equal number of molecules of the diamine and of the dibasic acid. This problem is solved by feeding the reactor by the salt. There are two methods to form this salt: either in water or in methanol.

(i) *Process in water*

An aqueous solution of hexamethylene diamine is added to a mixture of water and adipic acid. The temperature rise is controlled. When the pH is adjusted to that of the neutral salt, the product — a solution of about 50 per cent of salt — is concentrated to 70 per cent by evaporation.

(ii) *Preparation in methanol*

Solutions of adipic acid and hexamethylene diamine in methanol are introduced continuously into a stirred reactor. The heat of reaction vaporizes the methanol and this is removed by condensing the vapours. The salt, insoluble in the methanol, is separated by crystallization. The crystals are centrifugated and dried. The salt is then dissolved in distilled and demineralized water. We obtain a 60-70 per cent solution.

(b) *Polymerization*

The aqueous solution of salt is sent to a heated autoclave, the atmosphere of which is free from oxygen. The pressure and temperature in the reactor are increased. Then pressure is reduced, while the temperature continues to rise. The total residence time is about five hours.

The polymer is then extruded; to realize the extrusion, we apply a nitrogen pressure in the autoclave. The polymer ribbon is cooled by water jets. The surface moisture is removed by air; then the ribbon is cut into "chips".

C. MANUFACTURE OF POLYAMIDE FIBRES

The conversion of nylon polymers into fibres is carried out in two steps: spinning and drawing.

1. THE SPINNING PROCESS

There are three methods of spinning:

(*a*) Grid spinning, mostly used for nylon 66;

(*b*) Band spinning, to treat nylon 6 of an accurately dimensioned form;

(*c*) Direct spinning from the polymerization reactor; this method which avoids the need to remelt, is most easily applicable to nylon 6.

(a) *Grid spinning*

To avoid thermal decomposition, the polymer flake is placed under inert atmosphere (steam or nitrogen). For spinning under nitrogen, the flake is dried and charged into a hopper, free of air, under nitrogen pressure. Then the flake is passed into a second hopper, which permits a continuous spinning during purge and recharge of the superior hopper. The second hopper is purged by nitrogen to remove the moisture produced during melting. The polymer passes through a heated melt block and falls into a hot grid.

Melting under steam needs not more than one hopper and is carried out at a known pressure, generally one atmosphere. Thus, the melting control is easier, but an overcharging pump must be added.

The molten polymer is filtered by sand and sent to a spinneret; the holes are circular, about 2/10 mm in diameter. The extruded filaments are cooled by air and solidified. They feed a steam-filled tube where their moisture increases and the static electrical charges reduce. After an oil finishing, the filaments are wound.

(b) *Band spinning*

The installation is fed by an accurately sized band of polymer. The band passes at a fixed rate into a heated channel of the same dimension as the band. The polymer melts and passes through a filter of sand and a spinneret. The filaments are cooled and treated in a similar manner as with grid spinning.

(c) *Direct spinning*

At the end of the polymerization tube, the viscous polymer is pumped through a battery of spinnerets and extruded to filaments. Then the filaments are cooled, lubricated and collected.

2. THE DRAWING PROCESS

The yarn is fed at a uniform rate to a draw roll. The peripheral speed of the roll is greater than that of the feed.

A number of wraps around the rolls are needed to avoid slippage. Then the yarn passes to a down-twist spindle, giving a low twist to the yarn to facilitate handling.

3. STAPLE FIBRE MANUFACTURE

After drawing, the yarn is crimped. Then the crimped tow is passed on to a cutter.

D. PRODUCTION OF 5,000 TONS/YEAR NYLON 6 FILAMENTS 40/50 AVERAGE DENIER

The elements of the operating cost for such a plant, starting from caprolactam monomer and including: polymerization, spinning and draw-twisting, are given below :

Investment	
Process units (MM $)	**12.5**
Raw material consumption	
Caprolactam (tons/year)	**5,500**
Utilities requirements	
Electricity (10^3 kWh/year)	**35,000**
Steam (10^3 tons/year)	**15**
Cooling water (10^3 m^3/year)	**18,000**
Demineralized water (10^3 m^3/year)	**20,000**
Nitrogen (10^3 m^3/year)	**500**
Labour	
Men/shift	**40**
Men/day	**5**

IV. Acrylic fibres

The main raw material for acrylic fibres is acrylonitrile. This constitutes 100 per cent of the monomer for Du Pont's orlon, but only 40 per cent of the raw material for Union Carbide's Dynel (a vinyl chloride copolymer). Other fibres vary in acrylonitrile content from 55 to 85 per cent.

A. MANUFACTURE OF ACRYLONITRILE MONOMER

By far the most important source of acrylonitrile is the direct synthesis from acetylene and hydrogen cyanide, although a smaller quantity is reportedly still made by the conventional route based on hydrogen cyanide and ethylene oxide.

An alternative route, in which propylene and ammonia serve as raw materials, is expected to become an important factor in future production and utilization, both in the United States of America and abroad. The advantages are the following:

(a) Greater abundance of suitable raw materials at lower prices than acetylene, ethylene oxide and HCN;

(b) Process simplicity compared to other processes which require several steps;

(c) Lack of necessity to feed and store the HCN;

(d) High product quality.

Extension of acrylonitrile consumption in the major outlets: acrylic fibres, nitrile rubbers and plastics, notably ABS resins, allied to the development of these new manufacturing processes, allows cheaper acrylonitrile to be produced.

TABLE 3. 30,000 TONS/YEAR ACRYLONITRILE PRODUCTION BASED ON PROPYLENE FEED-STOCK

Operating cost elements

Investment	
Including process units, general installation and tankage (MM $)	**12**
***Material balance* (tons/year)**	
Propylene at 92 %	**48,300**
Ammonia	**21,600**
H_2SO_4	**24,800**
By-products credit :	
Ammonium sulfate	**30,900**
HCN	**4,500**
Acrolein	**1,200**
Acetonitrile	**900**
Catalyst and chemicals	**$360,000/year**
Utilities requirements	
Electricity (10^3 kWh/year)	**42,000**
Steam (tons/year)	**216,000**
Cooling water (10^3 m^3/year)	**18,000**
Labour	
Men/shift	**6**
Men/day	**2**

TABLE 4. 30,000 TONS/YEAR ACRYLONITRILE PRODUCTION BASED ON PROPYLENE FEED-STOCK

Manufacturing cost

	Unit	*Unit cost $US*	*Annual quantity*	*Annual cost 10^3 $/year*	
Variable charges					
Raw materials					
Propylene	Tons	50	48,300	2.415	
Ammonia	Tons	70	21,600	1,515	
H_2SO_4	Tons	30	24,800	745	
					4,675
By-products credit					
Ammonium sulfate . . .	Tons	24	30,900	740	
HCN	Tons	240	4,500	1,080	
Acrolein	Tons	500	1,200	600	
Acetonitrile	Tons	500	900	450	
					— (2,870)
Utilities					
Electricity	10^6 kWh	10	42,000	420	
Steam	Tons	1.6	216,000	346	
Cooling water	10^6 m^3	6	18,000	108	
					874
Catalyst and chemicals . . .	Tons	12	30,000		360
Labour					
Salaries and wages	Men/year	5,000	26	130	
Supervision at 25 % of salaries and wages				32	
					162
TOTAL VARIABLE CHARGES					3,201
Fixed charges					
Depreciation at 12.5 % of total investment					
Interest at 3.5 % of total investment					
Maintenance at 4 % of total investment					
General plant overhead at 2 % of total investment					
Taxes and insurance at 1 % of total investment					
TOTAL FIXED CHARGES					2,760
MANUFACTURING COST					5,961

A comparison of the acrylonitrile manufacture based, respectively, on acetylene and propylene feed-stocks, is given below.

Raw materials	*Propylene ammonia*		*Acetylene methane ammonia*
Investment (MM $)	12		11
Raw material price ($/ton) . .	Propylene : 50		Acetylene : 290
Manufacturing cost ($/ton)			
Raw materials and by-products	60 [a]	164 [b]	340
Utilities, catalyst and chemicals, labour	47	47	80
Fixed charges	93	92	83
Profits [c] and taxes [d]	60	60	53
Acrylonitrile selling price ($/ton)	260	363	556

---

[a] The by-products are fully valorized.

[b] Only ammonium sulfate is valorized.

[c] Corresponding to a five-year payout.

[d] Taxes on profits at 30 per cent.

Detailed elements of the operating cost for a 30,000 tons/year acrylonitrile plant based on propylene are presented in table 3. Manufacturing cost and derived selling price are given, in tables 4 and 5, respectively.

TABLE 5. 30,000 TONS/YEAR ACRYLONITRILE PRODUCTION BASED ON PROPYLENE FEED-STOCK

Acrylonitrile selling price

	Annual cost 10^3 $/year
Net cash flow at 20 per cent of total investment . .	2,400
Depreciation provides	1,500
Net income after taxes	900
Net income before taxes at 50 per cent	1,800
Manufacturing cost	5,961
TOTAL SALES	7,761
Acrylonitrile selling price ($/ton)	260
(or ¢/lb)	12

B. POLYMERIZATION OF ACRYLONITRILE

Acrylonitrile is polymerized in suspension. Acrylonitrile is introduced into a reactor with methyl acrylate (about 6 per cent), demineralized water and reactants able to form free radicals such as SO_4 or OH. Such radicals are polymerization initiators. The reaction is carried out under nitrogen atmosphere. The temperature in the reactor is controlled. The reaction product is sent to a stripping column. The monomer is withdrawn at the top; the polymer and the water leave at the bottom of the column. The polymer is separated by rotational filters, and then granulated and dried.

C. MANUFACTURE OF POLYACRYLONITRILE FIBRES

The polymer is ground and dispersed in a solvent. The dispersion is degasified under vacuum, heated and passed to a pressure filter. The collodion passes through another filter and goes to a coagulating bath. The filaments are gathered in bands and are cold drawn. They are passed into a washing vat and hot drawn. Solvent and water are recovered; the solvent is concentrated by distillation and recycled. The bands must be dried and then stabilized by saturated steam. The filaments are plasticized and crimped by compression, to increase their cohesion.

D. PRODUCTION OF 20,000 TONS/YEAR ACRYLIC STAPLE FIBRES

The elements of the operating cost for such a plant, based on acrylonitrile monomer, are given below:

TABLE 6. 20,000 TONS/YEAR ACRYLIC STAPLE FIBRE PRODUCTION

Operating cost elements

Investment	
Process units, including: polymerization; spinning; finishing; solvent distillation (MM $)	14.4
Raw material	
Acrylonitrile (tons/year)	20,400
Utilities	
Electricity (10^3 kWh/year)	37,000
Steam (10^3 tons/year)	400
Cooling water (10^3 m^3/year)	17,400
Demineralized water (10^3 m^3/year)	640
Compressed air (10^3 m^3/year)	860
Chemicals and catalyst ($/year)	800,000
Labour	
Men/shift	75
Men/day	20

V. Polyester fibres

Terephthalic acid and its ester (dimethyl terephthalate) (DMT) are the key intermediates in the polyester fibres production. The polyester fibres are made of polyethylene terephthalate which is obtained by reaction of a molecule either of terephthalic acid or of dimethyl terephthalate, with two molecules of ethylene glycol.

All the manufacturing processes of the ester have a step where terephthalic acid is produced: this acid is impure and very difficult to purify. So it is preferred to produce the ester by distillation, in which it is more easily purifiable.

At present nearly all the world production of polyester fibres is carried out by the DMT route. However, with the problem of the acid purification being solved, in Japan we assist in the erection of units to prepare terephthalic acid.

A. MANUFACTURE OF TEREPHTHALIC ACID

Terephthalic acid is prepared commercially by the partial oxidation of p-xylene. The agents for the oxidation of p-xylene are: air, or nitric acid.

1. AIR OXIDATION PROCESS

This is the most attractive approach, but if it is a relatively simple means to oxidize one of the two methyl groups, the difficulty remains in converting the second methyl group of the xylene molecule.

2. NITRIC ACID OXIDATION PROCESS

This method is practiced by Du Pont, who is the largest manufacturer of terephthalic acid.

Economics of DMT manufacture

The elements of operating cost for a 10,000 tons/year plant based on oxidation by air of p-xylene are given below:

Investment (Process units and off-sites) (MM $)	4
Consumption per ton of DMT	
Raw materials	
p-xylene	0.75 ton
Methanol	0.31 ton
Utilities	
Electricity	500 kWh
Vapour	5 tons
Cooling water	1,000 m^3
Chemicals and catalyst	$4
Labour (men/shift)	4

B. POLYCONDENSATION OF DMT AND ETHYLENE GLYCOL —POLYMERIZATION AND MANUFACTURE OF POLYESTER FIBRES

1. POLYCONDENSATION

One molecule of dimethyl terephthalate reacts with two molecules of ethylene glycol under formation of methanol and dihydroxyl diethyl terephthalate, the monomer. Industrially, the reaction is carried out between 150 and

210°C, in the presence of a catalyst and with an excess of diethylene glycol. The equilibrium is displaced, by removing the methanol formed, in a column.

2. POLYMERIZATION

The monomer is not separated; some polymerization occurs in the reactor, and the effluent is a mixture of monomer, dimer, trimer and ethylene glycol. The polymerization is carried out in autoclaves, under an absolute pressure inferior to 1 mm of mercury, at about 280°C. The reactor is stirred and the glycol formed is removed. When the desired viscosity is reached, the polymer is extruded, cooled and cut into "chips".

3. POLYESTER FIBRES

Polyethylene terephthalate is melt-spinnable to give drawable fibres which then possess desirable properties of high strength and flexibility. Polyethylene terephthalate fibres are being produced as filament yarn, staple fibre and continuous staple.

C. PRODUCTION OF 5,000 TONS/YEAR POLYESTER STAPLE FIBRES (60 PER CENT COTTON TYPE AND 40 PER CENT WOOL TYPE)

The elements of operating cost for such a plant, including polycondensation, polymerization and fibre manufacture are given below:

Investment (Process units and off-sites) (MM $)	7
Raw materials consumption	
Dimethyl terephthalate	5,500 tons
Ethylene glycol	1,000 tons
Utility requirements	
Electricity (10^3 kWh/year)	4,500
Steam (10^3 tons/year)	25
Labour	
Men/shift	40
Men/day	5

2. THE PRODUCTION OF SYNTHETIC FIBRES ON A PETROCHEMICAL BASIS

P. Seifert, Director, Inventa AG. für Forschung und Patentverwertung, Switzerland

I. INTRODUCTION

Petroleum chemicals form part of the chemical industry, so that their substantial development can best be anticipated in areas with a highly developed chemical industry. The lack of availability of raw materials was the early limitation restricting petrochemical development beyond the United States. After 1945, for a variety of reasons, it became the policy of the petroleum industry to locate oil-refining capacity in the regions of major consumption. This resulted in a vast expansion in the refining capacity of Western Europe and caused attention to be diverted to the possibility of chemical production from these refinery sources.

II. RAW MATERIALS FOR PRODUCTION OF PETROCHEMICALS

The basic raw materials for chemical manufacture are natural gas, refinery gases and liquid hydrocarbon fractions. From these basic raw materials are derived the secondary raw materials, such as:

(a) *Acetylene*, prepared from methane;

(b) *Methane*, a major constituent of natural gas;

(c) *Higher paraffins* (ethane, propane, butane), which may be separated from natural gas or from refinery gas streams;

(d) *Ethylene, propylene*, present in refinery gas streams, or produced by pyrolysis or thermal cracking.

The lower paraffins are used too for the production of synthesis gas, which may be transformed to a mixture of CO_2 and H_2. Hydrogen gas produced in this way goes into the manufacture of ammonia, as well as into a variety of hydrogenation reactions.

For the production of synthetic fibres, not only aliphatic hydrocarbons are necessary, but also *aromatics*. These are obtained by catalytic reforming of naphthenic hydrocarbons. Benzene, toluene and xylene are used, mainly, as aromatic, secondary raw materials in the synthetic fibre industry.

All these compounds are available from coal also to the extent that coal is carbonized. This, in turn is related to the progress of the steel- and gas-making industries. However, these industries are not expanding in tune with the demand for aromatic hydrocarbons. The trend from coal to oil may best be illustrated by the United States production figures for aromatics (table 1).

Petrochemical units are usually continuous, elaborate, operating with catalytic promotion, and highly automated. They consequently require a large scale of operation to secure an economic advantage. Unless there is an economic advantage, there is little purpose in the development of petroleum raw materials to serve the chemical industry in any particular instance. Therefore, it is important to ensure that any project envisaged includes production facilities of not less than "minimum economic size". Having established the minimum economic size for a particular operation in a particular area, it is necessary to take a clear, cold look at the market available. A single petrochemical unit may be expected to serve a much higher proportion of the total market than most petroleum units would do. Since the final product is likely to be the subject of precise chemical specifications, there is little flexibility in production available to such units. This low flexibility of petrochemical units is a point to keep in mind.

The chemical industry thrives best in an industrial climate. Only in such a climate will exist the major con-

TABLE 1. UNITED STATES AROMATICS PRODUCTION

	Benzene		*Toluene*		*Xylene*	
	Coal	*Oil*	*Coal*	*Oil*	*Coal*	*Oil*
1952	216,000	35,500	64,000	41,000	10,000	61,500
1954	165,000	92,000	36,000	123,000	10,000	100,000
1956	225,000	112,000	43,000	131,000	12,000	124,000
1958	144,000	142,000	32,000	207,000	9,000	191,500
1960	140,000	309,000	33,500	240,000	8,500	274,000

SOURCE: Waddams, *Chemicals from Petroleum*, p. 122.

TABLE 2. WORLD FIBRE PRODUCTION

	1950 Mill. metr. tons	*1950* Per cent	*1963* Mill. metr. tons	*1963* Per cent	*1980 (estim. per cent)*
Cotton	6.25	69.5	15.50	72.4	60
Wool	0.95	10.6	1.50	7.0	
Cellulosic fibres	1.73	19.2	3.05	14.3	40
Synthetic fibres	0.07	0.7	1.32	6.3	
TOTAL	9.00	100.0	21.37	100.0	

sumers of its products, which the large-scale operations of petrochemical manufacture demand. Moreover, the production of chemicals from petroleum and—as we shall see—of intermediates for the synthetic fibres production, involves a considerable consumption of such chemicals as sulphuric acid, nitric acid, ammonia etc. These are generally available on an economic basis only in an industrial region.

The above outline will indicate the difficulties of initiating petroleum chemical manufacture in less industrialized areas, even where the raw materials are cheaply and abundantly available. One is faced with the alternative of building a plant mainly to meet local needs, in which case it will be so small as to be below the normal economic size (and may require government subsidy or some sort of protection to be viable), or of building the plant to an economic size, and then to hunt for external markets. Chemical plants are normally more expensive to construct (and maintain) in a less developed country, the techniques of industrial exporting are less highly organized, and most of the nearby markets will also be relatively small. Exporting chemicals from a less developed area is therefore a matter of some difficulty.

In the main part of our discussion paper, we would like to show the way from the secondary raw materials mentioned above to the production of the different synthetic fibres.

Let us first take a look at the present role of the synthetic fibres in world fibre production (tables 2 and 3). The magnitude of the sums involved in the synthetic fibre business may be assessed by the fact that, with an assumed mean price of $2,000/ton, an annual sales volume of $2,600 million is reached (1962).

TABLE 3. WORLD PRODUCTION OF MAN-MADE FIBRES (1,000 METR.TONS)

	Cellulosic fibres	*Synthetics*	*Total man-made fibres*
1959	2,521 (81 %)	577 (19 %)	3,098
1960	2,603	710	3,313
1961	2,690	838	3,528
1962	2,865	1,079	3,944
1963	3,050 (70 %)	1,320 (30 %)	4,370
Increase 1959-63	21 %	129 %	40 %

SOURCE : *Chemiefasern* (1964). S. 78.

TABLE 4. SYNTHETIC FIBRE PRODUCTION 1963

	Per cent
Polyamides	51
Polyesters	20
Acrylic fibres	16
Others	13

Polyamides, polyesters and acrylic fibres are the most important representatives of the synthetic fibres known today. The relative position of these groups is shown in table 4.

The rapid development in the field of polyamides and polyesters may best be seen in figure I. It reveals that the relative growth of polyester production is superior to that of the polyamides. This trend may, however, change in the coming years, depending on which of the two, polyamides or polyesters, wins the final contest for tyre cord.

In the following, we shall try to take a closer look at the production methods of some of these fibres.

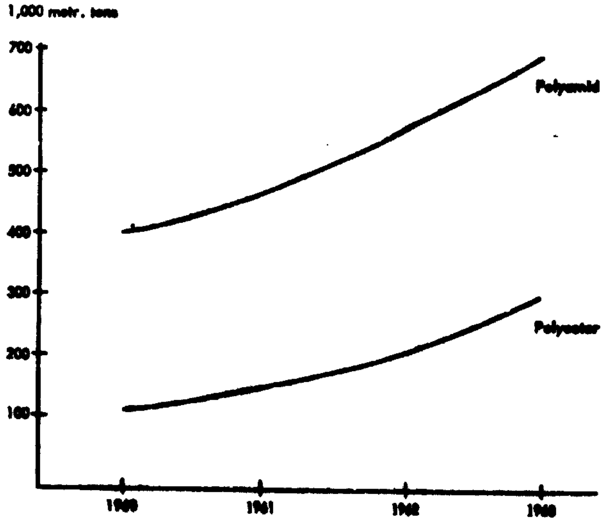


Figure I. *World production of polyamide and polyester*

III. POLYAMIDES OF THE NYLON 6 TYPE

Nylon 6 represents a European development originated by Professor Dr. Schlack, whereas nylon 66 was invented before the Second World War by W. H. Carothers of Du Pont (United States). The different development in the United States and in Western Europe persists to the present day. It seems, however, that in the near future this difference will get smaller, as nylon 6 capacities in the United States are built up, and production of nylon 66 starts in Western Europe. The figures relating to the East European countries are as yet uncertain and will therefore be disregarded in this survey.

The assumed capacities for caprolactam, the starting material for nylon 6 are given in figure II. A cheap caprolactam synthesis is decisive for any economical process for the production of nylon 6. It goes without saying that questions of location and starting materials available must be considered in the selection of a process. In the main, the following processes so far adopted for industrial utilization are known at present:

(*a*) The classical process starting from phenol;

(*b*) The classical process starting from cyclohexane with direct oxidation;

(*c*) The photo nitrozation process (PNC);

(*d*) The SNIA Viscosa process, starting with toluene;

(*e*) The nitration process of Du Pont.

The next illustration (figure III) is a formula representation of the various syntheses.

We would like to discuss now in more detail the cyclohexane oxidation process and shall, as an example, describe the procedure developed by Emser-Werke, and licensed by Inventa Ltd.

The process is in principle performed in two stages: i.e., it involves *first* the oxidation of cyclohexane with atmospheric oxygen at elevated temperature to yield a product mixture of unreacted cyclohexane, cyclohexanone, cyclohexanol and higher oxidation products, and *secondly*, the catalytic dehydrogenation of cyclohexanol to form cyclohexanone.

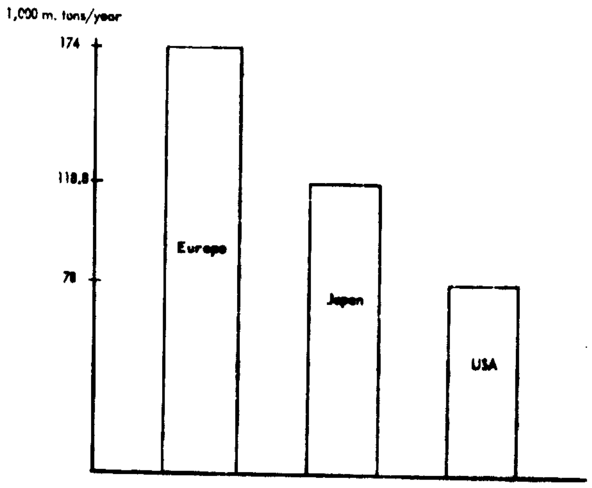


Figure II. *Caprolactam production (1963) (broken down for the United States, Western Europe and Japan)*

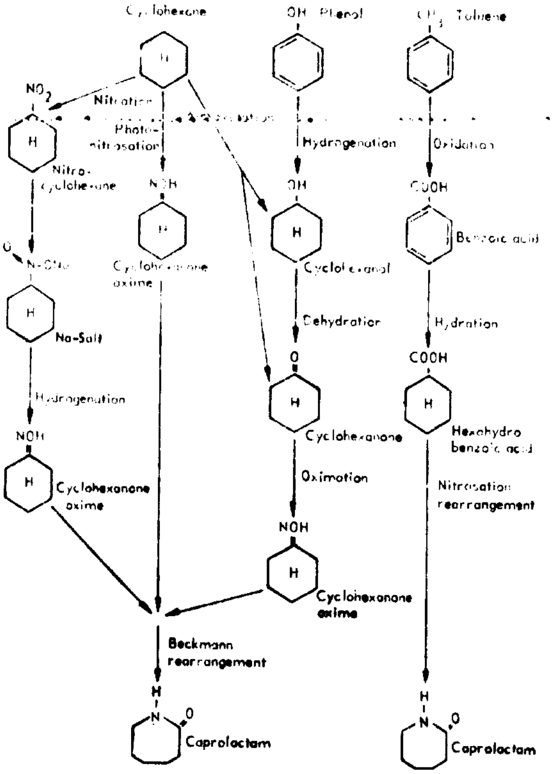


Figure III. *Lactam 6*

The oxidation stage yields part of the cyclohexanol esterified with by-product carboxylic acids. Therefore, the oxidation stage is followed by a hydrolysis step, in which the cyclohexanol is liberated, while all acid by-products are simultaneously separated. Next, unreacted cyclohexane is distilled off from the refined oxidation mixture, and the bottoms are pumped to a combined distillation-dehydrogenation system to give pure cyclohexanone. This product, derived from cyclohexane, gives on oximation and Beckmann rearrangement high-quality caprolactam and subsequently polymeric nylon 6 which is at least equal to the product obtained from phenol.

A cyclohexane-oxidation plant with a capacity of 1,000 t/month cyclohexanone was put on stream in March 1962. In more than two years of operation now, the process data originally established in the pilot plant were industrially confirmed and partially even exceeded. In addition, the plant supplied a wealth of chemical and technical data. The yields of cyclohexanol/cyclohexanone-mixture reach up to 80 per cent depending on the level of cyclohexane conversion. The following figures show the flow-sheet of this process and a few glimpses of the plant itself.

It is our opinion that the synthesis of caprolactam according to the cyclohexane oxidation process is a very economical way to produce nylon 6. UBE Industries (Japan) is operating successfully an Inventa oxidation plant, so is Mitsubishi Chemical Industries (Japan): further plants are in construction. BASF in the Federal

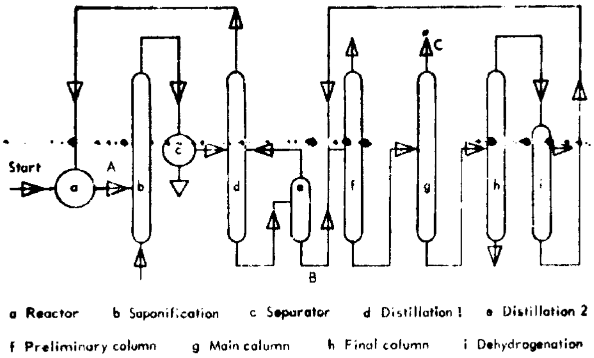


Figure IV. *Cyclohexane oxidation process*

Republic of Germany and Staatsmijnen in the Netherlands operate on a similar principle. Recently, Scientific Design sold a cyclohexane oxidation process to France. This process is, however, not yet industrially proven.

The importance of cyclohexane oxidation may be shown by listing the leading producers of caprolactam and their processes. The figures are taken from literature or estimated.

The economy of a process depends on the prices of the starting materials, i.e., cyclohexane, phenol, or toluene (SNIA) prices as the case may be. In addition, the size of the plants may be decisive for the selection of a process. According to our calculations, with capacities under 5,000 tons per annum the phenol process is more economical than the direct oxidation process, due to the lower capital requirements. On the other hand, the cyclohexane oxidation process is profitable above 5,000 tons per annum.

In the classical process involving the oximation stage, the provision of ***hydroxylamine*** and its price is of particular significance. For hydroxylamine, the following processes are known today:

(*a*) The classical process via sodium nitrite according to Raschig;

(*b*) Gas-phase nitration of methane, ethane or propane. The corresponding nitroparaffins formed are converted to oximes by means of concentrated sulphuric acid: finally the oximes are hydrolised to hydroxylamine;

TABLE 5. CAPROLACTAM PRODUCERS AND CAPROLACTAM PROCESSES

Producers	*Capacity 1963 (m. ton/year)*	*Process*	*Expansion/plans*
JAPAN			
Ube Industries,			
Ube	**32,400**	**Inventa**	**60,000**
	10,800	**Own Process**	**(end of 1964)**
Toyo Rayon,			
Nagoya	**43,200**	**Phenol/direct oxydation**	—
	14,400	**PNC**	
Toa Gosei,			
Nagoya	**18,000**	**Phenol**	—
Mitsubishi Kasei		**Inventa**	**14,400** **(April 1964)**
Nippon Lactam		**BASF**	**21,000** **(end of 1964)**
USA			
Allied Chemical Co.			
Hopwell, Virginia	**37,000**	**Phenol process**	**65,000**
Du Pont de Nemours Co.			
Beaumont, Texas	**23,000**	**Du Pont Nitration process**	—
Dow Badische			
Freeport, Texas	**18,000**	**(Phenol)** **(direct oxydation)**	—
EUROPE			
BASF, Ludwigshafen,			
Federal Republic of Germany .	**100,000**	**Direct oxydation**	**150,000**
Farbenfabriken Bayer,			
Uerdingen	**12,000**	**Phenol**	**36,000**
VEB Leuna-Werke,			
Leuna	**20,000**	**Direct oxydation**	**35,000**
AKU, Geleen,			
Netherlands	**30,000**	**Direct oxydation**	**40,000**
Emser Werke AG, Ems,			
Switzerland	**12,000**	**Inventa process** **(direct oxydation)**	

(*c*) The direct hydrogenation of nitrous gases;

(*d*) The Inventa process via ammonium nitrite.

Direct hydrogenation and the Inventa process provide the advantage that the only by-product formed is ammonium sulphate, which can be used as fertilizer. This possibility is of interest wherever by-products cannot be conducted into water courses as waste owing to water contamination.

To round off the picture, mention may be made of some caprolactam production processes which, for a variety of reasons, are not yet industrially performed. A process developed by Union Carbide Corp involves cyclohexane oxidation to cyclohexanol, followed by controlled oxidation to caprolactone and reaction with ammonia under pressure to give caprolactam.

Scientific Design starts with a cyclohexane oxidation step and continues in a not hitherto disclosed way to caprolactam. Emser-Werke/Inventa have developed processes as shown in the next figures.

Caprolactam passes into nylon 6 production virtually exclusively. The largest part thereof is used for textile production for yarns, fibres or silk for tyre-cord. A small part thereof goes into the plastics sector, which will be dealt with in another section. It would now appear that textile requirements in the polyamide field can at present virtually be covered by nylon 6 or nylon 66. Other polyamides can hardly ever compete with these products since prices are relatively low, thanks to large-production rates. In recent years, a certain stabilization of prices has been witnessed as well.

Again, the properties of nylon fibres and yarns commonly suffice so that fewer basically new polyamides are sought for the textile field: rather, the existing products are subject to improvement. As an example, we have the elimination of flat spotting in tyre-cord which Du Pont appears to have solved by polymerizing in trimellite or terephthalic acid.

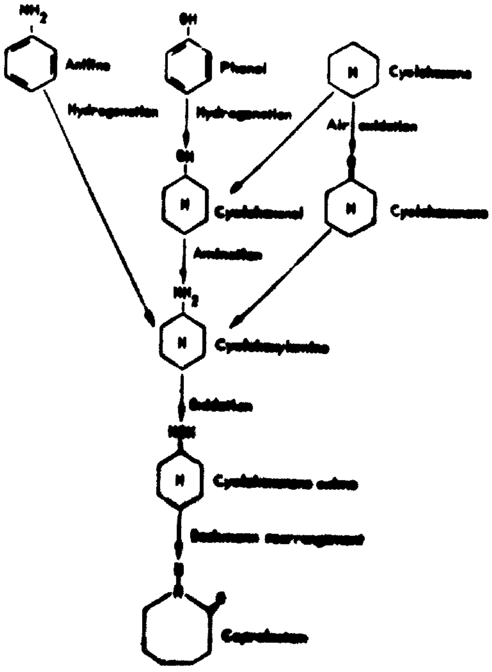


Figure V. *Lactam 6*

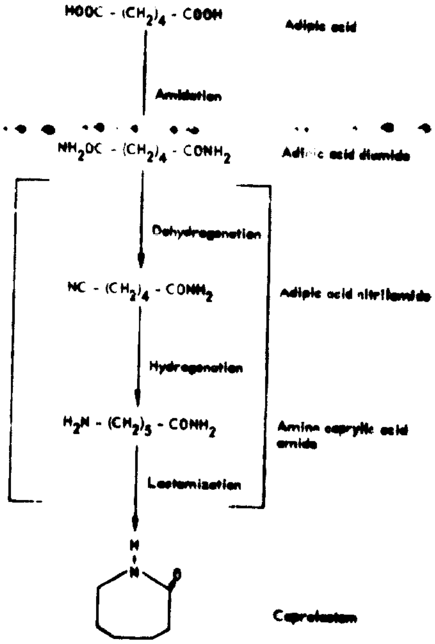


Figure VI. *Lactam 6*

IV. POLYAMIDES OF THE NYLON 66 TYPE

The synthesis of the primary raw materials for the production of nylon 66 can easily be based on petrochemicals: propylene, butadiene or cyclohexane. In principle, the production of these materials may also be based on acetylene (Reppe), but it is generally agreed, that these processes are at present no longer competitive.

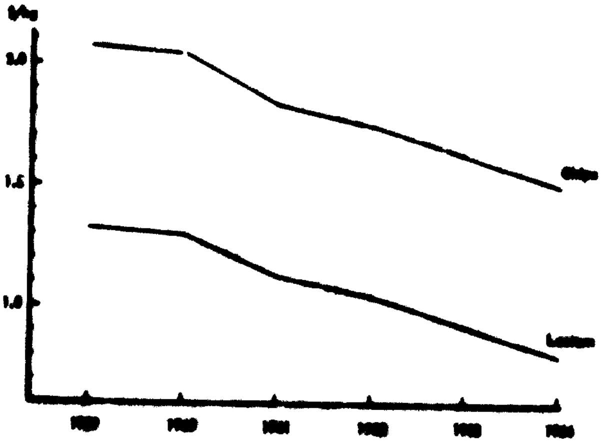


Figure VII. *Caprolactam and chips prices*

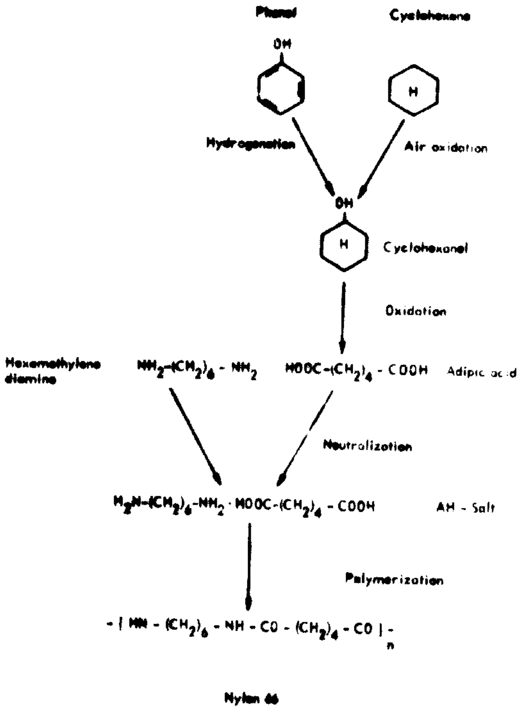


Figure VIII. *Nylon 66*

Polycondensation of caprolactam and AH-salt, spinning

A few words may be appropriate here to the subject of polycondensation. Caprolactam may be polycondensated continuously at normal pressure in a very simple apparatus. The polymer may, then, be extruded to bands and cut into chips: these are then washed to remove unreacted monomer, dried and subsequently spun to yield staple or fibres. In a more sophisticated way, monomer is removed from the melt by means of vacuum, steam or warm inert gas, and the melt is spun—without intermediate chips-stage—directly into fibres or staple.

For AH-salt, continuous polycondensation has as yet not been carried out industrially. AH-salt—and rarely caprolactam—are polymerized discontinuously in autoclaves under pressure and then worked up to chips as noted earlier. For nylon 66, an extraction of the chips is unnecessary.

V. POLYACRYLONITRILE FOR THE FIBRE PRODUCTION

The production of acrylonitrile may be based on

(*a*) Acetylene + HCN;

(*b*) Ethylene (ethyleneoxide) + HCN;

(*c*) Acetaldehyde + HCN;

(*d*) Propylene + NH_3 + air

— two steps

-- one step.

In industrial practice, mainly the processes based on acetylene or propylene are used. The acetylene process is, however, hard-pressed to compete with the newer, propylene-based methods. For example, ICI has discontinued production of acrylonitrile from acetylene. It is building propylene-based facilities.

The acetylene-HCN synthesis is carried out in aqueous ammonium chloride solution with cuprous chloride as a catalyst. The reaction is carried out at 80-90°C and slightly elevated pressure. The yield is 80-85 per cent, based on acetylene, 90-95 per cent based on HCN.

In a two-step synthesis, based on propylene, a very dilute stream of propylene in air is passed over molten selenium and then over a copper on aluminia catalyst heated to 280°C: the exit gas, containing acrolein and uncombined propylene and oxygen, is then mixed with ammonia and passed into a second reactor, which contains pellets of phosphomolybdic acid on silicagel, maintained at 370°C. The contact time is parts of a second, the yield around 75-80 per cent. Distillers Co. Ltd. and Shell keep patents on this process.

The presently most popular synthesis of acrylonitrile is the single stage process developed by the Standard Oil Co. of Ohio. Following the patent description, a mixture of propylene, ammonia, air or oxygen, and water is passed at 425-500°C, at a pressure of 2-3 atmospheres, over a fluidized bed of catalyst comprised of bismuth- or tin-phosphomolybdate on a carrier. The contact time is around 25 seconds. The conversion to acrylonitrile is 50-55 per cent (based on carbon): minor by-products are acetonitrile and acrolein.

The polymerization of acrylonitrile is industrially carried out in emulsion or aqueous solution, with the

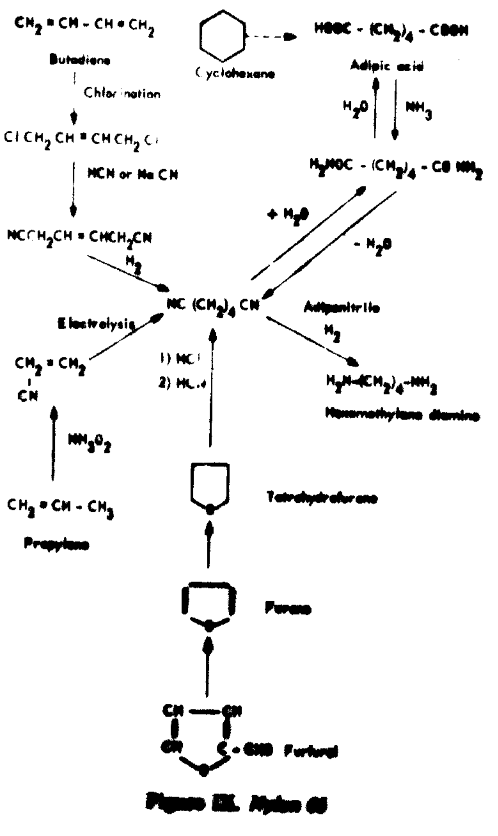


Figure IX. *Nylon 66*

aid of peroxy- or redox-catalysts. The dry polyacrylonitrile powder may, then, be spun into fibres by two different processes:

(*a*) A solution of polyacrylonitrile in dimethylformaldehyde is dry-spun into air;

(*b*) A solution of polyacrylonitrile in dimethylformaldehyde is wet-spun into a coagulating bath containing glycerine or certain inorganic salt solutions.

Pure polyacrylonitrile cannot be satisfactory dyed by the usual processes, although special techniques are available today. To improve dyestuff-affinity, other monomeric substances are copolymerized with acrylonitrile, such as methyl methacrylate, 2-vinylpyridine, polyvinylacetate and others. The chemical composition of the modified acrylic fibres produced varies rather widely.

VI. POLYESTERS

Owing to the ready availability of its raw materials, the polyester of ethylene glycol and of terephthalic acid has so far made its way, particularly in the field of films and fibres. Polyethylene terephthalate fibres differ mainly in respect of their elastic properties from fibres made of polyamides and have thus become accepted mainly in the field of garments. This difference in the elasticity of polyamides and polyesters is shown in figure X.

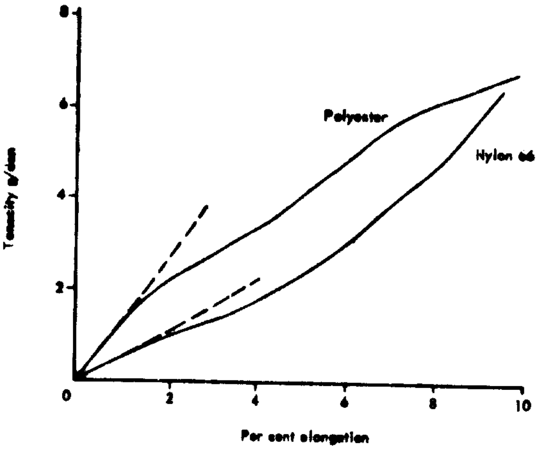


Figure X. *Stress-strain diagram for polyester and nylon 66*

Polyester fibres are also characterized by their low water absorption and their good light fastness. Thus, they are used for curtains, and, on the technical side, in the manufacture of conveyer belts, tyre-cord, tarpaulins, screen fabrics, filter cloths, fishing nets and the like. Woven fabrics made from polyester fibres—or from blends with wool—such as trousers and women's skirts, are creaseproof. The polyesters based on terephthalic acid have also stood the test of time in the field of high-quality films and foils.

We have seen, at the beginning, that the share of polyesters in the world fibre production is still comparatively modest, but it was also shown, that the production curve of the last few years is on a steep upward gradient.

Before starting the discussion of the production methods of polyesters, let us mention some less satisfactory properties of the polyesters. Naturally enough, it has been and it is the aim of considerable research to improve these properties. By way of example, the comparatively poor dye affinity of fibres formed of terephthalic acid and ethylene glycol is due to the low water absorption, the low-swelling tendency and the high crystallinity of the stretched fibre. Another property of polyethylene terephthalate fibres worthy of improvement is their proneness to polling. This results in poor appearance owing to the pollets forming on the surface of the fabric.

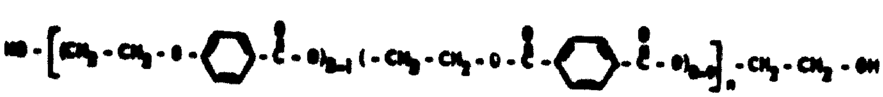
A modified polyester fibre which is easy to dye and less subject to polling has been developed by the Emser-Werke, Switzerland. It is a copolyetherester which contains besides terephthalic acid and ethylene glycol, p-hydroxybenzoic acid. This may be see in the figure XI.

This copolyetherester contains besides the ester bonds also ether bonds, which are formed during transesterification as well as during precondensation and polycondensation. With increasing contents of p-hydroxybenzoic acid, the melting point decreases, the crystallinity of stretched fibres is lowered and the dye affinity improved. The next illustration shows the influence of a 10 per cent content of p-hydroxybenzoic acid in the polymer on dye absorption under comparable conditions.

Dyeing was in both cases effected at boiling temperature without pressure and without the use of carriers. The

$$HO-CH_2-CH_2-\left[O-\overset{O}{\overset{\|}{C}}-C_6H_4-\overset{O}{\overset{\|}{C}}-O-CH_2-CH_2\right]_n-OH$$

Polyethylene terephthalate



$$HO-\left[(CH_2-CH_2-O-C_6H_4-\overset{O}{\overset{\|}{C}}-O)_{n-1}(-CH_2-CH_2-O-\overset{O}{\overset{\|}{C}}-C_6H_4-\overset{O}{\overset{\|}{C}}-O)_{n-1}\right]_n-CH_2-CH_2-OH$$

Copolyetherester

Figure XI

incorporation of p-hydroxybenzoic acid in the polymer chains interferes with the formation of the macromolecules and causes reduced crystallisation This phenomenon benefits not only the dye affinity, but also the production of films and foils made from copolyether ester. Incidentally, the p-hydroxybenzoic acid may be replaced by vanillic acid or other aromatic hydroxyacids of similar structure. This may be important if attempts are made to obtain vanillin from sulphite waste liquor in an economical manner. The most important raw materials for the production of linear polyesters are still terephthalic acid and ethylene glycol. There are various methods of producing them.

Terephthalic acid

The different processes for the production of terephthalic acid are shown in figure XII.

1. *Nitric acid oxidation of p-xylene*

The oxidation is carried out at 200-230°C under system pressure (25 atm: 400 p.s.i. at 200°C). 2.1 kg 100 per cent HNO^3 are used (supplied in 25-40 per cent strength) per 1 kg xylene. The yield is reported as up to 89 per cent. In this process, a comparatively highly contaminated acid is obtained which can be purified via the dimethyl ester. This is the reason why dimethyl ester and not free terephthalic acid has been taken as the starting material so far in all major production plants. The dimethyl ester can be readily brought to a purity of 99.99 per cent by distillation and recrystallization. This high purity is essential, as small quantities of impurities may block the growing polymer chains and prevent the formation of products with a sufficiently high molecular weight.

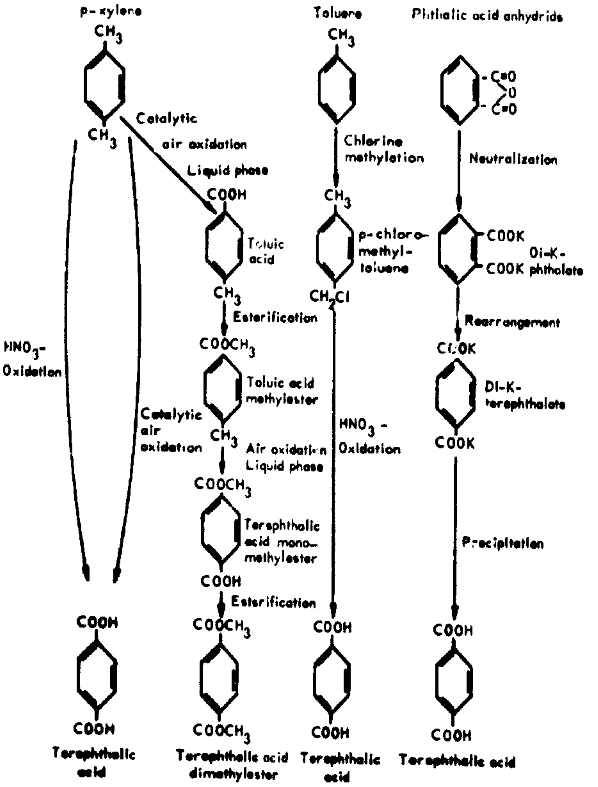


Figure XII. *Terephthalic acid*

2. *Catalytic air oxidation of p-xylene in solution*

This process was developed in the United States. It provides a better terephthalic acid than does the nitric acid oxidation process, but purification is still effected via the dimethyl ester. The oxidation is carried out between 140-200°C, under system pressure. Manganese acetate combined with ammonium bromide are reported as catalysts: sometimes, acetic acid is used as a solvent.

3. *Chloromethylation and nitric acid oxidation*

Toluene is taken as the starting material: it is first chloromethylated, then the product is oxidized with nitric acid. Forty per cent o-phthalic acid is obtained as a by-product. The crude acid must also be purified via the dimethyl ester.

4. *Two-stage air oxidation of p-xylene in the liquid phase (Wittener process)*

Xylene is oxidized, in the presence of catalysts such as Co-toluate, at 140-160°C to p-toluic acid (conversion 20-40 per cent per pass). The toluic acid formed is esterified with methanol. The toluic acid methyl ester formed is catalytically oxidized with air to yield terephthalic acid monomethyl ester, which is finally esterified to the dimethyl terephthalate, which may be readily purified.

5. *Rearrangement of the dipotassium salt of o-phthalic acid to salts of terephthalic acid (Henkel process)*

O-phthalic acid is produced from naphthalene, from o-xylene or by carboxylation of toluene. The rearrangement of the dipotassium salt is occurring at ca. 400°C. Cadmium salts are reported to be used as catalysts. The dipotassium terephthalate is dissolved in water. This solution may be readily purified. When the terephthalic acid is precipitated by means of hydrochloric acid or o-phthalic acid, an exceptionally pure terephthalic acid is obtained. It need not be purified via the dimethyl ester, but can be directly esterified with ethylene glycol.

This process has thus made it possible for the first time to start from free terephthalic acid in the production of the polyester. This involves considerable advantages, since the recovery of methanol is rendered unnecessary.

In addition, terephthalic acid can be more economically produced according to the Henkel process than an equivalent quantity of dimethyl ester according to any one of the processes described.

While the direct esterification of terephthalic acid with glycol still offers a number of technical and chemical difficulties (problems of charging, formation of diglycol), the production of polyesters appears to have obtained a considerable impetus.

3. POLYESTER SYNTHETIC FIBRE MATERIALS FOR DEVELOPING COUNTRIES

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I. GENERAL INTRODUCTION

Polyester fibres are relative late-comers to the field of synthetic fibres, arriving on the scene as they did a few years later than rayon. While the use of polyesters in fibres (as well as films and other forms) has enjoyed a rapid growth, polyesters are still out-paced by nylon.

Polyesters, by general definition, are a polymeric substance made by the reaction of polybasic acids (or their esters, anhydrides etc.) and polyhydric alcohols. In actual commercial production, the acids and alcohols used as the basis for fibre polyesters consist in the main of one combination—terephthalic acid (or its derivative: dimethyl terephthalate, known in the trade as "DMT") and ethylene glycol (or its precursor ethylene oxide). The polymer formed is known as polyethylene terephthalate. It might be worth noting, in passing, that a relatively small amount of isophthalic acid is used along with terephthalic in special cases, but not in important enough quantities to deserve attention here.

There are a relatively small number of companies in the world who have the "know-how" and who are producers of polyester fibres. The fibres are sold under the trade names Dacron (Du Pont), Terylene (Imperial Chemical Industries (ICI)), Fortrel (Celanese-ICI), Tetoron (Japanese), Trevira (German), Tergal (France), Terital (Italy) etc. Increased emphasis on polyester fibre production may be expected now that United States patents covering polyester fibres have expired. These patents were originally owned by United Kingdom's Calico Printers' Association, which sold world rights, except in the United States, to Imperial Chemical Industries. The United States rights went to Du Pont. The new American entrants thus far into polyester fibres are Tennessee Eastman, Beaunit Mills, and Fiber Industries (the ICI-Celanese Joint Venture). Considerable publicity has recently been given to the licensing by ICI of its polyester fibre technology to countries with centrally planned economies, particularly the USSR.

By contrast, however, the "know-how" and production facilities for the polyester precursors — to some extent for terephthalic acid and certainly for the case of ethylene glycol — are far less concentrated. It is interesting to note a difference between the two precursors at this point. Terephthalic acid (or DMT) is a relatively new industrial chemical and is manufactured essentially for the *sole purpose* of use in polyesters· it is consequently manufactured by a reasonably limited number of organizations. Ethylene glycol (or ethylene oxide), on the other hand, has been a major industrial chemical for many decades and is used mainly for the purposes *other* than polyesters (major example: anti-freeze); the world production of ethylene glycol is consequently many times that of terephthalic acid. Possibly because of the situation described above, the cost of production and "transfer" price of ethylene glycol is about half that of terephthalic acid. Since more than two-thirds of the weight of polyester fibres is made up of the more expensive component, terephthalic acid, it is obvious that economic developments in the production of terephthalic component will have the greatest effect on polyester fibre cost. Incidentally, it is far more likely that important economic improvements in the manufacture of terephthalic acid *will* be made in the future than is the case for ethylene glycol, which is now almost at a rock-bottom price and will probably enjoy only marginal improvements in the future. As a matter of fact, as will be discussed later, the costs of manufacturing terephthalic acid have already undergone drastic reductions in the past few years, and still more are soon to come, which could possibly contribute to a noticeable improvement in the competitive position of polyester fibres vis-à-vis other synthetic fibres.

It will be the purpose of this paper to examine factors affecting costs and competitive situations for terephthalic acid and ethylene glycol as they exist today in the highly industrialized countries. It is hoped that from this discussion may arise constructive ideas as to the strategies which should be considered by nations in the earlier stages of industrial development.

II. TEREPHTHALIC ACID AND DIMETHYL TEREPHTHALATE

A. *General survey of commercial methods of manufacture*

The major raw material used today for the manufacture of terephthalic acid is p-xylene. The source of p-xylene is a reformed product made in modern processes of petroleum refining, and results from efforts to increase yields and octane numbers of hydrocarbon raw material sources by a process of cyclization and aromatization of the more paraffinic hydrocarbons. While it is possible to synthetize p-xylene from isobutylene, it is not known that this process is practiced on a large commercial scale, if at all. A commercial process for terephthalic acid, but used on a relatively small scale, involves the rearrangement of the potassium salt of benzoic acid or o-phthalic acid. Other materials that have been considered as raw materials for terephthalic acid are p-diisopropyl benzene and p-cymene; since, among other things, there is more carbon and hydrogen to oxidize in the preparation of terephthalic acid for these two materials, they have not to date been found to be economical in the major industrial countries.

The oxidation of p-xylene to terephthalic acid or DMT is done in two basic fashions: by nitric acid and by air. Nitric acid oxidation was the original process used, and commercial production of terephthalic acid was performed by this process for approximately a decade before the discovery of economic methods of air oxidation, which have rendered nitric acid oxidation uneconomical for new plants. The commercial methods of air oxidation include the Witten (formerly the Imhausen) process and the Mid-Century process, the Mid-Century process being by far the more predominant commercially. Other air oxidation processes have appeared lately on the scene, but comprise only a minute fraction of the commercial picture. Needless to say, since the discovery of economical methods of air oxidation of p-xylene to terephthalic acid, essentially all new plant capacity based on p-xylene oxidation has been installed using these new techniques.

The following discussion includes more details on processes commercially used and considered for terephthalic acid manufacture.

B. *Discussion of important commercial processes*

1. *P-xylene manufacture*

P-xylene is found in the C_8 aromatic fraction of petroleum refinery reforming operations that are directed towards the improvement of octane numbers by cyclization of straight chain compounds, followed by isomerization and dehydrogenation reactions leading, in the areas in which we are interested, to a number of alkyl-substituted benzenes. The major proportion of the so-called "aromatics" cut which is generally isolated and purified by the petroleum refineries consists of benzene, toluene and mixed xylenes. These materials are generally not isolated for the purpose of use in gasoline blending but only to provide a source of either solvents or petrochemical raw materials. It is, of course, the xylene cut in which we are interested here. The composition of this cut generally approaches the thermodynamic equilibrium of the four alkyl benzene isomers in the C_8 range; approximately 15 to 20 per cent each of ethylbenzene, o-xylene, p-xylene, with the remainder (and majority of the mixture) m-xylene. Para-xylene is commercially recovered from the mixture of xylenes by fractional crystallization which, to the author's knowledge, is the only commercial method used today, although such processes as Clathration (formation of crystal complexes with other materials) have been widely studied. Commercial crystallizations have been done in many types of equipment, i.e., scraped surface crystallizers, evaporative crystallizers, and the like. There is generally a system included which involves the re-melting of the product and counter-current washing of the crystallizers with this re-melt, so as to obtain a high-purity p-xylene product. Unfortunately, only approximately two-thirds of the p-xylene can be extracted from the mixed xylene stream by this method, since in order to increase the amount of xylene recovered the temperature must be lowered until eventually other materials such as ortho and meta xylene begin to cocrystallize with the p-xylene. Since only about one-fifth of the original mixed xylene feed-stock is p-xylene, and since only about two-thirds of that p-xylene is recovered by crystallization, it is obvious that very large amounts of feed-stocks must be handled, undergoing costly refrigeration at extremely low temperatures (lower than 100°F.) In order to reduce the amount of material handled, and at the same time isolate other raw materials of industrial interest, there is considerable practice today of the removal by distillation of both o-xylene and ethylbenzene, prior to crystallization of the p-xylene. Of the two, the o-xylene is the easiest to remove and, because of this fact, coupled with the wide availability of cheap mixed xylenes, o-xylene now offers an invitingly low-cost and widely available raw material for phthalic anhydride manufacture. Ethylbenzene removed from the xylene mixture is used in a few commercial concentrations for styrene manufacture.

Since only slightly more than one-tenth of a pound of p-xylene may be recovered from a pound of mixed xylene feed-stock, there often arises a situation in which the need for xylenes is greater than can be supplied by direct crystallization of p-xylene from the available mixed xylene raw material. An answer to this problem has been found in the inclusion of a xylene isomerization system, which can form new p-xylene, up to the equilibrium concentration of about 20 per cent, from the effluent stream from the crystallization process (which contains approximately 10 per cent or less p-xylene). Although it is obvious that the feed to the crystallization system will not be reduced by such measures and, therefore, the cost of crystallization will be approximately the same, the inclusion of the isomerization scheme will permit essentially *all* of the xylene feed-stock to be converted to p-xylene, thus allowing substantial production of this terephthalic acid precursor to be made in areas in which the supply of xylenes is limited either by virtue of the presence of small refineries or by the necessity for importation of xylenes specifically for terephthalic acid manufacture.

With regard to factors affecting costs and prices, there has been a considerable change throughout the world in the past decade. Originally, it was almost what one might call a "sellers" market in p-xylene, since there were a limited number of sources of the desired mixed xylene stream, but a strong demand for the product by the first companies engaged in terephthalic acid manufacture for polyesters. As a result, the price of p-xylene approximately ten or fifteen years ago used to hover in the range of sixteen to twenty cents per pounds in the United States, for example. At this price, it just barely did not pay large p-xylene consumers to develop their own processes for xylene isomerization, with uses for the by-product derived therefrom. As time went by, and more and more aromatic fractions became available to the refining industries (notably by the Udex process as a major factor in this area), coupled with larger p-xylene plants and process improvements in p-xylene crystallization, competition has become greater and, again as an example, the p-xylene price in the United States has tended to approach the ten cents per pound level; it is believed that it may drop even one or two cents lower in the not-too-distant future. This price drop has naturally been encouraged by large consumers who have resorted to various strategies, such as the public announcements of interesting developments of other terephthalic acid precursors. Also a few isomerization-crystallization units have been installed commercially, for example by ICI in England and Mitsui Petrochemical in Japan, enabling these producers to start with the very low-cost mixed xylene raw material to make p-xylene.

Costs of production of p-xylene are typical of other petrochemicals in that probably the strongest factor is plant size. In the case of the manufacture of p-xylene from mixed xylenes, the effective net cost of production is immensely complicated by the necessity of obtaining a suitable market and by-product credit for the xylenes that are discharged from the crystallization step (approximately six to seven pounds per pound of xylene product). Since the xylene solvent market is limited, as is the use of xylenes in gasolene, it may be necessary for refineries to dispose of the waste mixed xylene stream at very low cost, as in diesel fuel. How these matters would be handled by a petroleum company would probably vary with the internal bookkeeping picture from company to company. Other costs of manufacture in the crystallization plant, at least for large plants, are a relatively small factor in arriving at the selling price, since the process costs exclusive of raw materials and by-product credits, will run only two to three cents per pound of p-xylene in very large plants for such items including utilities, labour, maintenance and depreciation.

For the combined isomerization-crystallization plant the processing costs are a few cents per pound higher, again very largely dependent upon plant scale, but the by-product disposal problem is largely absent. For commercial scale p-xylene plants incorporating recycle isomerization, assuming a low-cost mixed xylene raw material and a 60-70 per cent weight yield of p-xylene from mixed xylenes (in the general neighbourhood of that obtained in commercial processes) the total works cost of production, including raw materials, utilities, labour, maintenance and depreciation, can vary within the range of five to ten cents per pound of p-xylene, the variation depending mainly on plant size, mixed xylene cost and by-product credits.

It should be noted, in passing, that certain air oxidation techniques, notably the Mid-Century process, can oxidize combined mixed xylenes to form a mixture of benzoic acid, isophthalic acid and terephthalic acid, which can then be separately isolated and refined as products. This system has been in commercial use for several years and while it avoids the separation of p-xylene from mixed xylenes it does involve the isolation of the individual acid products from the crude product mixture and, more significantly, the development of a market for the acid products other than terephthalic acid.

2. *Nitric acid oxidation of p-xylene*

As mentioned above this was the first developed process for the commercial production of terephthalic acid. Since it is not being used today in any plant expansions and would, in any case, be of very little interest to developing nations, we will give it an abbreviated treatment in this discussion. Basically, the process is a liquid phase operation in which p-xylene and nitric acid are mixed together with a catalyst in a kettle and the solid terephthalic acid product recovered from the mixture. This product must be converted to dimethyl terephthalate before it is used in fibre manufacture, since the acid itself would be extremely difficult to purify. This purification difficulty is due, to a considerable extent, to the formation of nitrated materials in the terephthalic acid product. A small, but not inconsequential, disadvantage of the nitric acid process is the fact that the very large quantities of oxidant and p-xylene which may be simultaneously contained in the reactor has led to violent explosions in this system. However, the major disadvantage of the nitric acid process, even though selectivities to terephthalic acid are high (ca. 90 per cent), is the large consumption of nitric acid—about two pounds per pound of terephthalic acid. Even though the oxides of nitrogen which leave the nitric acid oxidation step may be sent through a portion of the nitric acid plant and be re-oxidized to nitric acid, this large throughput of nitric acid has a crippling economic disadvantage to the nitric acid oxidation process as compared with the newer process to be discussed below. As with many older processes, however, it often does not pay to abandon a smoothly-running existing operation completely for the installation of the more efficient process, and for this reason nitric acid oxidation in already existing facilities is still practised on a large scale. However, it is believed that the time has finally arrived, particularly in view of important improvements in air oxidation techniques when large-scale abandonment of existing nitric acid oxidation facilities will be economically justified, particularly to those who have access to the most efficient air oxidation technology.

With regard to costs of manufacture, again these are tremendously affected by plant scale and by the general integration of the manufacturer in nitric acid operations. Because of the large nitric acid consumption, however, information available to us indicates that the cost of production by this route is approximately one to three cents per pound higher than by the best air oxidation technique.

One further word with regard to nitric acid oxidation. In the highly industrialized countries, and also very probably in the case of the developing countries, more and more attention is being paid to the effect on society of atmospheric pollutants. Organizations engaged in nitric acid manufacture and nitric acid oxidations are particularly sensitive to these trends, since the fumes from such plants are particularly noxious. It is believed that the economic consequences of various social and governmental pressures on such manufacturers have not been fully realized.

3. *The Witten or Imhausen process*

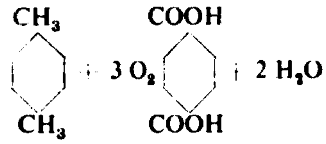
This method, used for a number of years by Hercules Powder Company (among others) for producing DMT, utilizes a four-stage oxidation process as follows: (*a*) p-xylene is oxidized to toluic acid, (*b*) the toluic acid is esterified with methanol, (*c*) oxidation of the remaining methyl group to form the half ester of terephthalic acid, and (*d*) esterification with methanol to product DMT. California Research Corporation has patented the basic chemistry of this process in the United States, and Imhausen has similar foreign patents. This process is also in use abroad by companies such as Chemische Werke Witten and Hoechst.

While this method is most ingenious in that it effectively permits the high-velocity conversion of p-xylene to the dicarboxylic form (in this case, the dimethyl ester), it is somewhat more complicated than the direct air oxidation system (discussed below) due to the increased number of steps involved in the partial conversions. It also has the growing disadvantage of forming only the DMT product and thus not being entirely flexible for the polyester market, for which considerable interest is now being developed in the direct use of terephthalic acid as a feed-stock for the polymer. It is true that pure terephthalic acid could be made directly by hydrolysis of the DMT ester made by the Witten process, but this would introduce yet another step in the process and make the cost of production of terephthalic acid quite uncompetitive with that produced by direct air oxidation of p-xylene. With regard to costs of the Witten process, complete details are not known by the author. Such information as is available to us, however, indicates that the yields and cost of manufacture for the production of DMT from p-xylene are approximately the same for the Witten process as for the Mid-Century process (incorporating an esterification to DMT added to this Mid-Century oxidation) but that the capital investment for similar-sized plants is approximately 20 per cent lower for the Mid-Century process. In general, it takes approximately 1 pound of p-xylene to produce 1.4 pounds of DMT and assuming that p-xylene would be in a ten to twelve cents per pound range, costs of production of DMT by the Witten process should then run in the fifteen to twenty cents per pound range, depending to a very large extent on plant size.

4. *The Mid-Century process*

In 1956 the Mid-Century Corporation (then a Scientific Design affiliate and now a subsidiary of Standard Oil Company, Indiana) developed a series of processes for the liquid phase oxidation of xylene and other petroleum feed-stocks into several aromatic acids. After further development by Amoco's parent company, Standard Oil Company (Indiana), Scientific Design built and designed a 60 million pounds per year commercial aromatic acids plant for Amoco. In the process used in this plant, a mixed xylene stream is charged with catalyst, a heavy metal and some form of bromine into a reactor. Air is passed through the reactor at the proper ranges of temperature and pressure. The resulting solid acids — isophthalic, phthalic, terephthalic, and benzoic — are then separated. In a similar manner, in a simple one-step operation, meta-xylene alone can be oxidized to isophthalic acid, ortho-xylene oxidized to phthalic acid, ethylbenzene oxidized to benzoic acid and para xylene oxidized to terephthalic acid. A typical reaction (to form terephthalic acid from p-xylene) is as follows:

(1)



This is the first process to make terephthalic by direct oxidation in one step. Besides Amoco, other companies now using this process (under licence) are ICI, Maruzen and Mitsui in Japan, and AKU in the Netherlands.

As could be expected during the period of commercial operation of the Mid-Century (M-C) process, considerable development and improvement of the process has taken place, so that important cost reductions and improvements in product quality have now been realized. A most important area that lies ahead is believed to be the field of pure terephthalic acid product which may be used directly as feed-stock for the polyester fibre process without forming the intervening DMT. As alluded to previously, DMT was developed as a feed-stock for the polyester process since it was in early days quite difficult to purify terephthalic acid (a most insoluble material in ordinary solvents) while DMT easily could be purified to almost any desired degree by conventional distillation procedures. Developments in the Mid-Century process have resulted in the producibility at low additional cost of a highly purified terephthalic acid product which has been found by the fibre makers to be acceptable as a raw material for polyesters.

With regard to costs of production for the Mid-Century process, DMT may be manufactured at a works cost in the range of ten to twenty cents per pound, the costs being mainly a function of plant scale and p-xylene transfer price. Pure terephthalic can be made at a cost of production in the same general area. Crude terephthalic (99 + per cent pure but not suitable for direct use in fibres) will be several cents per pound cheaper. When mixed xylenes are used as a feed-stock for the oxidation, the presence of a very large number of co-product acids complicate the cost picture, so that no generalization can be made regarding the products of terephthalic acid itself.

5. *Henkel process*

The Henkel process is based on the discovery that under the proper conditions of temperature and pressure the potassium salt of an otherwise unsubstituted carboxylic aromatic acid will rearrange to form dipotassium terephthalate. For example, dipotassium orthophthalate can be used as a raw material or potassium benzoate may alternately be used; in the latter case, there is a benzene co-product along with the dipotassium terephthalate. Since potassium is an expensive chemical, a considerable portion of the process development of the Henkel process has been directed to the recovery and recycle of potassium in order to minimize its loss.

The author of this paper has no direct personal knowledge of the detailed break-down of operating costs for various versions of the Henkel process. From talking with many people in the field, however, who have had experience with other processes for terephthalic acid manufacture, and who are also familiar with the economics of the Henkel process, it is believed that the Henkel process is less economical than either the Mid-Century or Witten processes for the production of DMT and is less economical than the Mid-Century process for the production of pure fibre-grade terephthalic acid, except in very special situations. Although the Henkel process might appear to offer the use of cheap raw materials, such as toluene or o-xylene, as the basic raw material, the processing steps are apparently numerous, complicated and expensive before the final pure terephthalic acid is obtained. It must also be remembered, in counter-argument for the air oxidation processes, that p-xylene itself is made from very cheap raw materials. The fact that the Hercules Powder Company in the United States has made an exhaustive pilot plant investigation of the Henkel process, and was in fact the first to do so on such a large scale, but has chosen to proceed with the commercial exploitation of the Witten process may be of some significance.

Other processes

Considerable information has been made available in the literature regarding the oxidation of p-diisopropyl benzene to terephthalic acid. It is understood by the author that this may currently be practised commercially, but on a small scale. An obvious disadvantage to this route is the large amount of carbon and hydrogen that must be oxidized to carbon dioxide and water along with the formation of terephthalic acid. Furthermore, the selectivities to terephthalic acid by the air oxidation route are noticeably lower than for the case of p-xylene oxidation by the Mid-Century process. Nevertheless, this route should not be completely ignored by the countries who happen to have ample supplies of benzene and propylene, (for example, an area which is manufacturing phenol from cumene) and to which a source of xylenes is quite expensive. It is believed that the Mid-Century techniques are by far the best when applied to air oxidation of p-diisopropyl benzene to terephthalic acid.

A number of syntheses for preparing other para-substituted benzenes which could be used as precursors for terephthalic acid have been proposed. It is not known that any of these have been even seriously considered as a basis for commercial manufacture.

Another alternate to terephthalic acid, using cheap mixed xylenes as raw material, which has been given strong consideration is as follows: with the M-C process, oxidize mixed xylenes to their respective dibasic acids and benzoic acid; these acids can then be used as feed to the Henkel process to produce terephthalic acid. While this procedure is technically adequate, it is our understanding that it is cheaper to use a xylene isomerization and crystallization unit rather than a Henkel rearrangement plant to produce, in essentially the same over-all transformation of mixed xylenes, terephthalic acid.

D. *Present and future economic factors*

As is usually the case in the chemical industry, it is very difficult to definitely point out a clear-cut advantage of any one route or process over all the others. In particular, the development of manufacturing methods for terephthalic acid and DMT has been an extremely rapidly moving field, and it is most difficult for any one organization to have access to all of the facts at the same time. Probably the general conclusions at which one might arrive concerning terephthalic acid and DMT manufacture, might be summarized as follows:

(*a*) The nitric acid oxidation process is clearly outmoded and it is highly unlikely that any new plant capacity for terephthalic acid or DMT will use this technique.

(*b*) The Mid-Century and the Witten processes for DMT are fairly close in operating costs of production, but the Mid-Century process appears to have an appreciable advantage with regard to capital cost. The Mid-Century process has a substantial advantage when it comes to the manufacture of pure terephthalic acid.

(*c*) The Henkel process, while in commercial use, apparently has some cost disadvantages when compared with the Mid-Century and Witten processes.

(*d*) The basic material for terephthalic acid will very probably continue to be p-xylene. It is likely if developing countries manufacture their own p-xylene it could very well be based on use of the above-described isomerization-crystallization cycles, unless the country happens to be heavily committed to large petroleum refining operations.

One of the interesting problems facing developing nations is at what point in the process raw materials should be imported. For example, in making polyester fibres should one import the pre-polymer, the terephthalic acid (or DMT) and glycol, the xylenes for making p-xylene, or the crude hydrocarbons for making the mixed xylenes? It would seem that, since the total investment in any given period of time to which a developing nation has access is limited, the contributions that each segment of capital corresponding to the various conversion stages of raw materials listed above must be thoroughly evaluated and compared with the contributions that investments in areas other than fibres might contribute. Such decisions certainly cannot be made internally, but must involve the evaluation of prices negotiable for various stages of raw materials obtainable from the outside world. It is certainly not a strictly technical matter and will involve economics and political leaders, as well as technical -- and businessmen.

III. ETHYLENE OXIDE AND GLYCOL

A. *General comments on commercial processes*

Ethylene oxide (and glycol) is among the select few synthetic organic chemicals that are manufactured world-wide on a multi-billion pounds per year scale. Almost all of the ethylene oxide and glycol made in the world today is based on ethylene raw material, which in turn is almost entirely based on the cracking and dehydrogenation of petroleum-based hydrocarbons. The only known exception to the use of ethylene as a raw material is Du Pont's process, a small fraction of the total world production, which is based on formaldehyde and carbon monoxide; this process is considered to be uneconomical for future plant expansions and will, therefore, not be discussed in detail in this study. The remainder of the world's ethylene oxide is manufactured from ethylene by chlorohydrination and hydrolysis, or by direct oxidation, using either air or oxygen; these processes are discussed in greater detail below.

B. *Ethylene chlorohydrination process*

The first large-scale chlorohydrination process for ethylene oxide was put on-stream in the United States in 1925. Even though, as will later be shown, the chlorohydrin route generally operates at an economic disadvantage as compared with direct oxidation, sizeable plants using the chlorohydrin synthesis were installed in the United States as late as the 1950's, and many of the older ones are still in commission. This process has been described at length in many reference books and other publications, and no attempt will be made here to discuss it in detail. The main reactions include the formation of ethylene chlorohydrin:

$$(a)\qquad C_2H_4 + H_2O + Cl_2 \rightarrow CH_2OH\ CH_2Cl + HCl$$

followed by the lime hydrolysis of the chlorohydrin and neutralization of the solution:

$$(b)\ CH_2OH\,CH_2Cl + HCl + Ca(OH)_2 \rightarrow C_2H_4O + CaCl_2 + 2H_2O$$

The major side reaction is the formation of ethylene dichloride:

$$(c)\qquad C_2H_4 + Cl_2 \rightarrow C_2H_2\,Cl_2$$

which is very easily formed by the reaction of chlorine and ethylene. Small and economically unimportant amounts of dichloroethyl ether are also formed. A high dilution of the reactants in water is necessary in order that high ethylene oxide yields, in the neighbourhood of 75-80 per cent of theory, may be realized. Although it is possible to obtain higher yields (mainly by higher dilution), it is generally not justified to incur the increased capital and operating costs which would be necessary, since the ethylene dichloride by-product usually has a market at a price which just covers its raw material value.

The chlorohydrin process is extremely corrosive at points where aqueous hydrochloric acid is present, and selection of suitable materials of construction is further complicated by the presence of chlorinated organic solvents. Gases purged from the system generally must be treated for removal of chlorine-containing compounds. A likely candidate for attention as a community nuisance is the extremely large aqueous effluent stream, which contains about four pounds of calcium chloride per pound of ethylene oxide manufactured. Waste treatment or special handling of this stream can provide a significant proportion of the process costs.

Among the advantages of the chlorohydrin process, relative to direct oxidation, lie the high yield of useful products from ethylene, its ability to use a more dilute ethylene, and a somewhat lower capital investment; among its disadvantages are the dependency on large amounts of chlorine (approximately two pounds per pound ethylene oxide produced) and lime, its corrosiveness and potential high maintenance costs, and its sizeable waste-disposal problem.

The works cost of production of ethylene oxide by the chlorohydrination process is in the neighbourhood of ten cents per pound, depending greatly, of course, on the price at which chlorine is charged into the system; note that each one cent-per-pound of differential in chlorine price represents a two cents-per-pound change in ethylene oxide price.

C. *Direct oxidation processes*

1. *Process description*

The world's first commercial direct oxidation process for the manufacture of ethylene oxide was installed in the United States in 1938. Air was used as the oxidant. Since then, installation of further direct-oxidation facilities has proceeded at a very rapid rate, so that by now the direct oxidation production is several times the chlorohydrination production, some chlorohydrin manufacturers having switched over to direct oxidation plants. The economic justification for such a switch-over is probably aided by the fact that the abandoned chlorohydrin facilities can be used for the manufacture of propylene oxide, for which there is a growing demand.

The direct oxidation of ethylene to ethylene oxide has been the object of a tremendous amount of costly experimental study by most of the major chemical and petroleum refining companies in the United States and abroad, as well as by a number of research institutes. It appears to the author, and it could very well be a fact, that more pilot plants have been installed for the study of ethylene oxide by direct oxidation of ethylene than has been the case for any other single chemical process. Many sophisticated approaches have intrigued investigators. Since heat transfer and "hot spots" are major design problems in the conventional fixed-bed tubular reactors, a considerable amount of money has been spent in investigating fluidized-bed reactors, as well as reactors in which the catalyst is coated upon an extended heat transfer surface. In spite of all this work, the only direct oxidation processes known to be practiced commercially today use conventional fixed-bed tubular reactors, filled with a catalyst consisting of silver deposited upon an inert support.

The reactions for the silver-catalyzed direct oxidation of ethylene are shown below:

$$(a)\qquad C_2H_4 + 1/2\,O_2 \rightarrow C_2H_4O \text{ (main reaction)}$$

$$(b)\qquad C_2H_4 + 3\,O_2 \rightarrow 3\,O_2 + 2\,H_2O \text{ (side reaction)}$$

The reaction selectivity decreases slowly with increased ethylene conversion per pass; it is, therefore, economically attractive to operate at an incomplete ethylene conversion. For this reason, gas recycle is usually practiced. Recycle is further required because it is necessary to dilute the reactor feed stream to an oxygen content of less than 8 to 10 per cent to avoid an explosive mixture.

When air is used as oxidant, a substantial bleed stream must be removed from the gas cycle in order to carry off nitrogen which enters with the incoming air. This bleed stream contains unconverted ethylene, which would be lost to the process were it not passed through a high-conversion purge reactor system for essentially total conversion to ethylene oxide.

When oxygen is used as the oxidant, (approximately 1.5 pounds of oxygen per pound ethylene oxide), there is no necessity for bleeding off large amounts of nitrogen and so the purge reaction system may be omitted. In this case, however, carbon dioxide removal facilities must be added to remove this by-product of the side reaction described above.

Over-all yields in commercially operating plants using direct oxidation generally run in the neighbourhood of 60-70 per cent of theoretical, depending on the age of the plant, or how hard it is being "pushed". Probably a good industrial average yield is slightly over one pound of ethylene oxide (or abour 1.4 pounds ethylene glycol) per pound of ethylene feed.

2. *Basic differences between air and oxygen processes*

The essential differences between oxygen and air processes which can effect economics, can probably best be summarized as follows :

(*a*) The cost of the air compression plus the oxygen compression for the oxygen process is only slightly greater than the cost of air compression alone for the air process. The difference is small because it is not necessary to compress air for the oxygen plant to as high a pressure as is economically desirable for the ethylene oxide process.

(*b*) The main investment difference between the two processes lies in the oxygen-nitrogen separation unit which is, of course, required for the oxygen process. It is of some interest to note that when oxygen is used, considerable effort is first made to separate it from the nitrogen, after which it is almost immediately diluted with a large stream of recycle nitrogen to avoid explosive mixtures. The penalty of this cost differential as well as (*a*) above, can be greatly minimized or even eliminated if oxygen is taken from a very large facility which also serves other oxygen consumers.

(*c*) The oxygen process requires one additional process step for CO_2 stripping which results in a small economic penalty.

(*d*) A sizable utility saving may be made in the air process, as compared with the oxygen process, since the energy contained in the high pressure nitrogen purge gas stream may be used to drive mechanical equipment in the process.

(*e*) A major factor which can influence costs, but in an unknown way, is the basic question of safety. Misoperations due to untrained personnel, faulty maintenance of equipment and control instruments can result in errors in the ratio of oxidant and ethylene. When air is used as oxidant, the resulting combustions are not disastrous, as has been found out in decades of operating experience in air-fed plants. On the other hand, experience has shown, as one can also calculate, that when oxygen is used as the oxidant, any serious mistake in ratio in reaction gas composition can lead to a devastating explosion.

In addition, the oxygen plant itself is a matter of serious concern from a safety point of view. There have been many explosions in oxygen plants (including those connected with ethylene oxide manufacture), leading to extended damage and shutdowns, and these catastrophes continue to this day. Obviously, the safe distillation of oxygen requires the most sophisticated attention not only to the original plant design, but also to operating and maintenance techniques.

D. *Ethylene glycol*

Little need be said here with regard to the manufacture of ordinary ethylene glycol, since it is one of the most simple of the chemical processes. Ethylene oxide is mixed with a considerable excess of water and then reacted thermally (without catalyst) at moderate temperature, pressure and residence time to substantial extinction of ethylene oxide. The higher the ratio of water, the higher is the yield of the monoglycol and the lower the yields of diglycols, triglycols and heavier, according to the reactions :

(*a*) $C_2H_4O + H_2O \rightarrow C_2H_4(OH)_2$ monoglycol

(*b*) $C_2H_4O + C_2H_4(OH)_2 \rightarrow C_2H_4(OH)OC_2H_4OH$ diglycol etc.

The dilute glycol solution is then sent to an evaporation system for water removal and a distillation system for purification of the various glycol products. The yield of total glycols is almost quantitative, based on ethylene oxide feed, and comes to slightly less than 1.4 pounds per pound of ethylene oxide. The yield of monoglycol will vary with the water ratio to the reactor, but is generally about 85-90 per cent of the total glycol weight.

More elaborate purification provisions are necessary for the preparation of a "fibre-grade" glycol, suitable for use in polyesters. Our organization has built several commercial plants which can make fibre-grade glycol directly from dilute ethylene oxide produced in air-oxidizer plants making it unnecessary to go through the expense of concentrating and purifying the ethylene oxide for this purpose.

E. *Factors affecting present and future economics*

As was mentioned above, the works cost of production of ethylene oxide made by the chlorohydrination process is approximately ten to twelve cents/lb., United States basis, assuming chlorine can be purchased in the neighbourhood of fifty dollars/ton. The United States works cost of production for ethylene oxide by the direct oxidation processes, assuming modern large-scale plants, is about five cents/lb. lower than for chlorohydrination. For this reason, coupled with calcium chloride disposal problems, there has been no new ethylene oxide plant expansion in recent years based on the chlorohydrination process, nor is there likely to be in the future for either the industrialized or developing nations.

The main decisions, therefore, to be made by those who are contemplating the manufacture of polyester fibres will be:

(*a*) Make or import ethylene oxide/glycol?

(*b*) Make or import ethylene?

(*c*) Use oxygen or air?

As was discussed in reference to terephthalic acid manufacture, a number of the considerations involved in these questions are political and economic in nature and not particularly related to the technology of the manufacturing operations with the exception of item (*c*) above and possibly, to a small extent, item (*b*).

1. *Make or import ethylene oxide glycol?*

This question, for a developing nation, must very likely be decided on the bases of how large a scale of glycol manufacture is envisaged by the area to be served. As we have discussed above, ethylene glycol comprises less than one-half of the weight of the polymer used in the polyester fibre and, therefore, very large fibre manufacturing operations would have to be undertaken to require a glycol supply that would be of an economic plant size for this use alone. A major consideration, therefore, would be whether or not there were other uses for ethylene glycol in the geographical area to be served. As an example, if it were desired to make 20,000 tons per year of polyester fibre only about 7,000-8,000 tons of ethylene glycol would be required. In a plant of this small size, assuming ethylene at the same price as in the United States (four to five cents/lb.), the cost of production of ethylene glycol would probably be from two to four cents/lb. higher than in the very large plants now recently installed in the major industrial countries. Furthermore, the investment in the small glycol plant per unit of annual product would be high compared to major plants elsewhere, requiring a considerable burden on the transfer price of the glycol made therefrom in order to recover the value of this invested capital in a reasonable number of years. A basic question must, therefore, be considered by areas contemplating glycol production on this small scale as to whether it would not be better to negotiate a long-term supply of glycol from an industrialized area and pay the relatively modest freight of perhaps one cent/lb. or less.

Very naturally, it would help matters greatly if other uses could be found for ethylene oxide and/or glycol in the territory to be considered, and though it is beyond the scope of this study, it might be well to re-emphasize that the percentage of total glycol produced in the industrialized countries that is used for polyester fibres is practically miniscule. It is, therefore, highly probable that any developing area that was planning to undertake such a sophisticated manœuvre as the manufacture of polyester fibres would also simultaneously contemplate other industrial ventures that would be consumers of glycol.

2. *Make or import ethylene?*

Practically the same consideration obtained here as for the question regarding the manufacture of ethylene oxide and glycol. This question would probably not have existed a few years ago, since it is only in recent years that ethylene has been transported on a large scale. Great strides have been made in the bulk transportation of ethylene at low cost in large specially designed vessels, and it is not entirely inconceivable that such transfers of ethylene could be made in the future from, say, an industrialized area to a developing area, or between developing areas, one of which has a very large production of ethylene.

In some cases, for small consumers, ethylene has been made by the dehydration of ethyl alcohol, which in turn has been made by the fermentation of local products. While we do not believe this can be a long-range solution to the problem of economic advancement of developing areas, it could be a temporary solution to some problems of raw-material supply, and we have ourselves been called upon to install such ethylene-from-alcohol plants in a number of circumstances as described above.

3. *Oxygen or air for direct oxidation?*

This question is a moot one for the highly industrialized countries. It is a difficult decision to make, since the economics are exceptionally close when very large plants making low-cost oxygen are available to supply an ethylene oxide plant with this incremental oxygen. Forgetting, for the time being, the safety question, an economic case can be made for oxygen in these exceptional cases. Where the oxygen plant must be built directly to supply the ethylene oxide plant, however, our studies seem to always show that no matter what size plant is contemplated, it is slightly more economical to use air as the oxidant, particularly when one insists upon a high-quality oxygen plant of the highest available performance from a safety point of view.

For the developing areas, however, the decision is far simpler. Here there is far less chance that very large oxygen plants (say on the 500-1,000 tons/day scale) will be in the vicinity of the desired ethylene oxide/glycol production. Furthermore, the size of the plant will undoubtedly be smaller than would be justified for the installation of an oxygen plant for ethylene oxide manufacture alone. The one exception to the above analysis might be the case in which nitrogeneous fertilizers are made, in which case there could conceivably be a by-product production of oxygen which would be available for petrochemical manufacture; this availability has been the exception rather than the rule, however, in the industrialized nations and would not be expected to play a large part in the developing ones.

Probably a major consideration to be taken into account by the developing areas in the choice of whether to use oxygen or air would lie again in the question of safety. As discussed above, the use of oxygen requires sophistication and precision in control, operation and maintenance, which might be difficult to achieve in areas in which large numbers of newly trained personnel of perhaps limited education must be relied on for not only routine operations but also supervisory responsibilities.

4. FROM CRUDE OIL TO SYNTHETIC FIBRES

with special consideration of process sequences for polyester-type fibres

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INTRODUCTION

The growth of the population of the world is indicated in figure I. The present figure is 3.2 billion, and by 1977/78 approximately 4 billion people will have to be fed and provided with clothing. We all know how difficult it is to provide the present 3.2 billion people with adequate food. How much more difficult will it be to meet not only the demands of the growing population, but also the requirements regarding increased production, better quality, and greater variety of products. Figure I also indicates that the growth rate is highest in those countries which are in the process of economic development.

With the increasing population of the world the output of natural fibres, such as cotton, wool and silk can no longer meet the requirements for clothing.

The consumption of chemical fibres, and particularly synthetic fibres, is nowadays a criterion for the standard of living.

The textile industries in almost all countries have created fabrics which are produced from blends of natural and synthetic fibres. Hereby the good qualities of various fibres are combined to yield products of optimum characteristics which offer a greater variety of new fashions. Also the technical sector demands ever-increasing requirements from chemical fibre producers regarding quantity, quality and typical characteristics.

The present total demands for textile raw materials are roughly 16-17 million tons *per annum*, of which about 10 million tons are cotton. The chemical fibres involve 4-5 million tons including 1.3 million tons of synthetic fibres.

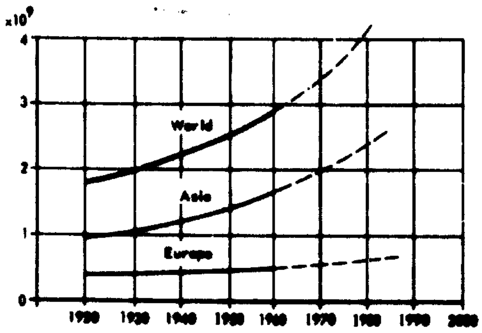

Figure I. *Growth rate of world population*

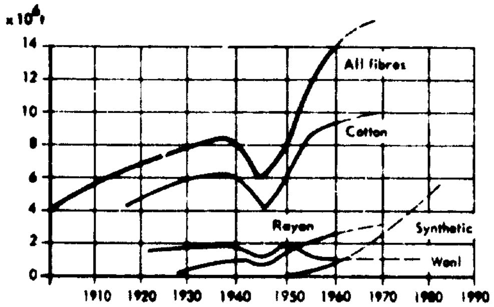

Figure II. *World textile fibre production*

Since its recession during the Second World War, world production shows a strong upward trend. Cotton is still the dominating fibre, although its production volume rises only slightly and its relative proportion of the total fibre output is declining. Wool has been overtaken long ago by the chemical fibres, and recently even by the synthetic fibres. As can be seen in figure II, rayon production is rising, but not as rapidly as the synthetics which have an annual growth rate of 20-25 per cent. Experts forecast that in the seventies the volume of synthetic fibres will have exceeded the output of cellulosic fibres.

In summing up, it may be concluded that the needs and consequently the production of synthetic fibres will rise considerably in the future. It is necessary for the economy of any country to analyse and solve the problems connected with the supply of synthetic fibres. It is hoped that this paper will make a small contribution to the solution of these problems.

II. CONSUMPTION AND PRODUCTION OF SYNTHETIC FIBRES

Nowadays synthetic fibres are known all over the world, but not all people enjoy the privilege of using synthetic fibres for their clothing or to raise their standard of life. As mentioned earlier in this paper, the consumption of synthetic fibres is in direct relationship with the standard of living. The annual *per capita* consumption in the different countries therefore varies rather considerably.

The consumption of textile fibres is first analysed in a more general way (see figure III). The figures available from United Nations statistics or other sources are

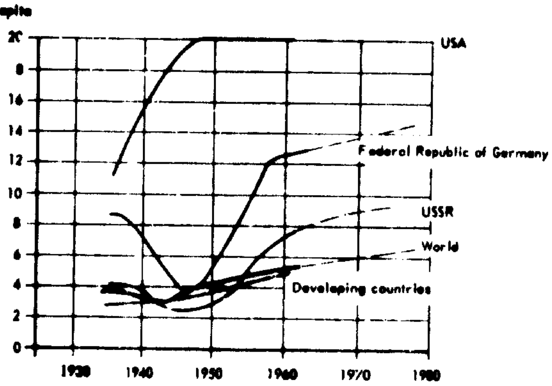

Figure III. Per capita *consumption of textile fibres*

not identical so that only rough average figures can be quoted. But for the purposes of this paper the general tendency is of interest rather than absolute figures. Average world *per capita* consumption shows a constant upward trend and is presently at a level of 5.5 kilogrammes per annum. In some developing countries which have already established a powerful modern textile industry, the *per capita* consumption is almost parallel and at the same level. The figures apply to countries like the United Arab Rep. and Brazil. Countries which have not yet developed their textile industry to the same standard should have a lower annual consumption of two to four kilogrammes *per capita*. Of particular interest is the curve for the United States where the *per capita* consumption of textile fibres of roughly twenty kilogrammes in 1960 was twice the consumption in the Federal Republic of Germany, three times the consumption in USSR, and almost four times the average world consumption. For the last few years this *per capita* consumption seems to have remained constant, and one might wonder whether the twenty kilogrammes per year are the upper limit of consumption. Production of course increases permanently. The curve for the Federal Republic of Germany equally applies to other highly industrialized countries, such as the United Kingdom, France, Japan, Italy etc. The consumption of textile fibres has been increasing but seems now to be levelling off.

Figure IV shows the *per capita* consumption of various fibre types as a world average. The total world average consumption is 5.5 kg.

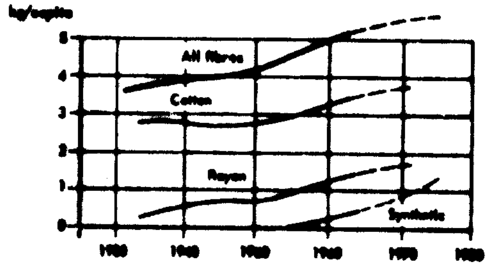

Figure IV. Per capita *consumption of various fibre types (world average)*

Cotton is in the lead, rayon is striving towards 1.2-2 kilogrammes, while the consumption of synthetic fibres is increasing at a fast rate; the present level is 0.3 kilogrammes, and consumption in 1970 is likely to be 0.8 kilogrammes.

The estimate of the *per capita* consumption of synthetic fibres for the coming years is of particular interest (see figure V).

The consumption in the United States has exceeded 2.2 kilogrammes per annum. Federal Republic of Germany and comparable countries will soon have reached 2 kilogrammes, while the world average is only 0.3 kilogrammes. Various forecasts indicate that the *per capita* consumption will reach a level of 0.8 kilogrammes in 1970. This clearly characterizes the dynamic development of this young branch of industry. To meet the increasing demands a lot of work remains to be done towards the establishment of production facilities, the supply of raw materials and textile processing. This is a big task for planning authorities and industry in all countries.

The evaluation of all data available on the consumption of synthetic fibres is shown below :

Year	*Per capita*	*World population*	*Need*
1962	0.27 kg	3.03 × 10^9	850,000 t
1965	0.43 kg	3.22 × 10^9	1,300,000 t
1970	0.80 kg	3.50 × 10^9	2,800,000 t
1975	1.20 kg	3.80 × 10^9	4,500,000 t

Although the forecast for the future is vague, it can be expected that the consumption of synthetic-fibres will increase threefold during the next decade.

An analysis of the production of synthetic fibres shows the following sales of synthetic fibre products in the United States :

	Million US dollars
In 1940	10.5
In 1950	315.1
In 1960	1,500

Since the United States produced about 40 per cent of the world output in 1960, the total sales of synthetic-fibre products in the world during that year can be estimated

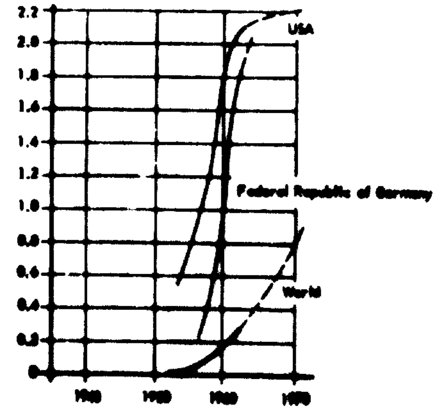

Figure V. Per capita *consumption of synthetic fibres* at 3.7 billion. This proves the great economic importance of this branch of industry.

The following percentages show the proportion of synthetic fibres used in the manufacture of commodities for our daily life :

Per cent synthetics	In usage for
41	All outer garments
91	Linings
95	Umbrellas
85	Bedspreads
69	Ties and shawls
70	Upholstery and curtains
50	Shirts

To conclude this section an examination is made of the proportion of each particular type of synthetic fibre in total production. Consumers are puzzled by the immense number of different types of fibres and by the great variety of fashions. In the fifties, the technical press reported about the creation of many new chemical compounds having fibre-forming properties, and it seemed that a different type of fibre could be developed for each particular application. At the same time, research work was carried out with a view to finding fibres for universal application, and advertisements spoke of miracle fibres. This enthusiasm which is typical for the development of a new branch of industry of great economic importance has given way to a sounder judgement in conformity with market requirements. Excessive hopes have dwindled away, and there exists no miracle fibre for universal application. New fibre-types seldom become known to the public and even more seldom gain any importance on the market. Any inventor of a new fibre will have to struggle hard to meet the extremely high standard of conventional fibres on a commercially economical basis. The development of a useful fibre from its discovery to its industrial application surely takes between six to ten years and requires capital investments at a rate of 10 million US dollars or more.

During recent years research has therefore been concentrated on the conventional popular fibres, such as : polyamide, polyester, polyacrylonitrile, polypropylene, and others, such as polyvinyl alcohol, polyurethane, and polyvinyl chloride.

Nowadays research work in almost every industrialized country is directed towards the following objects :

(*a*) Supply of additional and low-cost raw materials, chiefly based on petroleum;

(*b*) Improvement of the processes for polymer production spinning, and further processing into textile products;

(*c*) Development of new processes for blending with other chemical fibres or with natural fibres;

(*d*) Discovery of new copolymers which permit better adaptation of the fibres to optimum requirements.

All in all, attempts are being made to create less expensive, better and more universal fibres on the basis of the conventional types.

The production of all types of fibres is increasing rapidly. Forecasts for future output vary rather considerably, although they are frequently exceeded by the dynamic development. The curves on the diagram showing the future growth are therefore fanned, and it can be expected that the production figures will be within the area of the fan (see figure VI).

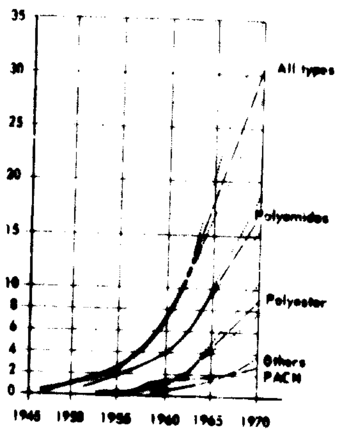

Figure VI. *Development of synthetic fibre production in the world*

Polyamide fibres are leading and represent roughly 60 per cent of the total output of synthetic fibres. Amongst the popular fibres are nylon, perlon, enkalon, lilion, amilan and many others. In the second position are polyester fibres with a very steep rise in output which is likely to increase further in the future. The popular polyester fibres include terylene, dacron. trevira, diolen, tetoron, fortrell, and others. Also polyacrylonitrile fibres hold a considerable proportion of the market although their growth rate is less than that of the two leading fibre types. The conventional polyacrylonitrile fibres are orlon, dralon, acrilan, courtelle. Included in the general category of "other" fibres are products based on polypropylene, polyvinyl alcohol and polyurethane; they constitute an almost equal proportion of the total world production.

The growth rate of all synthetic fibres is roughly 20-25 per cent per annum, and it is expected to be 250,000 tons this year. A rough estimate leads to the supposition that approximately one US dollar per kilogramme of additional annual output will have to be invested for the processing of the monomeric raw material into the fibre alone. This means that roughly 250 million dollars will be invested for this production step. When adding the investments for the expansion of the raw material supply and for modern textile processing equipment, the total investments will be several times the above figure, i.e., in the order of one billion dollars.

III. GENERAL SURVEY OF PRODUCTION PROCESSES

The large-scale production of synthetic fibres is a typical development of the present century. Strictly speaking, production began during the Second World War, about 1940.

Many branches of industry are involved in the manufacture of synthetic fibres. Most processes are based on

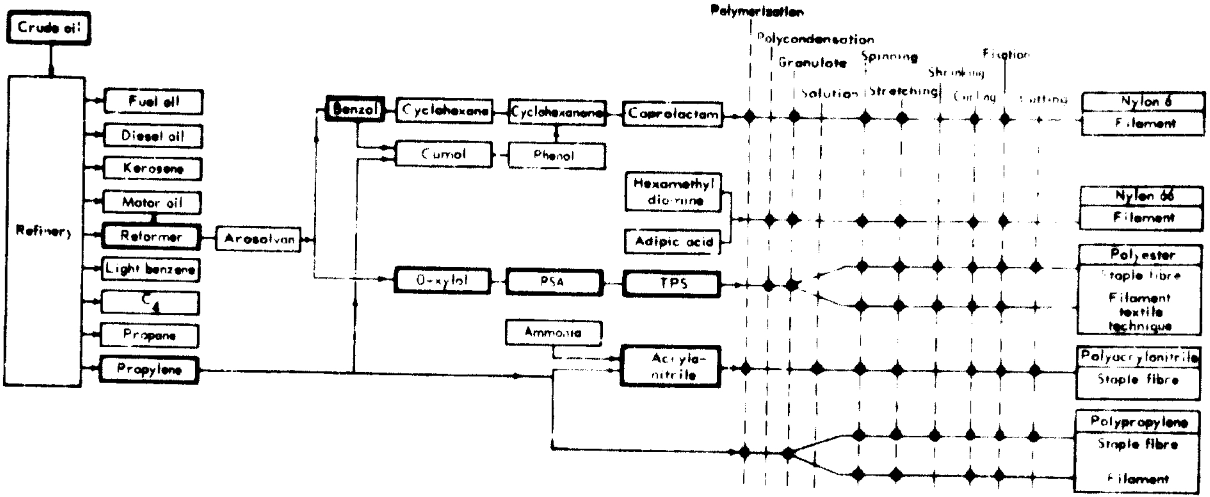

Figure VII. *From petroleum to synthetic fibres*

petroleum from which various routes lead to the petrochemical raw materials for the textile industry which processes these materials into a great variety of fabrics.

As will be seen from figure VII the process routes include the following major steps : petroleum extraction; refining; aromatics and olefin recovery; petrochemical raw materials; synthetic-fibre production (polymerization, spinning, finishing); synthetic fabrics; consumers.

In the following a brief description is given of the principal methods used nowadays for the manufacture of synthetic fibres.

The process route from petroleum to synthetic fibres includes the following five major steps: production of chemical raw materials; production of monomers; formation of high-polymers; spinning and stretching of fibres; finishing.

These steps are required for the manufacture of all types of fibres. They are therefore of general importance no matter whether orlon, nylon, or terylene are to be produced.

A. *Production of chemical raw materials*

Since the starting material is always petroleum, the first step would be the refining of the petroleum which furnishes, apart from motor fuels, gas and fuel oils, also a great variety of valuable raw materials. Certain hydrocarbon cuts are suitably treated by special processes to recover aromatics and olefins of high purity. These substances include benzene, toluene, xylene, ethylene and propylene which are the basic materials for all fibre types. Polyester is based on xylene, polyamides on benzene polyacrylonitrile on propylene, and so on.

In view of the fact that many countries have resources of petroleum, it can be expected that the manufacture of synthetic textiles from petroleum base stocks will be taken up also by the developing countries in the future so that still more people will become the beneficiaries of modern, high-quality and low-cost textile products.

B. *Production of monomers*

This processing stage must already consider the specific properties required from the particular type of fibres. The high-purity requirements demanded by synthetic-fibre producers have led to the specification "fibre-grade" which characterizes a very high standard.

The aromatics and olefins are converted by several processes into monomers which constitute the direct raw material for polymerization.

If the polymers obtained have sufficient intermolecular attraction forces, if the molecules are stable, and if the polymer melt or solution has fibre-forming properties, they will be suitable for the synthetic-fibre industry. The fibres must have the properties required by textile producers, such as mechanical strength, elasticity, dyeability, light and heat stability, high melting point, pleasant feel, and many others. Last but not least, fibre-grade monomers should have a high purity and good keeping properties, and their price should not be more than twenty to forty US cents per pound, or forty-five to ninety cents per kilogramme. The low price is of greatest importance, because the price of the monomers constitutes about 50-75 per cent of the fibre production costs and exceeds by far the cost for amortization, energy, labour and maintenance. This is the reason why the petrochemical industry has centred on the manufacture of low-cost monomers by economic processes.

The following are the major types of monomers:

(*a*) For nylon-type fibres: nylon salt, i.e., the salt from adipic acid and hexamethylene diamine;

(*b*) For perlon-type fibres: caprolactam;

(*c*) For terylene-type fibres: glycol ester from terephthalic acid;

(*d*) For orlon-type fibres: acrylonitrile.

C *Formation of high polymers*

The monomers are converted by polycondensation or polymerization into high polymers which can be spun into fibres. The processes vary with the individual type of polymers. Recent developments tend towards continuous methods as commonly applied for caprolactam polymerization since 1940. In special cases, nylon, too, is produced by continuous polycondensation; this is relatively easy when polyacrylonitrile is involved. However, the continuous processing of polyester is more difficult and it is applied only on a limited scale, although comprehensive patent literature has been published about this processing method. The plants are generally built for large capacities of three, six or ten tons per day. Modern plants are arranged for substantislly automatic operation, and the polycondensation process is programme controlled to provide for optimum conditions.

Polyacrylonitrile is polymerized in an aqueous suspension or in a solvent. Other polymer types may be processed direct. For instance, in the case of polycaprolactam the molten mass of monomer is charged to a reactor where it is polymerized over 24 hours at 260°C, under atmospheric pressure and in the presence of a small amount of water and a stabilizer (chain breaker). In the case of polyester, the glycol ester of the terephthalic acid condenses to set free glycol in the presence of a catalyst. The final temperature is 280°C, and the pressure ranges from above atmospheric to adequate technical vacuum of a few millimetres of mercury. Also nylon salt can be condensed into nylon under similar operating conditions, whereby water is formed which has to be removed.

As the polymeric substances generally have little resistance to oxidation, the processes take place in an inert gas atmosphere. Even the slightest effect from oxidation would cause filament breakage during textile processing and would create troubles during dyeing. Optimum purity and uniform properties are therefore absolute requirements for polymers.

Polymerization processes imply equilibrium reactions which means that after reaction the formed high polymers and the unreacted low-molecular proportion are in equilibrium. The latter is generally removed as it might have an adverse effect during spinning and stretching. In some processes the molten mass or the solution is spun directly into filaments, although most processes first produce the polymer in the form of chips or powder which, after drying, constitutes a marketable product. Small spinning or plastics processing plants purchase these polymers from large producers until their own plants have a sufficiently large capacity so as to justify the establishment of their own polymerization plant. After the polymerization plant has been incorporated in the over all scheme as a new stage such company purchases the monomeric raw material.

Although polymerization processes are basically identical there are a lot of modifications, since each producer develops his own ideas and operating methods. Polymer viscosity and pigment addition have to be chosen to suit the specific use of the fibre. Moreover, the manifold requirements demanded by textile processors, fashion, industry, military equipment, etc. have to be considered.

While one single polymer grade is sufficient for all polymer products of one type, polymerization and the subsequent processing steps have to produce a great variety, possibly several hundreds, of different types of fibre. The major uses for synthetic fibres are: outer garments, underwear, hosiery, household textiles, carpets, tyres, industrial textiles, and bristles.

Each particular use requires different viscosities of the polymer, different stabilizers, dyes, dulling grades, finishing treatment, and of course different deniers, twist, strength, elongation etc.

D. *Spinning and stretching of fibres*

This stage converts the polymer into the fibre for the textile industry. The spinning section is therefore the heart of any synthetic fibre plant. It produces the great variety of fibre types and deniers. Although spinning processes are basically identical they can be divided into the following two main categories.

The polymer is dissolved, e.g., polyacrylonitrile in dimethyl formamide, and the solution is dry-spun or wet-spun in a bath. Dry-spinning permits higher spinning speeds (several hundred metres per minute), but it is limited to a few hundred holes, i.e., single filaments, per spinneret. Wet-spinning affords the use of larger spinnerets having 10,000 holes and more, but the spinning speed is low. In both processes the solvent is separated and recovered. The deniers are within the range of 1 to 20 which is adequate for all fibres, such as cotton type, wool type or filament.

Compared with the above, the use of melt-spinning is easier. The polymer chips are melted on heated grids or in heated screws at 250-270°C. The melt, also when it comes direct from polymerization, is metered by gear pumps through spinnerets having 1-500 holes each and spun into fibres. Spinning speed ranges from 500 to 1,800 metres per minute. The filaments are finally wound-up on bobbins or deposited in cans as tows.

At this stage, the molecular chains of the filaments are in a disordered condition so that they lack tensile strength and other mechanical properties. Molecular orientation is therefore indispensable and is accomplished by stretching the filaments under elevated temperature at a speed of 200-800 metres per minute. The filaments are stretched to three to five times their original length. The stretched filaments have the necessary mechanical strength of, for instance, 4-9 grammes per denier at an elongation at break of 15-40 per cent. Spinning and stretching generally require special air-conditioned rooms and this has to be considered in the design of the buildings.

Constant control of the quality of the produced fibres, proper textile testing and grading are of major importance. The present quality standards in the synthetic fibre industry have reached a remarkably high level. Filament lengths of several hundred kilometres should have one fault at the maximum, and the uniformity of the deniers must be maintained with a tolerance of ± 1-2 per cent. It is obvious that the production of such high grade fibres requires raw materials and intermediates of optimum purity, and modern plants which operate economically and which are based on proven and trouble-free processes.

E. *Finishing*

In many synthetic fibre plants the stretched filaments are subsequently twisted, thermo-set and delivered to the consumers as precision wound filaments in packages. Fibre tows are shrunk under temperature, crimped, thermo-set, cut into staples and baled. Yarn for socks, bathing costumes, pullovers, etc. are crimped by various methods, such as helanca, ban-Loon, to make them elastic and voluminous. These additional processes are to make the product more adaptable for use by the textile industry, and they are the last step in the sequences of processes from petroleum to synthetic fibres.

The individual types of fibres have preferred fields of application where their specific characteristics are specially effective. Examples of these are:

(*a*) *Outer garments:* polyester or polyacrylonitrile fibres, separately or in blends with wool, cotton or rayon;

(*b*) *Underwear and shirts:* chiefly nylon and perlon, i.e., polyamide and polyester-based fibres;

(*c*) *Stockings and socks:* polyamide fibres;

(*d*) *Pullovers:* polyacrylonitrile and polyester fibres;

(*e*) *Tyre cord:* polyamide and polyester fibres;

(*f*) *Industrial yarns, and fishing industry:* polyamide and polypropylene-based fibres;

(*g*) *Carpeting:* polyamide and polypropylene-based fibres;

(*h*) *Curtains and ties:* polyester fibres.

Any new production scheme should therefore be planned with consideration of the market situation, textile demands, climatic conditions, industry, capacity and many other aspects.

IV. PRODUCTION OF POLYESTER FIBRES

The preceding chapter described the various process routes which lead from petroleum to synthetic fibres. The processing steps for one particular type of fibre are now described in somewhat more detail. The example refers to the production of polyester fibres since this fibre has the fastest growth rate at present. A great number of polyester plants are likely to be built during the next years. Polyester fibres are very suitable for blending with natural fibres, and also polyester filaments have excellent properties, so that even the automobile tyre industry shows an ever-increasing interest in polyester fibres.

Since Whinfield and Dickson made their invention, and since ICI and Du Pont developed the technology of polyester fibres, almost the entire polyester-fibre production in the world has been based on dimethyl terephthalate and ethylene glycol. Only recently a few new processes were developed which furnish modified polyesters based on comonomers, such as para-oxybenzoic acid, isophthalic acid etc. Moreover, it has been possible to produce terephthalic acid of high purity which permits direct esterification with glycol, so that the route *via* DMT can be saved. These processes have been developed by Amoco and Henkel-BASF and they appear to offer economic advantages over the classical DMT process. Various types of polyester are produced nowadays to meet the specific requirements of industry and textile processers. Co-polyester with much better dyeability and reduced pilling effect is preferably used for the textile clothing industry. The production of high strength yarn, and particularly tyre cord, requires highly viscous homopolyester.

In principle, there are two major routes from petroleum to polyester fibre.

The classical route starts with the petroleum and includes the following steps: refinery; reformer; primary distillation; paraxylene recovery by crystallization; possibly isomerization of orthoxylene and metaxylene into paraxylene to increase the yield; single or two-stage processing into dimethyl terephthalate; interesterification with ethylene glycol; polycondensation and chips production; chips drying; melt spinning; take-up or tow take-off; stretching, shrinking, crimping, thermo-setting, cutting into staples, and baling.

The production of filaments proceeds similarly.

These processes have been developed to a high standard and are arranged for largely automatic operation so that they furnish products of optimum yield and quality. Since the processes for the classical route are commonly known nowadays, they need not be described in detail. This paper therefore deals with a new route to polyester which became known approximately one to two years ago and which should be of interest.

This new route again starts with petroleum and includes the following steps : refinery; reformer; primary distillation; final distillation to produce orthoxylene; phthalic anhydride; high purity terephthalic acid; direct esterification with ethylene glycol; polycondensation and chips production; chips drying; melt spinning; take-up or tow take-off; stretching, shrinking, crimping, thermo-setting, cutting into staples, and baling.

The major difference between the new route and the classical route is the use of lower-cost orthoxylene, the production of phthalic anhydride, the production of high purity terephthalic acid by a new process and the direct esterification of the terephthalic acid, so that any methanol does not occur. All other stages are classical processes similar to the original route, except for chips drying which should preferably be accomplished in a continuous whirling and fluidized bed dryer with hot air. At the present market prices for paraxylene and orthoxylene, the production cost of the polyester by the new route is somewhat less expensive. According to publications by a large Japanese synthetic-fibre producer, the price difference is nine cents per pound. This is the reason why some firms in Japan, the Federal Republic of Germany and Switzerland have shown an interest in this new route.

Apart from the discontinuous polycondensation processes, continuous polycondensation processes have also become available recently which have, however, not yet proven their suitability for industrial application. Although some large producers might have collected sufficient experience in this field, the major output of polyester is still produced by discontinuous processes in autoclaves.

A detailed description is now given of the new process route.

A. *From orthoxylene to phthalic anhydride (by the process of Chemische Fabrik von Heyden AG.)*

The raw material is orthoxylene with a minimum purity of 95 per cent. The end product is high purity phthalic anhydride which is suitable for further processing into terephthalic acid.

A mixture of orthoxylene and preheated oxidation air is charged to the top of a reactor consisting of a bundle of tubes which accommodate the catalyst and which are externally heated by a salt melt. Since the reaction, the partial oxidation of orthoxylene to phthalic anhydride, is strongly exothermic, the salt melt is used for cooling the mixture after reaction has started. The surplus heat of reaction is transferred by the salt melt to a tubular vaporizer for the generation of high pressure steam, which contributes towards an improved economics of the process.

The reaction mixture is cooled and sublimated in gilled tube coolers. The surplus air is cleaned and discharged to atmosphere. As soon as one sublimator is loaded with phthalic anhydride crystals, the anhydride is molten and subjected to distillative treatment in a three-stage vacuum distillation plant. The high purity phthalic anhydride runs off into heated intermediate tanks from where it is supplied to the next processing plant.

The smallest economical size plant should have a capacity of 6,000 tons per year. The production of 1 ton of phthalic anhydride requires 1.022 tons of 100 per cent orthoxylene and approximately 1,000 kWh. The process generates steam at 5-15 atmospheres gauge at a rate of 1 ton per ton of phthalic anhydride. The operation of a 6,000 tons per year plant requires 14 operators and helpers on the basis of four-shift operation.

The plant is installed out in the open and requires a groundfloor area of approximately 25 × 60 metres.

B. *From phthalic anhydride to terephthalic acid (by the Henkel-BASF Process)*

The raw material is high purity phthalic anhydride and the end product is high purity terephthalic acid which is suitable for direct processing into polyester.

The phthalic anhydride is converted to dipotassium orthophthalate by two-stage precipitation and then neutralized. After evaporation and the addition of zinc catalyst, the mixture enters a spray dryer and leaves it in the form of powder at a temperature of 100°C. The powder is briquetted, and the briquettes discharged from the press are heated further. The briquettes are then introduced via a lock chamber into a reactor with a travelling steel conveyor belt where the major reaction takes place. During the isomerization reaction, the dipotassium salt of the ortho-phthalic acid is converted into the dipotassium salt of the terephthalic acid at 430°C and 20 atmospheres gauge pressure. The caking properties of the feed-stock created some difficulties, but the travelling belt has mastered this problem and the dipotassium terephthalate is discharged from the reaction chamber by extrusion presses as properly crushed material. After dissolving the reaction product in water, it is separated from the catalyst slurry. The colour of the solution is improved by treatment with activated carbon. The purified terephthalate solution now enters the first precipitation stage where the potassium terephthalate reacts with potassium hydrogen terephthalate solution from the second precipitation stage to form dipotassium orthophthalate and insoluble potassium hydrogen terephthalate. The latter is passed to the second precipitation stage where is reacts with molten phthalic anhydride to form insoluble terephthalic acid and soluble potassium hydrogen phthalate which is returned to the first precipitation stage.

After filtration and drying, the terephthalic acid is stored in an intermediate bunker from where it is supplied to direct esterification.

The minimum size plant should have a capacity of 6,000 tons of terephthalic acid *per annum*. The production of 1 ton of terephthalic acid requires 1.01 tons of phthalic anhydride, 800 kWh, approximately 5 tons of steam and 200 cubic metres of water. Operation of the plant requires 32 operators and helpers on the basis of four-shift operation.

The plant is installed partly in the open and partly in a building. The floor space requirements are 83 × 25 metres.

The terephthalic acid has a purity of 99.8-99.9 per cent which makes it suitable for direct esterification with glycol.

C. *From terephthalic acid to polyetherester chips (by the Ems/Inventa Process)*

The raw material is high purity terephthalic acid, and the end product is dried polyester chips which can be spun into fibres.

This process furnishes a modified type of polyester of improved dyeability. For this purpose, a co-product, the parahydroxybenzoic acid, is incorporated. The example described starts with the terephthalic acid, and not with the dimethyl terephthalate, which means that trans-esterification is replaced by direct esterification.

Terephthalic acid and parahydroxybenzoic acid are esterified separately. The ester and the ether are charged together with catalysts and dulling agents, to a polycondensation autoclave which operates fully automatically and which is programme controlled. Temperature, pressure, and vacuum are therefore identical for each batch which ensures that the product has uniform properties. At the end of the process cycle, the molten mass is extruded through a slotted spinneret and a casting machine as a ribbon. The ribbon is chopped into chips of uniform size. Water cooling of the chips reduces their moisture content to approximately 1 per cent. This moisture must be reduced further to less than 0.01 per cent before spinning for which a continuous drying system consisting of whirling dryer and fluidized bed dryer is used.

From the cutting machine the chips are conveyed pneumatically to a storage and blending silo. Several batches are combined at the bottom outlet of the silo compartments which provides for a still higher degree of evenness of the polymer. Pre-drying in the whirling bed of a Venturi tower in an air current of 180°C takes

5 minutes. The chips are then passed automatically to the fluidized bed where they are dried to a residual moisture of 0.01 per cent in an air current during approximately forty-five minutes. The dried chips are conveyed pneumatically to the spinning section where they are automatically distributed between the various spinning hoppers.

A polycondensation plant should have a minimum capacity of 6,000 tons per year, although a 2,000 tons per year plant might also be economical under favourable conditions. Plants of this capacity are already in operation in small countries and also in developing countries. The complete polycondensation plant is accommodated in an enclosed building, except the oil- or gas-fired Dowtherm heating unit which is located out in the open.

D. *From polyetherester chips to fibres*

This processing stage converts the polymer chips into the fibre. It is the last stage in the route from petroleum to fibre and the preliminary stage for the textile industry. Spinning, stretching, and finishing should therefore be adapted to the future use of the fibres. The conventional types of fibres are cotton-type of 1.5 or 2 denier, wool-type of 3, 6, or 8 denier, and filament of 40, 70, 90, or 150 denier.

The process arrangement for the production of staple fibres is as follows:

Each spinning hopper supplies one melter with chips. Screw melters are substantially employed with screw lengths of twenty-four times the diameter. The use of special material and adequate surface finishing of screw and casing ensure continuous service over many months and the supply of a homogeneous melt of uniform characteristics. Screw melters have an inert gas purge system, five different temperature zones, automatic pressure control, and they feed several spinnerets. For instance, in a fibre plant for six tons per day or 2,000 tons per year, three screw melters feed eighteen large spinnerets. One precision gear pump is arranged between each screw melter and spinneret which accurately meters the melt to form the proper denier. One spinneret is preceded by a number of filters and has up to 500 holes depending upon the denier required. A take-off machine located three to five metres below the spinnerets provides for a constant take-off speed which is far beyond 1,000 metres per minute, or sixty kilometres per hour.

The filament bundle leaving the spinnerets is cooled uniformly in blowing ducts with conditioned air. On the take-up machine, the filaments are wetted, treated with finishing oil, and combined to a tow of 30-80,000 deniers. The tow is deposited in cans, approximately fifty cans being mounted on a creel. The so-formed tow of roughly 2 million deniers is stretched in several zones with the application of steam and also shrunk, depending upon the type of fibres. The tow is then washed, treated with Avivage and crimped. After thermo-setting the tow is cut into the required staple lengths. The staples are passed to the baling press, and after textile testing in the laboratory, the baled fibres are supplied to the textile processers.

The production of filaments requires smaller spinnerets with maximum fifty holes. In that case sixteen spinnerets are combined in one Dowtherm-heated spinning box, and one screw melter normally feeds thirty-two spinnerets, i.e., two spinning boxes. Here again the melt is metered by gear pumps through a filter pack to the spinneret. From the spinneret the filaments pass through blowing ducts to the take-off machine where they are wound on bobbins. After hot stretching on draw twisters the filaments are finished on cops. Further processing of the filaments on false twist or other texturizing machines, or on twisting, shrinking and coning machines to the finished filament on cardboard tubes is handled either by the fibre producers or by the textile processers.

It should be mentioned that fibre plants have to be installed in largely air-conditioned buildings without windows. Extensive analyzing and testing facilities are required to test the products and to sort them according to the various quality grades. These facilities in conjunction with properly trained personnel and modern and economic equipment are necessary to produce fibres which meet the high quality standard required on the market.

The production of one ton of polyetherester fibre requires the following raw materials:

	Kg
Terephthalic acid	902
Parahydroxybenzoic acid	92
Ethylene glycol	445
Titanium oxide	4
Also catalyst, Avivage etc.	

The production of one ton of polyetherester fibres requires the following utilities:

Electric power	2,200	kWh
Steam	2.8	tons
Water	230	cu.m.
Fuel gas	280	st.cu.m.

The operation of a plant from terephthalic acid to fibre with a capacity of 6,000 tons *per annum* requires approximately 230 engineers, chemists, operators, and helpers, substantially on the basis of four-shift operation. The plant is accommodated in one multi-storeyed building of twenty metres height and approximately 45,000 cubic metres, and one single-storeyed building of approximately 35,000 cubic metres.

Other processes for the production of polyester fibres are basically identical to the above-described process. The object of all processes is to provide for largely automatic operation, high quality of the products and optimum economics. The progress made is reflected by the decreasing market prices of the products. The production costs per kilogramme of fibre largely depend on the cost of the raw materials, while the costs of amortization, energy and labour are comparatively low.

V. GENERAL ASPECTS FOR THE PLANNING OF SYNTHETIC FIBRE PRODUCTION PLANTS

The comments on the market situation for synthetic fibres, given in section II, has shown that in almost all countries efforts are being made towards the expansion of the existing production facilities. Although the big centres in the United States, Japan and Central Europe are still dominating, there are also smaller countries in South America, Europe and Asia which have established production facilities. Their capacity is generally low and their production programme is limited to the spinning and stretching of imported chips, but in some cases also includes polymerization for which the monomers have to be imported.

These countries frequently have a domestic textile industry. For instance, in Pakistan several textile factories were built since 1947. But even countries which are less developed industrially may start with the development of a textile industry, apart from agriculture, foodstuffs industry, transportation system and a light industry. These countries have a desire to install modern types of machines which are suitable also for the processing of synthetic fibres. They may soon thereafter import synthetic fibres and process them into textiles either alone or in blends with domestic or imported natural fibres. This development is promoted by the desire of these countries to expand their export market to get the necessary foreign exchange for the payment of machinery and equipment. Hence, many countries base their domestic textile industry on imported fibres, such as polyester fibres in bales, or filaments on cops.

At the same time petroleum refineries are being built in many countries which process domestic or imported crudes. These refineries initially include equipment for the distillation of petroleum to produce fuel oil, kerosene or diesel oil, but they are soon expanded by the inclusion of reforming plants and facilities for the production of high octane gasolene, olefins and aromatics. The next step would be the upgrading of these intermediates to manufacture plastics and petrochemical raw materials. This leads to the establishment of plants for PVC, polyethylene, fertilizers, general chemicals, and many other products.

An interesting situation exists in many countries in so far as they have a textile industry based on imported synthetic fibres, while their petroleum processing industry produces valuable aromatics, such as benzene and xylene, which are not fully utilized yet.

Consideration might therefore be given to closing this gap between the petroleum industry and the textile industry by incorporating the relevant process routes. The setting up of such compound industry is certainly the object of many planning authorities and is attractive to many countries. Projects of this magnitude, however, have to be planned most carefully since they have an influence on numerous secondary industries. Besides, each country is faced with different problems for which an individual solution has to be found. The model of the large industrial countries should not be copied before a very critical study has been made.

Since the above-described development is bound to take place, sooner or later, in all countries, those countries which already have large petrochemical industries should give reasonable assistance. The planning of projects should not be confined to the territory of any one country, but should also consider markets in large trading areas and in the whole world.

In consideration of the aforesaid, some recommendations for the establishment of synthetic fibre plants may be given. They should be installed in locations where the demand for ordinary type fibres has reached such a level that one or two economical-size plants would be sufficient to satisfy the market requirements. For the production of special types of fibres and development work reliance should be placed upon large and experienced producers in the United States, Japan and Europe.

A reasonable economic evaluation of a fibre plant is often altered completely by special laws in force in a particular country. For instance, some companies have managed to monopolize their business by means of protective duty, while other countries stop all imports as soon as the first fibre is spun in their own plants. Subject to these problems there are certain standards for smallest economical-size plants. For the start, the production of synthetic fibres should be based on imported polymer chips. The plant would include spinning, stretching, and possibly also crimping or other finishing treatment. When nylon or perlon-type fibres are to be produced, the plant should have a minimum capacity of two to three tons per day. A general rule is that the higher the denier of the produced filaments, the larger the production capacity shall be. In the case of polyester, the initial plant shall be for three to six tons per day, and in the case of polyacrylonitrile five to ten tons per day.

The capital costs for these plants are within the range of 1 to 2 million dollars of which 25 to 33 per cent are required in local currency to cover the cost of buildings, erection etc. The local personnel can be trained in the operation of the plants by a few experts, and after an adequate running-in period of several months, it can be expected that the plant will produce marketable products. It is recommended that production be confined to a few ordinary types of fibres.

The establishment of domestic synthetic fibre plants will result in a rapid increase in the demand for synthetic fibres. This also leads to higher imports of raw materials and of some special fibre types from highly industralized countries, which are also processed. This is the reason why there was never a decline in sales or production anywhere in the world, although many countries have built their own fibre plants.

When an initial plant is expanded and reaches a capacity which justifies the establishment of a polymerization plant of its own, this will considerably improve the economics of fibre production. The chemistry and technology of polymerization for all fibre types are rather complicated and difficult so that new specialists are needed, and new laboratories and facilities have to be installed. A polymerization plant for nylon should have a capacity of three to six tons per day, for polyester six to ten tons per day, and for polyacrylonitrile ten to fifteen tons per day. The additional capital investment is within the range of 0.5-2 million dollars.

Petrochemical intermediates and monomers, such as dimethyl terephthalate or terephthalic acid, caprolactam, and acrylonitrile, can be produced economically only in large-capacity plants of fifteen to thirty tons per day, for which the capital investments are between 8 and 15 million dollars. The operation of these plants demands a considerable amount of know-how and experience from the plant owner and his personnel. The products available on the world market are of such high and uniform quality that equivalent products have to be produced in order to be competitive.

It should further be considered that compound plants for synthetic fibres in the main producing countries have presently reached capacities of 50-100 tons per day and more, after several expansions have been made. At the same time, intensive research work is carried out in laboratories and pilot installations. The capital invested in these big industrial complex plants amounts to 100 million dollars. This shows that it is difficult for a company which starts production on a small scale to compete. New projects should therefore be limited to the production of a few ordinary-type fibres utilizing the experience and know-how from competent producers and engineering companies from developed countries. This can be arranged either on a licence basis, or by co-operation with competent producers who provide the necessary specialists for an adequate period of time.

To sum up it can be said that consumption and production of synthetic fibres are in a state of rapid development and that in almost all countries new plants or additional plants are being built. Production and research are centred on the improvements and reduction of cost of the four or five popular fibres. All synthetic fibres are produced from petroleum base stocks. The process routes lead from petroleum refining to fibre spinning as has been illustrated by the example of the polyester fibre. Some general recommendations have been given for the planning of new synthetic fibre projects on the basis of practical experience which would have to be elaborated in more detail for any particular project. It is advisable to start the development of new synthetic fibre plants with the last stage, namely the spinning of the fibre from the chips, and to expand the plant stage by stage towards the petroleum raw material corresponding to the increasing demands. This is also the best way for the progressive training of the personnel in the operation of the plants. When considering these points it should be possible to establish complex plants, ranging from petroleum to synthetic fibre, which can supply the raw material for domestic textile industries.

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5. DEVELOPMENT OF A SYNTHETIC FIBRE INDUSTRY, SUCH AS NYLON 6, IN DEVELOPING COUNTRIES

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I. INTRODUCTION AND FIELDS OF APPLICATION FOR NYLON 6 FIBRES AND FILAMENT

If the Government, an organization, or an enterprise of a developing country intends to construct petrochemical plants, the prerequisites are: careful planning, detailed marketing information, and customer acceptance of the end products.

E-caprolactam, a petrochemical product, is used as raw material for the production of the synthetic fibre nylon 6.

The producer intending to manufacture nylon 6 filament or fibres, has to examine most carefully all possibilities of sales in order to be in a position to establish the production programme, and the capacity of the plant. The buyers as well as those who use chemical fibres for further processing, must consider sales, this remains a basic consideration with regard to the whole chain of production and consumption and extending to the textiles customer.

The production requirements of synthetic fibres are determined by many factors; such as

(*a*) Population of the country;

(*b*) Industrial development of the country in general;

(*c*) The efficiency of the domestic textile industry in particular;

(*d*) The textile raw material basis;

(*e*) The social structure of the population;

(*f*) The buying power of the individual consumer;

(*g*) The climate;

(*h*) Last, but not least, fashion.

Most of these factors are intimately connected and influence each other. There is a relationship between population growth, progressive industrialization, and improvement of the standard of living, on the one hand, and increased consumption of synthetic fibres, on the other.

It may be considered that an increased production of natural fibre raw materials due to better cultivation methods may be desirable. However, the more intensive methods of agriculture or increased cultivation must, above all, ensure and improve the food basis.

The following tables show the production and consumption of chemical fibres, particularly of polyamide fibres.

TABLE 1. CONSUMPTION, PER PERSON, OF SYNTHETICS DURING 1960
(In lb)

United States	3.652
Federal Republic of Germany	1.672
Japan	2.728
Spain	0.22
USSR	0.242
Latin America	0.198
Africa	0.044
Near East	0.022
Far East	0.308
World	0.55

TABLE 2. POLYAMIDE PRODUCTION
(Million lb)

	West Europe	*North and South America*	*Other countries*
1959	215.6	420.2	129.8
1960	283.8	451.0	162.8
1961	343.2	528.0	193.6
1962	431.2	673.2	228.8
1963	541.2	767.8	303.6
Capacity 1965	891.0	1,128.6	503.8

TABLE 3. WORLD PRODUCTION OF POLYAMIDE
(In lb)

1940	11,000,000
1950	123,200,000
1960	873,400,000
1970	2,530,000,000

Number of polyamide plants in 1963 = 149 (including pilot plants).

The figures show that many developing countries have to master enormous tasks in order to attain only the consumption per person of synthetics of Spain, or the USSR, or even the average world consumption per person. The consumption figure per person in the Far East is due to the high specific consumption of the Japanese population. The indicated figure of the polyamide-production plants of 1963 includes the very large plants, similar to those of North America, as well as pilot plants.

Due to the outstanding fibres properties of the polyamide, nylon 6 articles with extraordinary use value can

TABLE 4. FIELDS OF APPLICATION FOR NYLON 6 FILAMENT

Knitting :	*Hosiery :*	
	Stockings (15 and 20 den., 30-60 den. for reinforced hosiery)	
	Smocks (70, 100 den. textured)	
Knitting :	Underwear	40 to 60 den.
Weaving :	Shirts	
	Blouses	
	Overalls	
	Smocks	
	Light dress material for women	40-100 den.
	Rain coats	
	Umbrella cloth	
	Lining fabrics	
	Warp and weft elastic fabric for sport wear, bathing suits	70-100 den. textured
Miscellaneous :	Laces, bobbin lace work, ribbons, sewing thread, tulle, surgical silk, textured carpets.	
Technical articles :	Tyre-cord, fishing nets, filter material, sieves, parachute-silk, canvas (air supported structures for storage etc.) ropes, belts, ribbons, straps.	

TABLE 5. FIELDS OF APPLICATION FOR NYLON 6 FILAMENT IN MIXTURES WITH OTHER FIBRES

Articles with a prevailing part of nylon 6 filament :

Carpets, filter material, shirting, waist bands and bindings for trousers, ropes, straps, cords and ribbons.

Articles with an admixture of nylon 6 and other textile fibres such as cotton, wool, rayon filament :

Outerwear, work clothes, overalls and combinations, stockings and socks, pants for children, knitting thread.

be manufactured. The breaking strength of nylon 6 filament is approximately double that of cotton or natural silk, its abrasion resistance and bending strength is ten times superior to that of cotton, and the resistance against decay, attacks of insects, fungus, and bacteria is extremely good.

The percentage of polyamide used in processing industries in the United States is shown by product class in the table 6.

There are possibilities for producers and consumers to discover new fields of utilization for nylon 6 fibres or filament, which is demonstrated by the following example: instead of the poorly growing sea-weeds in a fish-breeding basin, a green coloured nylon 6 staple fibre was spread in an appropriate way in the water. The successful breeding of fish is said to have been astonishing, as apparently the breeding places have been decisively improved by the use of the nylon 6 fibre.

It must clearly be stated, however, that, due to influences of fashion or to the further advance of synthetic fibres with more favourable textile properties for special purposes, one or more fields of application may cease to exist in time.

An example may show that articles of nylon 6 can be introduced into a developing country with an agricultural structure. It is assumed that the actual textile industry based on domestic natural fibre (for instance, cotton) covers to a large extent the textile requirements of the population.

The population outside the large cities is mostly occupied with agricultural services. Due to climate and tradition the people have worn, perhaps for many generations, working clothes made of cotton. For this reason it may be difficult to start selling new textile materials to the farmer or farm worker. A cotton suit, however, essentially more wear-resistant made from an admixture of nylon 6 staple fibre and cotton will soon meet with the approval of these customers, even if the cost for the apparel is increased by a slight amount. This applies, also, to the use and sale of wear-resistant stockings, socks and underwear.

In seeking fields of application for synthetic fibre textiles, not only are the questions of expediency, customer acceptance, and tradition important but also fashion as well as the psychological attitudes of the consumer.

It is the same with a certain demand for ladies' stockings, underwear and other textile articles which would signify the higher living standard of the rural population.

TABLE 6. PERCENTAGE OF POLYAMIDE USED IN FINAL PRODUCTS IN THE UNITED STATES

	Per cent
Outerwear	7
Underwear	13
Jumpers	3
Stockings	10
Carpets	15
Curtains/furniture/house furnishing	5
Tyre cord	31
Other items	16
	100

In the field of the commercial and agricultural commodities, new possibilities can be found for the use of nylon 6 fibres and filament. Examples of these are: harness, traction-ropes, belts, girdles, and belting, all of which are resistant to high stress. Tarpaulins resistant to weather and decay may be used during the harvesting of certain agricultural products. In addition, we can mention the use of technical nylon 6 fibres and threads in the field of private and industrial fishing.

The normal consumption of textiles based on synthetic fibres can be determined after some time with due consideration to cities and industrialized areas existing in each country. The requirement of the synthetic fibres is influenced to a certain degree by the fact that the government prescribes or should prescribe the type of clothing that their officials and employees should wear in the performance of their civil duties, and certain standards for the admixture of chemical fibres in order to improve the quality. Certainly new fields of application will also be found in the military sector, with regard to wear-resistant uniforms and equipment.

II. TASKS OF THE TEXTILE INDUSTRY USING CHEMICAL FIBRES

The starting of production of chemical fibres in developing countries depends, on the one hand, on relevant demands of the population, and on the other, on the efficiency of the domestic textile industry. Those countries which are not yet in a position to satisfy the textile demand of the population from domestic textile plants using conventional fibre raw materials, should begin with the extension of their textile industry, rather than the production of the chemical fibres. In other cases, it will be necessary to rationalize whether to expand the existing textile plants or to modernize the machinery. Only when the textile industry in a country has been consolidated correspondingly can the further processing of synthetic fibres be considered.

The conditions are relatively simple where the natural fibres or common fibre raw materials are used to date. These can be directly substituted by relevant chemical fibres. In a country with a domestic natural fibre industry, it will not be so difficult to introduce synthetic fibres in a number of fields. However, there are difficulties for an enterprise where chemical fibres are to be admixed with natural fibre raw materials to produce yarns and textiles. Much experience and practice are needed in order to overcome any technical problems of synthetic fibres (electrostatic charging, pilling effect, colour fastness).

In many cases however, the firms for further processing of synthetic fibres are compelled to change their production process and to use new methods. Stocking knitting, warping, dying, setting of textiles, manufacture of crimp yarns, stretch fabrics, and the finishing of the textiles are influenced to such a high degree by chemical fibres that it is not possible to work with old machines using old methods.

For this reason, a transition period for the textile industry is necessary before starting a chemical fibre production. In this period, the chemical fibres can be imported and should not be produced internally.

The advancement contributed by chemical fibres to the manufacture of textiles in industrial countries is due to a close co-operation between the chemical fibre producers and the textile industry, and to an intensive and costly research programme. These costs were assumed, to a large extent, by the industry.

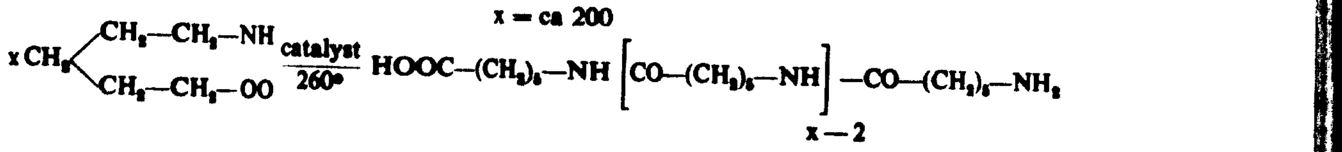
The enterprises of the developing countries are charged with many additional problems. Therefore, they will not be in a position to develop the methods and techniques for the introduction and processing of the synthetic fibres.

It is suggested that they should utilize the experience of foreign countries, or suppliers of raw materials. The cost of know-how or consulting assistance is relatively much lower than those encountered by internal development and overcoming problems which have been solved for many years.

Moreover, it is recommended that the governmental institutions or industrial organizations in a developing country establish adequate textile institutes. These institutes will be of great value when starting internal production and processing of synthetic fibres, and can keep the technology up-to-date regarding processes as well as market trends and problems.

III. DESIGN AND CONSTRUCTION OF THE NYLON 6 PLANT

The basic material for the nylon 6 fibre is E-Caprolactam, a ring-formed, low-molecular weight, organic-chemical compound, which with special reaction conditions joins after ring breaking via amide bridges to form linear high-molecular weight long chains. During this reaction no further chemical compounds are added and/or split off, therefore, it is called a polymerization.



Nylon 6 belongs to the class of the polyamides. The polymerization process does not produce only a high-molecular weight product but results in an equilibrium of reaction with a portion of about 10 per cent of caprolactam and low molecular weight compounds which affect the production of fibres and therefore must be separated from the high molecular weight main portion. In this connexion, there are only two possibilities :

(*a*) Washing of the cooled, solidified and pelletized polymer by means of a solvent. It is fortunate that water is a suitable extraction agent for the low-molecular weight compound.

(*b*) Evaporating of the low-molecular weight compounds from the polymerization melt mixture under vacuum.

The dried pelletized polymer, the so-called nylon 6 chips, is either melted again in spinning machines by means of extrusion apparatus or on heated contact surfaces. The melt is then pressed through spinnerettes by means of metering pumps and formed into continuous filaments. The threads formed of the filaments solidify in the spinning tubes and are wound at approximately 1,000 m/min., or, according to the polymerization process, (as per *b*) — the treated polyamide melt is conveyed to the spinning machine and spun into fibres.

The excellent strength properties of nylon 6 threads result from stretching operation together with a longitudinal orientation to the fibre-axis of the chain-formed macro-molecules. Further textile techniques depend on the end-use of the threads and fibres.

With regard to the production of nylon 6 material for the textile industry, the difference between nylon 6 filaments and nylon 6 staple fibres should be recognized. A nylon 6 filament plant comprises: polymerization; spinning; winding; drawing; and other textile operations such as warping, texturizing after-twisting, setting, dyeing, coning.

The auxiliary and secondary plants necessary for the operation are as follows: air-conditioning and refrigeration plants; inert-gas purification plant; plants for the treatment of water; plants for steam, vacuum and compressed-air generation. Secondary plants for spinning are as follows: spinning pumps, spinnerettes cleaning, instrumentation for control, and apparatus for the preparation and distribution of spin finish solution.

In addition, laboratory facilities for production control include equipment for the chemical and textile testing of raw materials, intermediates and finished products as well as for sorting of the nylon 6 filament production.

The nylon 6 fibre plant comprises:

(*a*) Polymerization;

(*b*) Spinning;

(*c*) Fibre tow-line with drawing equipment machinery for crimping of fibres, setting of the crimp (eventually the low molecular portion in the textile goods must be washed out if the polyamide melt is spun directly without vacuum extraction), cutting machine, and baling press. Also, there are the required auxiliary and secondary service plants similar to those mentioned above for the nylon 6 filament plant.

The principal difference between staple fibre spinning and filament spinning is that for filament spinning the delivered product is a continuous thread whereas the staple fibres are cut to various lengths and can be produced to blend with natural fibres or used on a 100 per cent nylon 6 basis on cotton or wool fibre processing systems.

Most interesting is the lowest capacity limit for a nylon 6 plant for profitable manufacture of filaments and fibres that can be started in a developing country. In general these standards may be indicated below:

TABLE 7

Type of production	*Raw material*	*End-product*	*Minimum capacity (lb/day)*
Nylon 6 filament	Nylon 6 chips	Textile filament	2,200
Nylon 6 filament	Caprolactam	Textile filament	3,300
Nylon 6 filament	Caprolactam	Technical filament	3,300
Nylon 6 fibre	Caprolactam	Cotton and wool type	4,400

A calculation of the production costs of textile nylon 6 filament for various plant capacities gives sufficient relevant information.[a]

Capacity of the plant		*Raw material*	*Production costs referred to the mean titers of 40-45 den. (DM)*	
Tons/day	*Lb/day*		*Per kg*	*Per lb*
0.75	1,650	Chips	15.50	7.04
(0.75	1,650	Caprolactam	15.10	6.86)
1.5	3,300	Chips	13.00	5.90
1.5	3,300	Caprolactam	12.25	5.56
3.0	6,600	Caprolactam	10.70	4.86
6.0	13,200	Caprolactam	9.75	4.43

[a] The production costs were calculated based on the following prices and rates of expenses :

Wage hour including social duties	DM 4.20
Caprolactam ex works	DM 1.64 per lb
Nylon 6 chips ex works	DM 2.22 per lb
Electric power	DM 6.00 per 100 kWh
Construction price	DM 60.00 per m^3
Depreciation rate :	*Per cent*
For equipment	10
For know-how	20
For building	5

The production costs do not include the cost for baling, shipping, selling, customers services, administration, interest for short-term and long-term capital loans, and taxes. Compared with the production costs calculated here for nylon 6 filament, the average selling price in Europe amounts to DM 13 - up to 13.50 per/kg.

For developing countries which charge chemical fibre imports with very high import duties, the above-mentioned minimum capacities are feasible. However, these lower capacity limits cannot be taken as a basis if it is intended to export nylon 6 fibres. In this case, the same standards hold good for the design of a nylon 6 filament as those existing in an industrial country, if the export is not subsidized by the government. In other words, there are opportunities for export to the world market only in case a production plant of at least three t/day minimum is available. The comparison of the production cost for plants of different sizes shows that for small-size plants the polymerization of caprolactam is not profitable. The investment capital of the small plant is put to better use when the synthetic fibres or filament is processed through the appropriate textile departments.

The following cost items are to be considered for the financing of nylon 6 filament plant corresponding to t' example given herewith:

Invested capital

(*a*) Land and preparation of ground;

(*b*) Building, roads, communications, and traffic. Installations for electric power and water supply, etc.;

(*c*) Machines and equipment including engineering and know-how;

(*d*) Erection of the plant.

Current assets

(*e*) Raw material requirements for three to four months;

(*f*) Storage of end-products and intermediates for one to six months.

Item (*f*) depends much on the production capacity and the production programme. In case of a small-type production plant with one spinning machine on which only one titer can be spun, alternate titers can only be spun after a period of production of about six weeks. Production can then be changed to another titer if the full service and the quality yield is to be guaranteed. In case of four different titers, material storage of about six months must be provided. In case of larger plants with separate spinning machines, relatively more titers can be spun at the same time and prepared more rapidly for shipment.

Due to the fact that the premises and building prices are different in various countries, so that no general standard for discussion can be found, a general figure representing the investment requirement for only the nylon 6 filament equipment is given below:

TABLE 8. EQUIPMENT COST F.O.B. FOR NYLON 6 FILAMENT PLANT OF VARIOUS CAPACITIES

Raw material caprolactam — end-product nylon 6 filament on draw-twist cops, mean titer 40-45 den. 330 operating days/year

Capacity of the plant				
Tons/day	0.75	1.5	3.0	6.0
Lb/day	1,650	3,300	6,600	13,200
	Per cent of cost	*Per cent of cost*	*Per cent of cost*	*Per cent of cost*
Polymerization	25	22.7	18.6	19.1
Spinning, winding, draw-twisting machines	35.4	43.9	52.9	57.3
Auxiliary and secondary plants	14.6	13.6	10.9	8.5
Engineering and know-how	25	19.8	17.6	15.1
TOTAL EQUIPMENT F.O.B.	100	100	100	100
Approximate cost per annual lb of production	*DM* 0.88	*DM* 0.61	*DM* 0.14	*DM* 0.14

An increased production capacity corresponds to a definite reduction of the specific equipment cost (equipment cost per installed plant capacity). The engineering and know-how fees cover a considerable portion of the total cost for the equipment of small-size plants. These fees increase in proportion to the larger-size plant and approach to a limiting value with large capacities.

The investment cost for auxiliary and secondary plants of smaller plants is also relatively high, and increases slightly for the larger capacities, and is therefore unimpo:tant. The sharp increase in prime cost for polymerization plants is due to the fact that when two types of polymer are produced simultaneously, two or more polymerization lines must be provided resulting in relatively higher investment costs, e.g., delustered and undelustered chips. Regarding the technical yarn production plants, the investment costs are increased almost linearly with the production capacity. The erection cost for a nylon 6 plant amounts to about 15 per cent of the equipment cost.

The total capital requirement for a nylon 6 filament plant ready for production is approximately twice that of the equipment cost. A relevant split-up is indicated here below:

	Per cent	
Equipment f.o.b.	50-55	Total investment about 75 %
Erection	7-8	
Building, purchase and grading levelling of the premises	13-18	
Current assets for raw and end-products for 3 months	18-23	
Other cost (approximately)	5	

The foreign exchange portion of the total capital requirement for a nylon 6 project is of interest for a developing country. The greater percentage of the cost for the equipment and the personnel cost, the supervision of the erection, starting up of the production, and cost for the training of own experts in the foreign country which is about two-thirds of the total investment cost, must be covered by foreign exchange. On account of the question of foreign exchange each government will try to procure a maximum of the equipment in their own country. However, the apparatus and machines which determine to a large extent the technical process, are based on the development of the licensee. These machines can be procured most advantageously from industrial countries. These countries have a highly developed, specialized, manufacturing plant for these machines. The machines cannot be manufactured in the developing country. Generally only the simple apparatus, containers, equipment for a number of auxiliary and secondary plants can be procured domestically: for example: lactam melting kettle; ship containers; water-treating plant such as natural water cleaning; permutit water plant; plant for the production of distilled water; bobbins and transport carriages and supports as per drawings; plants for generation of vacuum, compressed air, steam and refrigeration; air conditioning plants, etc. In addition, various erection material such a piping, wiring for the electric installation, can be procured locally. Usually the amount of equipment which can be manufactured in a developing country will not exceed 15 per cent.

The personnel requirement for a nylon 6 plant is as follows:

Size of the plant (tons/day)	*0.75 Without polymerization*	*0.75 With polym.*	*1.5*	*3.0*	*6.0*
			With polymerization		
Production worker, foreman, workman, laboratory personnel	68	82	120	180	290
Leading personnel employees	5-6		7	9	9

The leading personnel includes: a manager (university graduate), a chemist or chemical engineer, a textile engineer, a mechanic engineer and depending on the size of the plant, a chief operator, a chief laboratory chemist and a production assistant.

It is suggested that training of some of the leading personnel before start up of the production be completed so that they become acquainted with the technology of the plant.

In a developing country, an enterprise will have to train the expert personnel. It is advantageous to employ persons with working experience and personnel coming from the textile industry. The remaining male and female auxiliary personnel must be trained for special operations in the plant.

During the last stage of erection, it is important to train the personnel as much as possible at a number of spinning heads and drawing units: the work will hereby be facilitated and mistakes regarding production and the resulting increase in operations cost will be avoided.

The nylon 6 plant should be located in an area with good communications for traffic; and short distances from textile manufacturers offer some advantages. A cheap and reliable supply of electric power is important from an economical and technical point of view. Repeated break-down of the current supply results in an inferior quality and waste production which can be prevented only by a large investment in an emergency power supply system. Sufficient natural water must be available for the generation of refrigeration and air conditioning for the textile plant. Thus no extraordinary conditions are generally required with regard to the location of the plant.

E-caprolactam as the main raw material for the production of nylon 6 threads and fibres is available in the world market in sufficient quantity and good quality. The other raw and auxiliary materials such as stabilizer, preparation agent, delustering agent, nitrogen, hydrogen, and diphenyl are used in small quantities and do not influence the cost significantly.

Indeed, the import of caprolactam means for a developing country a loss of foreign exchange. However, only 25-35 per cent of foreign exchange is needed compared with the amount of foreign exchange for a relevant imported quantity of fibres. The demand for nylon 6 chips required for smaller production plants can be covered also due to an adequate supply in the world market; however, saving of foreign exchange compared with the import of nylon 6 filament will thereby be somewhat reduced.

Generally speaking, and in accordance with the above general background, a synthetic fibre industry in a developing country must be carefully planned, so that initially the plant is relatively small, with a low requirement of caprolactam. The minimum capacity of a plant for the production of caprolactam will amount to ten to twenty long tons/day, which represents only a fraction of the size of profitably operating plants in the world.

The raw materials for the production of caprolactam, depending on the process, are benzene, phenol, cyclobenzene and nitrogen compounds derived from ammonium plus sulphuric acid, and are made from oil and petrochemicals by large-size complex chemical plants.

The example of a synthetic fibre production shows that a country which intends to accomplish the first steps for a chemical industrialization is not in a position to solve the problems without an economic co-operation with other countries. Such a co-operation would allow petrochemical raw materials, intermediates and end-products to be produced at a central location or a few locations and only where the relevant economical capacities can be made available.

6. SYNTHETIC FIBRES OF POLYAMIDES

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This paper presents a survey of the present state of techniques in the field of polyamide fibres and their importance for the textile fibre industry considering, in particular, the technical situation existing generally in developing countries. One will thus get an impression of the extent to which the production of such fibres will be of advantage to a country.

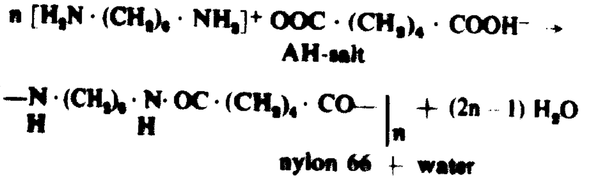
Since this meeting is being held to discuss particularly petrochemical problems, an endeavour will be made to point out the special advantages resulting from setting up polyamide fibre production and creating, at the same time, a petrochemical production capacity

The first attempts to produce, in an artificial way, suitable fibres for textile purposes were made at the end of the last century but it was impossible up to about the beginning of the Second World War to manufacture fully synthetic fibres that could be used in the textile industry. (The chemical fibres produced till then were known as semi-synthetic fibres since they consisted of a naturally grown material, the cellulose, made into fibres by means of chemical processes.)

The first fully synthetic fibres which gained greater importance were the products known today as polyamide fibres, i.e., nylon 6 and nylon 66. The corresponding materials are comprised under the term "polyamides" since they are obtained by polymerization and polycondensation, respectively, of organic amides.

The main difficulty that had to be overcome to develop such fibres — the costs for the development of nylon 66 by Du Pont are estimated at $US 30 million — was to find those few amides which guarantee sufficiently good fibre quality in the polyamide production. In fact, only two of these so-called monomers are so far used on a larger scale, i.e., the adipate of hexamethylene diamine for the production of nylon 66 and the aminocaproic acid in form of lactam for the production of nylon 6.

The chemical formulae of these monomers as well as of the polymerization processes are as follows:

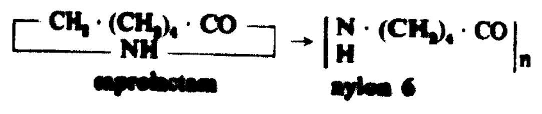


$$n\,[H_2N\cdot(CH_2)_6\cdot NH_3]^{+}\,OOC\cdot(CH_2)_4\cdot COOH^{-}\rightarrow$$

AH-salt

$$\left[\begin{matrix}-N\\H\end{matrix}\cdot(CH_2)_6\cdot\begin{matrix}N\\H\end{matrix}\cdot OC\cdot(CH_2)_4\cdot CO-\right]_n+(2n-1)\,H_2O$$

nylon 66 + water



$$\underbrace{CH_2\cdot(CH_2)_4\cdot CO}_{NH}\rightarrow\left|\begin{matrix}N\\H\end{matrix}\cdot(CH_2)_4\cdot CO\right|_n$$

caprolactam nylon 6

We shall first set aside details of polymerization and spinning in order to give you a brief impression of the importance these polyamides have gained and of the special properties by means of which they penetrated the textile sector to a considerable extent. Nylon 6 and nylon 66 differ only in some few points and in these merely to a slight extent. The physical and chemical data by which such materials are usually characterized are shown in table 1.

To simplify the matter it can be said that the actual differences with regard to the applicability of the corresponding fibres are so slight that they are known only by experts. But even specialists may have different opinions on the subject. In the following we shall, therefore, deal with both fibre types under the above-mentioned common term, i.e., polyamides.

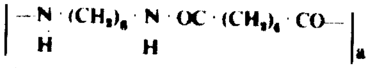
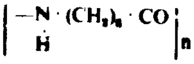
There is no doubt that the first great success of the polyamide fibres was in the manufacture of ladies' stockings. As it is known today, the threads of polyamides are much stronger than those of the cuprammonium rayon, e.g. the Bemberg silk, very popular in the federal Republic of Germany, or the natural silk which were formerly applied for this purpose. Thus it was possible to produce stockings that had the same appearance as those manufactured up till then but were much better wearing, and were made of finer threads. Another essential advantage is the reduced care since nylon-made materials are most easily washed and dried in a very short time.

In fact, today there is no material for ladies' stockings in competition with the polyamides or, in other words, 100 per cent of all ladies' stockings are made of polyamide fibres.

The next field won by the polyamide fibres was that of lingerie. Again, the decisive advantage was that dirt could be removed quickly by simple washing methods, that the articles dried in an extremely short time and needed no ironing. In the United States, about 35 per cent of lingerie was made of polyamide fibres in 1963.

With the application of the so-called texturing, polyamide was also used for socks and pull-overs. Without giving too many details, it should be explained that texturing means a treatment giving the thread a strong and lasting crimp. The so-called stretch material is obtained and the socks made thereof fit every foot size so that the production of different size numbers becomes unnecessary. Moreover, the crimp of the filaments makes it possible to use them instead of crimped natural fibres — known as staple fibres. So pull-overs for ladies,

TABLE 1. CHEMICAL AND PHYSICAL DATA OF POLYAMIDES

	Nylon 66	*Nylon 6*
1. ***Polymers***		
Formula	 $\left[-\underset{H}{N}\cdot(CH_2)_6\cdot\underset{H}{N}\cdot OC\cdot(CH_2)_4\cdot CO- \right]_n$	 $\left[-\underset{H}{N}\cdot(CH_2)_5\cdot CO \right]_n$
Melting point (°C)	245	215
Melting heat (cal/gr)	25	25
Spec. weight (grs/cm³)	1.14	1.15
Spec. heat (cal/gr °C)	0.5	0.45
Humidity take up at standard conditions (per cent)	4.0-4.5	4.0-4.5
Heat conductivity (cal/cm °C sec.)	0.20-0.22	0.20-0.22
2. ***Fibres***		
Tenacity (grs/den)		
Normal	4.5-6.2	4.5-6.2
High tenacity	7.5-9.0	7.2-8.3
Rel. wet tenacity (per cent)	85-95	85-95
Rel. loop tenacity (per cent)	75-95	75-95
Elongation at break (per cent)		
Normal	30-46	30-46
High tenacity	15-20	15-20
Swelling property (per cent)	9-12	9-12

gentlemen, and children are made of textured polyamide fibres. Here in particular, it is of considerable advantage that stains are easily removed and drying is quick. It must, however, be considered that polyester and especially polyacrylonitrile occupy a large section in this field of application. In 1963, 70 per cent of all ladies' pull-overs and 43 per cent of all gentlemen's pull-overs in the United States were made of fully synthetic fibres, part of them probably of polyester and polyacrylonitrile.

Since the polyamide material has proved a success for the above-mentioned articles, attempts were made at the beginning of the 1950's to use it also for shirts. Considerable difficulties due to the subjective wearing properties of the material were encountered in the beginning, a fact based on rather complicated theoretical connections. I need mention only the key words: moisture absorption and moisture transport. Both factors are comparatively unfavourable for the polyamides.

Recently, this disadvantage of the basic material was, however, compensated by a corresponding fabric structure. The manufacturer Rhodiaceta in the Federal Republic of Germany developed the so-called Nyltest shirts which were an extraordinary business success and paved the way for the nylon 6 shirt.

A field of application belonging to the textile sector in a wider sense is that of the so-called home textiles. Here again, the polyamide fibre with its particularly advantageous properties has gained more and more importance. In particular floorings of polyamide are extremely resistant to permanent stress. So such floorings are frequently found in department stores, offices, and also in private apartments. Further applications in this connexion are in carpet production, the manufacture of draperies and furniture covering as well as of motorcar and bathing mats. In 1962, 42 per cent of all textiles used in the United States as floorings were made of polyamides.

In the last two decades, the technical layman has taken part in the development outlined so far. But the polyamide fibre has gained a footing also in purely technical fields especially during the last five years of these two decades. Primarily, this applies to tyre cord, but apart from that also to fishing nets as well as to technical materials of various kinds, such as cables, ropes, conveyor belts, drive belts, filter cloths, fishing lines, protective clothes.

Although the application of nylon instead of rayon used till then for tyre manufacture naturally meant a certain technical conversion, its extremely high strength which has been increased today to about 10 g/den compared to about 6.5 g/den of the best rayon material was decisive when the applicability of this material was discussed in many countries, especially in the United States. In the Federal Republic of Germany, where the polyamides as cord material have not yet succeeded to such extent for reasons connected with the specificity of the artificial fibre home industry, tyres for high-speed passenger cars as well as for heavy lorries are equipped with polyamide carcasses. In the United States, 51 per cent of all tyres were provided with polyamide carcasses in 1963.

The application for filter cloth is based on the high chemical resistance to alkaline agents and a large number of organic solvents, and for the production of fishing nets on the good resistance to putridity and to the influence of seawater.

TABLE 2. DEVELOPMENT OF POLYAMIDE FIBRE PRODUCTION IN THE WORLD SINCE 1940

Year	Textile fibres total (t)	Polyamide (t)	Polyamide percentage of textile fibres	Value of polyamide fibre production ($ U.S.)
1940 . .	8,553,000	1,000	0.013	3,000,000
1941 . .	8,041,000	5,000	0.06	15,000,000
1942 . .	7,936,000	5,000	0.06	15,000,000
1943 . .	7,650,000	8,000	0.13	24,000,000
1944 . .	7,197,000	12,000	0.17	36,000,000
1945 . .	5,973,000	12,000	0.2	36,000,000
1946 . .	6,121,000	15,000	0.25	45,000,000
1947 . .	6,933,000	20,000	0.29	60,000,000
1948 . .	8,093,000	24,000	0.3	72,000,000
1949 . .	8,798,000	30,000	0.35	90,000,000
1950 . .	9,008,000	36,000	0.4	108,000,000
1951 . .	10,887,000	50,000	0.5	150,000,000
1952 . .	11,038,000	70,000	0.6	210,000,000
1953 . .	11,753,000	120,000	1.0	360,000,000
1954 . .	12,053,000	144,000	1.2	430,000,000
1955 . .	13,326,000	173,000	1.3	520,000,000
1956 . .	13,202,000	198,000	1.5	595,000,000
1957 . .	13,264,000	265,000	2.0	795,000,000
1958 . .	13,926,000	275,000	2.0	825,000,000
1959 . .	14,807,000	346,927	2.3	1,040,000,000
1960 . .	15,003,000	408,150	2.7	1,224,100,000
1961 . .	15,016,850	478,442	3.1	1,435,300,000
1962 . .	16,056,621	606,329	3.8	1,818,900,000
1963 . .	16,824,396	802,695	4.8	2,408,000,000

The figures for the qualitative development described above are given in table 2. They show that the development of the polyamide fibre industry has been unique in world trade. From these data, you can already draw the conclusion that, at the moment, the demand is continuously rising so that for manufacturers it is, at present, very promising to enter this market.

Here is some brief information on the technical process of polyamide production.

As already indicated, polyamide is formed by the linkage of caprolactam and AH-salt molecules, respectively — in the latter case under emergence of water — according to whether nylon 6 or nylon 66 is produced. This technical process is called polymerization. It can either be carried out discontinuously in an autoclave or continuously in pressure stages with succeeding vacuum extraction stages or in pressureless reactors, the so-called VK-tubes, which are followed by a vacuum or chips water extraction. Figure 1 shows the processes for nylon 66 and nylon 6.

At the beginning of the polyamide-fibre era, prices played almost no part — e.g. a fibre for which DM 12 is charged in the Federal Republic of Germany today, was sold for DM 50 per kg in 1950 — since, for a long time, demand rose at an enormous speed while production was lagging behind. Today, the potential manufacturer has to consider very carefully whether the price with which he will come on the market is sufficiently attractive to guarantee a corresponding production level and thus a utilization of the capacity of his plant.

Roughly stated, the costs are as follows:

Expenses for the conversion

(*a*) From AH-salt to nylon 66 and from caprolactam to nylon 6	DM 0.40/kg
(*b*) From polyamide chips to nylon 66 and nylon 6, respectively (the average denier being 40)	DM 2.80/kg

These figures do not, however, contain depreciation.

If the assumed price for a 1 ton/day polyamide polymerization plant is: (*a*) DM 1.5 million without building costs; and (*b*) DM 1.9 million with building costs, and for a 1 ton/day polyamide spinning plant (taking an average denier of 40) is : (*a*) DM 3.7 million without building costs, and (*b*) DM 4.7 million with building costs, and if, furthermore, the assumed price for the monomer used per 1 kg of the final product is DM 3/kg, for the polymer DM 6/kg, and for the produced fibre DM 15/kg, the following minimum depreciation times are the result:

Polymerisation :
(*a*) 580 days = 1.6 years
(*b*) 730 days = 2.0 years
Spinning plant :
(*a*) 600 days = 1.6 years
(*b*) 760 days = 2.1 years.

Of course, these figures are only a rough guide, for they are influenced by factors varying largely in the different countries. Nevertheless, the general fact that, with today's price conditions, a polyamide fibre plant comprising polymerization and spinning section will be depreciated

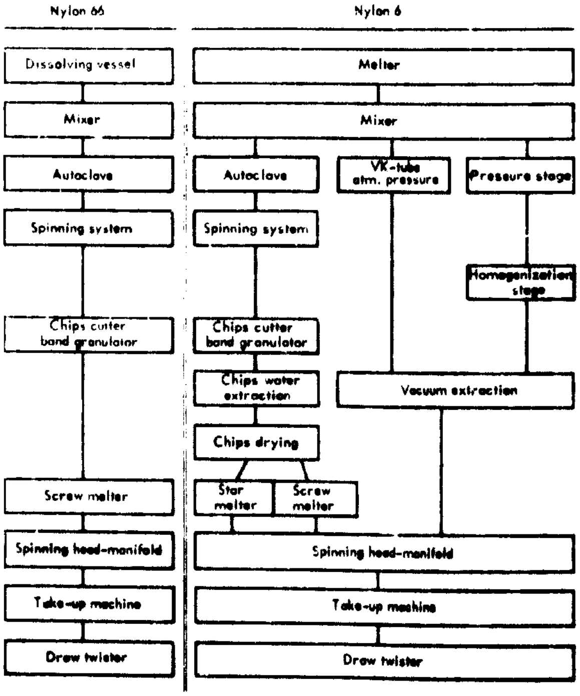


Figure 1. *Production diagram for polyamide fibres*

in approximately two years might be of some interest.

The possibility of a further price reduction for the two polyamides on the market today is restricted, to an ever-increasing extent, to lowering the raw material prices, since the costs for the conversion from monomer to polymer as well as from the polymer to the spun and stretched thread can hardly be reduced any further.

In addition, it has to be considered that these costs depend largely on specific local conditions, such as local prices for steam and electrical power, the quality of labour at hand, and, finally, the general wage level and the depreciation principles valid in the specific country, while the prices obtainable for the final product are influenced to a large extent by the specific relation between offer and demand. As far as we are informed, the present price for a denier of 70 den in Argentina is about $US 9 per kg, while in the Federal Republic of Germany $US 3 per kg is paid for the same denier.

There is no doubt that trade rivalry is intensified throughout the world so that by means of far-sighted planning, even at present, producers should keep their eyes on saving smaller amounts. This conception is the basis of comprehensive efforts to develop new, cheaper processes for the production of caprolactam and partly of AH-salt.

In order to be able to understand these connexions and the resulting economic consequences, it is, in the first place, necessary to get a clear picture of the principle of the caprolactam and AH-salt production or, in short, the production of the monomer.

Here, again, the problems of the two polyamides nylon 66 and nylon 6 can be brought to a common denominator.

In both cases, the intermediate product cyclohexanol and cyclohexanone, respectively, is required. To produce nylon 66, it is oxidized to adipic acid which is known to be one of the two components of the AH-salt. Part of the acid is converted to adiponitrile by being treated with NH_3 in the presence of dehydrating agents. By reduction with H_2, the second component of the AH-salt, the hexamethylene diamine, is obtained from the adiponitrile.

In the case of nylon 6, the cyclohexanone is converted to cyclohexanone oxime and then to caprolactam.

The two diagrams, figures II and III, give you a survey of these connexions.

The classical process still applied on a large scale is based on the conversion of phenol to caprolactam over the intermediate products cyclohexanol, cyclohexanone, and cyclohexanone oxime. A common characteristic of all later developed processes is that they are not based on phenol but either on cyclohexane, which is obtained from benzol (by hydration) or by distillation during petroleum refinery, or on toluene. The following production processes should be mentioned in this connexion:

(a) *Du Pont process*

Benzene is hydrated to cyclohexane which is converted by nitration to mononitrocyclohexane. By reduction, the latter is transformed into cyclohexanone oxime from which caprolactam is obtained according to the usual Beckmann rearrangement. As far as is known, this process has never been applied on a larger scale due to lack of profitability.

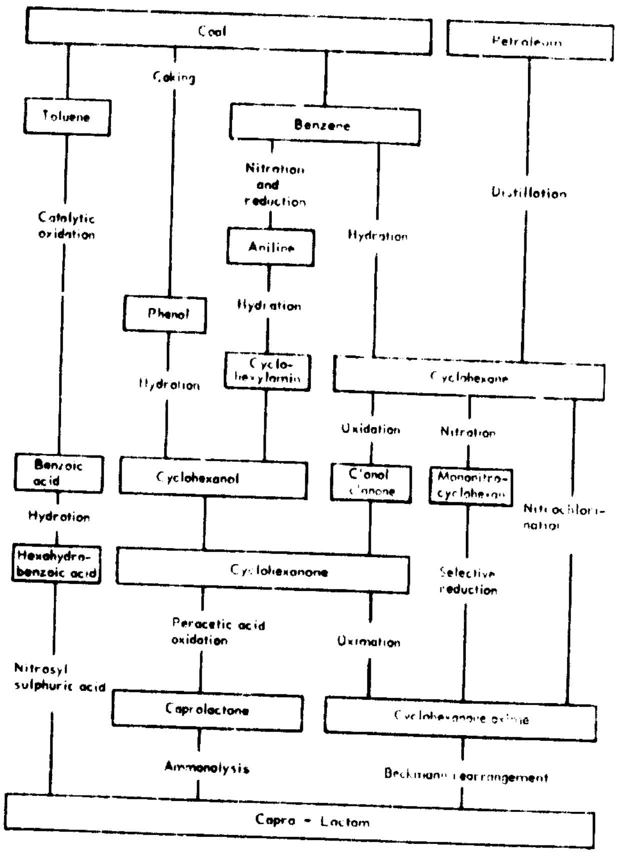


Figure II. *Production diagram for caprolactam*

(b) *Snie process*

According to a special process, toluene is oxidized catalytically with air to form benzoic acid. By subsequent hydration, hexahydrobenzoic acid is obtained which is directly converted to caprolactam by a treatment with nitrosyl sulphuric acid. A certain difficulty seems to be, on the one hand, the comparatively slow process of the conversion to caprolactam and, on the other hand, the necessity of separating the non-converted hexahydrobenzoic acid. The peculiarity of this process is that it is the only one based on toluene and, furthermore, does not require the application of hydroxylamine; ammonium sulphate does not accumulate as by-product.

(c) *Toyo Rayon process*

Cyclohexane obtained from benzene or petroleum is nitrochlorinated under ultraviolet rays of a wave length of 3,600-4,000 Angström units at 5-30°C. Thus, cyclohexanone oxime is produced which is converted to lactam under the influence of oleum. In this process, too, the application of hydroxylamine is not required and ammonium sulphate does not accumulate.

(d) *Union Carbide process*

This process utilizes the conversion of cyclohexanone to caprolactam passing the intermediate stage of caprolactone which is converted to caprolactam under the influence of peracetic acid with subsequent ammonolysis.

(e) *Zimmer process*

In liquid phase, cyclohexane is oxidized with air to cyclohexanone.

To answer the question of profitability of the caprolactam process, the following can be said: in principle, all processes which are not based on phenol have the advantage of a cheap starting material. While for phenol DM 1 to DM 1.10 are charged today per kg, the world market price of benzene is about DM 2.5 per kg. This makes the decisive difference. Since, apart from minor details, the conversion costs of benzene over cyclohexanone to caprolactam do not differ considerably from those of phenol to caprolactam according to the classical process — i.e., they amount to about DM 1.70 per kg — caprolactam prices for the two processes compared are as follows:

According to the phenol process (depending on the plant capacity, minimum size about 15 tons/day)	DM 2.80 to 3.10/kg
According to the benzene and cyclohexane process, respectively	DM 1.80 to 1.90/kg

The fact that even caprolactam produced from phenol can be bought on the market today, generally at the price of DM 3.0 to DM 3.10 per kg, depends on the manufacturers having phenol sources at hand from which they receive this basic product below the above-mentioned price of DM 1 per kg. As far as can be seen, this is already very near to the principle lower price limit.

A further advance made only recently in this sector is the Union Carbide process which makes it possible to cheapen the process additionally apart from making use of the low raw material price for phenol and cyclohexanone, respectively. So, by means of this process — of course, only in combination with the benzene cyclohexane-process — the cost-price of caprolactam amounts to DM 1.50 per kg.

The question as to which of the above-mentioned processes should be choosen depends always on the special conditions of the particular country. Sometimes, an unprofitable process, for instance, may be nevertheless attractive if it helps to make considerable savings of foreign exchange. In countries where only economic viewpoints are considered, the price must be checked at which the specific raw materials are available and the by-product can be sold, respectively. Finally, it may in some cases be advisable to prefer, for reasons of operating safety and qualification of the labour available, a technically simple though not quite so economic process to a complicated, technically refined one.

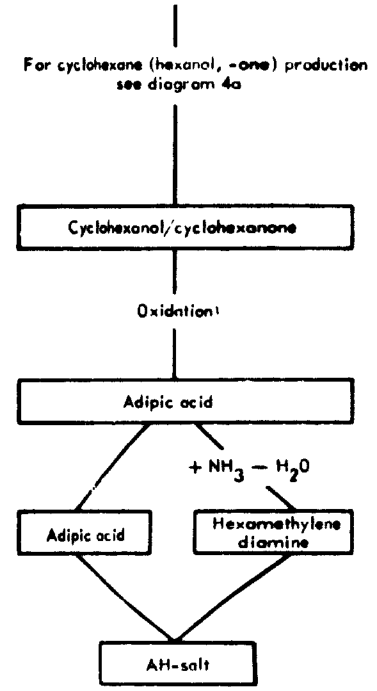


Figure III. *Production diagram for AH-salt*

For rough orientation, the following scheme may serve as a guide.

In countries where cyclohexane is produced in sufficient quantities in connexion with petroleum production and refinery, the classical phenol process has hardly any chance considering every point of view.

Where benzene or cyclohexane is not available, but phenol is, the phenol process will be preferred in many a case in spite of its smaller profitability.

Independent of the question whether the specific country intends to build up a petrochemical industry on a large scale, it will, in any case, be advisable to participate immediately in the turbulent development which is still taking place in the synthetic fibre sector. Should a country, however, actually decide to build up a petrochemical capacity, a synthetic fibre capacity of a suitable size should be part of the total planning.

7. METHODS FOR THE PREPARATION OF CAPROLACTAM AND THE SYNTHESIS OF LYSINE FROM CAPROLACTAM

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I. Introduction

Two of the primary necessities of life are clothing and food. It may therefore be called a fortunate coincidence that caprolactam can be used for meeting both needs. Firstly, it is a starting material for man-made fibre; polymerization yields the well-known nylon 6, which finds an outlet in the world market mainly as textile yarn. Secondly, the production of caprolactam is related to the manufacture of fertilizers, i.e., ammonium sulphate. The amount of fertilizer used in the world is much greater than the production of caprolactam itself. Thirdly, it has been found that caprolactam is a well-suited starting material for the synthesis of lysine, one of the chief essential amino acids, and, in consequence, one of the building elements of protein in foodstuffs and animal feed.

The chemical industry of the Dutch Statemines has been very active in the three fields just mentioned. Considering the interrelation between them, it will be clear that this is not a matter of mere coincidence, but rather the result of a natural development.

The gross daily production capacity of nitrogen fertilizer of this Dutch plant now amounts to approximately 800 tons of nitrogen. The caprolactam production is 60,000 tons annually. For lysine a production unit is now under construction which is to have a capacity of 3,000 tons annually.

II. Caprolactam

A. INTRODUCTION

There exist several lactams which, by polymerization, can be converted to valuable polymers (polyamides), as can be seen from the following survey, and table 1.

Among these starting products for polyamides, caprolactam is by far the most important. This priority is not based on the existence of large differences in properties between the various polyamides, but springs mainly from the fact that caprolactam has always been the cheapest lactam and will most probably continue to be so for a long time to come.

The world production of caprolactam has grown rapidly and this growth is still going on, as appears from

TABLE 1

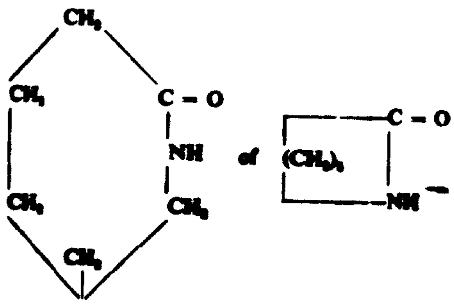
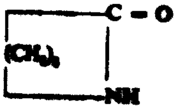
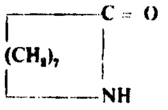
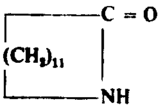
Monomer	*Formula*	*Number of C-atoms*
Caprolactam		6
Oenantholactam		7

TABLE 1 *(continued)*

Monomer	*Formula*	*Number of C-atoms*
Caprylactam		8
Amino-undecanic acid	$H_2N-(CH_2)_{10}COOH$	11
Lauril lactam		12

the following survey and the estimated production capacities:

Capacity in 1,000 tons per annum	*Western Europe*	*Eastern Europe*	*Asia*	*North, Central and South America*	*World*
1961 . . .	77	Appr. 45	56	61	240
1962 . . .	116	Appr. 60	56	79	310
1963 . . .	153	Appr. 70	79	97	400
1964 . . .	209	Appr. 95	121	134	560
1965 . . .	(286)	(Appr. 120?)	(166)	(136)	(710)

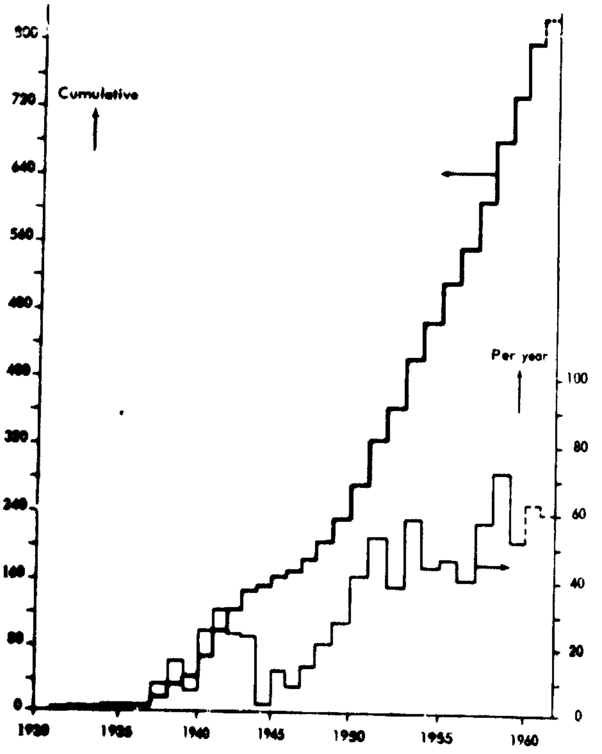


Figure 1. *Total number of patents for caprolactam processes (according to filing date)*

Running parallel with this growth in production are the activities which are still going on in research and development throughout the world. Around 1955 the five hundredth patent application for the production of caprolactam and the required auxiliary materials was filed; at the moment, the number will be not far from one thousand (figure 1). It is getting ever more difficult to find a new route and it is not at all simple to make a choice from the available processes. It will be clear that a review of the situation in a field where there is so much actively in motion as the present one, can be no more than a snapshot.

A brief description will now be given of a small number of the most suitable production methods. Technical details cannot be given even though some are very interesting. An effort will be made, however, to characterize these processes for the purpose of making a comparison. The processes related with the actual production of caprolactam for making the necessary auxiliary materials such as hyam (hydroxylammonium sulphate) etc., will only be indicated.

B. PRINCIPAL ROUTES FOR PREPARATION OF CAPROLACTAM

Figure II shows the principal routes used for the preparation of caprolactam. To facilitate the comparison of these various routes, aromatic benzene or toluene has in all cases been chosen as the starting product. For the preparation of phenol in this survey, the route via benzoic acid (Dow process) has been chosen, because this route is now being followed in our company, and also because it links up best with the preparation of caprolactam via hexahydrobenzoic acid (SNIA-VISCOSA).

1. *Phenol route*

At the moment, caprolactam is predominantly made *via* the well-known route starting from phenol or cyclohexane. The principle of this method is shown in figure III. Phenol is first hydrogenated to cyclohexanol. Subsequent dehydrogenation yields cyclohexanone which, by reaction

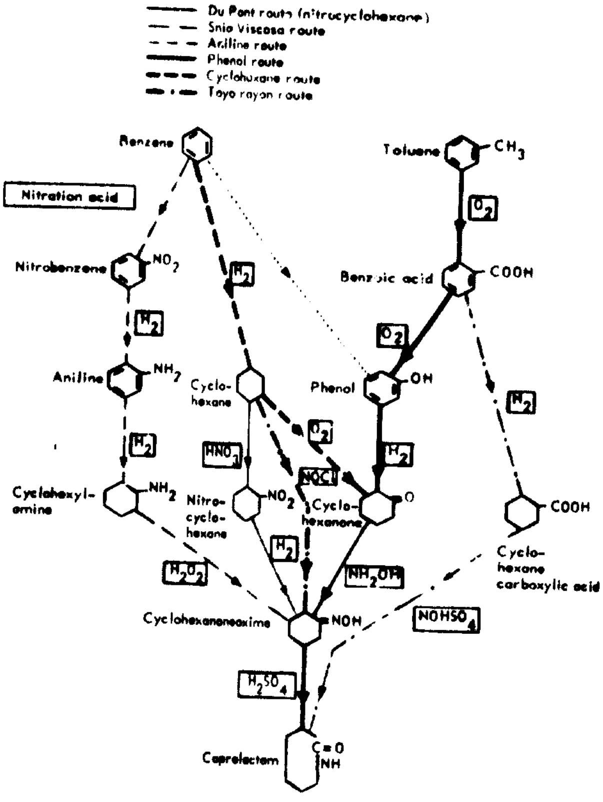


Figure II. *Methods for production of caprolactam*

with hydroxylamine, is converted into oxim. After that, the oxim is rearranged with H_2SO_4 to form caprolactam.

At Staatsmijnen, the phenol hydrogenation and the subsequent dehydrogenation have for a short time now been combined into one single step for which, as can be seen from the reaction equation, H_2 is still required.

This means a considerable improvement because the original phenol hydrogenation was a laborious operation: liquid phase, 25 at. pressure, Raney nickel filtration etc.

Of late years, one more method has been developed for making anol and anone, viz., the cyclohexane oxidation, which is now being employed by several large firms: BASF, Dow-BASF (United States), Toyo Rayon (Japan).

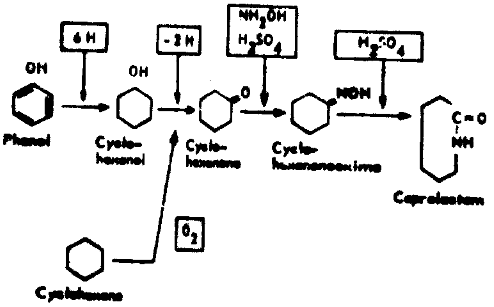


Figure III. *Caprolactam from phenol or cyclohexane*

Staatsmijnen also has its own know-how in this field and recently brought a unit in use for the oxidation of cyclohexane, so that the starting materials for the lactam production are now being made along two different routes.

The principle of the cyclohexane oxidation is a simple one: air is blown through cyclohexane at elevated pressure and temperature, whereafter the resulting oxidation oil is processed into anol and anone.

An interesting feature of the cyclohexane oxidation is that the process can be carried out not only with cyclohexane but also with other saturated ring compounds, such as cycloheptane, cyclooctane, cyclododecane etc. In consequence, this method is basically suited for the manufacture of caprolactam homologues.

However, this also involves a danger because if cyclohexane is contaminated with other cyclic paraffins, the corresponding anols and anones are also formed. Therefore, it is of the utmost importance to start from very pure benzene and cyclohexane, the more so as the demands made on the purity of the final product are very high. Whether the lactam process will be successful depends to some extent on the possibility of making a pure end-product at not too high cost.

In the manufacture of oxime from cyclohexanone, hydroxylamine is needed as an auxiliary material. This is made by reduction of ammonium nitrite with sulphur dioxide. The process is rather simple, but the chemical reactions involved are fairly complicated. Highly simplified, the following processes take place.

Absorption of nitrous gases

$$NO + NO_2 + (NH_4)_2CO_3 \rightarrow 2\,NH_4NO_2 + CO_2$$

Reduction with SO_2

$$NH_4NO_2 + 2\,SO_2 + 2\,NH_4OH \rightarrow NOH(SO_3NH_4)_2$$

hydroxylaminedisulphate

Hydrolysis

$$2\,NOH(SO_3NH_4)_2 + 4\,H_2O \rightarrow (NH_2OH)_2H_2SO_4 + (NH_4)_2SO_4 + 2\,NH_4HSO_4$$

These equations demonstrate that to make 1 mole of hydroxylamine two moles of SO_2 (in practice 2.4) are needed. In a later stage in the process, this SO_2 is completely converted to sulphate of ammonia, which consequently is formed as by-product. The subsequent stage, i.e., the rearrangement of cyclohexanonoxim to caprolactam, also uses sulphuric acid (oleum), in an amount of approximately 1.5 mole to 1 mole of caprolactam. This also is converted to sulphate of ammonia, which brings the total amount of this by-product at 3.9 mole per mole of lactam, or 4.5 tons per ton of lactam. The following quantity diagram expressed in moles (figure IV) may serve to clarify this.

It can be clearly seen here that the quantity of auxiliary materials is very large compared with the main stream of phenol and lactam.

In sum, it can be concluded that:

(*a*) In preparing hydroxylamine one must have the disposal of ammonia, nitrous gases and sulphur dioxide.

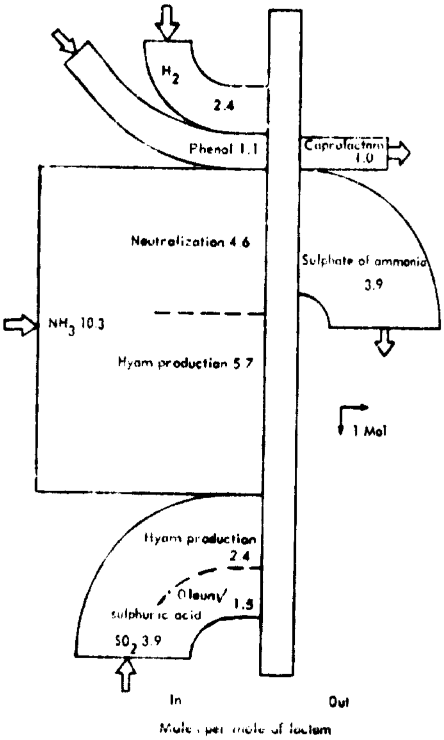


Figure IV. *Flowsheet caprolactam process (starting material: phenol)*

This implies that installations must be available for making these products. Obviously, it is a great advantage if large facilities for making them are in existence already, so that the lactam production can be readily fitted in with a current activity. This is the case at several firms, such as BASF, Allied and Staatsmijnen.

(*b*) Another important characteristic is the required amount of sulphuric acid, which is converted to sulphate of ammonia. The process discussed just now yields approximately 4.5 tons of this product per ton of lactam. At the moment, this certainly does not mean an objection because there are good outlets for sulphate of ammonia on the fertilizer market.

2. *Snia-Viscosa route*

This process, which has been known for some years now (Belgian Patent Specification 582, 793), starts from cyclohexane carboxylic acid (hexahydrobenzoic acid), i.e., hydrogenated benzoic acid (figure V).

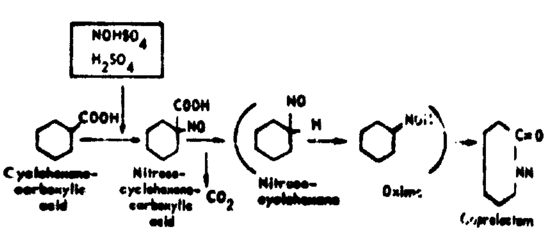


Figure V. *Caprolactam from cyclohexane carboxylic acid*

Caprolactam from cyclohexane carboxylic acid

This compound shows an aromatic substitution reaction at the C-atom bearing the COOH-group. During treatment with NO⁺-ions (e.g. $NOHSO_4$ in H_2SO_4: nitrosylsulphuric acid) the nitrosocompound (isomer with the oxime) forms intermediately. CO_2 escapes and the rearrangement to caprolactam takes place in an excess of sulphuric acid. Following this rearrangement, sulphuric acid is, just as in the phenol route, converted with NH_3 into sulphate of ammonia so that caprolactam can be separated off.

Of course, this process has received attention also at Staatsmijnen (benzoic acid is an intermediate product in the manufacture of phenol by the Dow process, which is applied at Staatsmijnen.)

The conclusions of our study can be summarized as follows:

(*a*) During the main reaction, the nitrozation and the rearrangement, contaminations are formed part of which get into the caprolactam. It is our impression that this highly complicates the purification of the final product.

Another part of the coloured by-products gets into the ammonium sulphate, which, as a result, assumes a dark colouration and, in consequence, is unfit for sale unless further treated.

(*b*) Hydrogenating the benzoic acid will have to be done in the liquid phase with the aid of a noble-metal

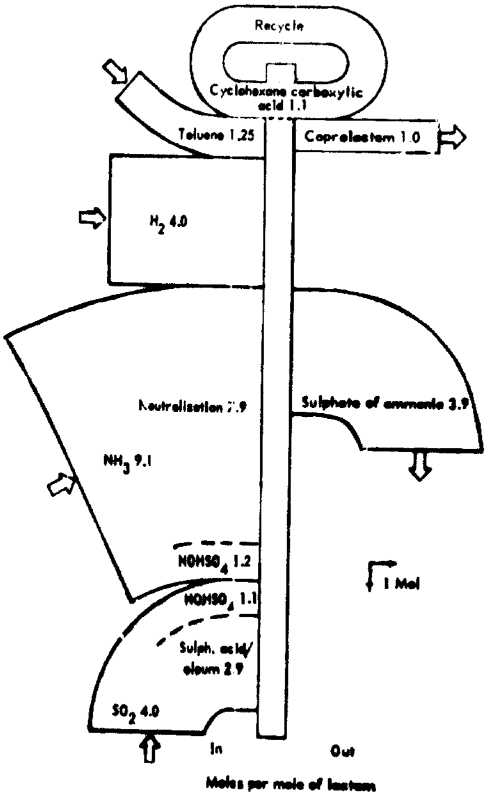


Figure VI. *Flowsheet of the caprolactam process (Snia-Viscosa) via cyclohexane carboxylic acid* catalyst, which, consequently, will have to be filtered off. This is a rather expensive operation; moreover, the cyclohexane carboxylic acid is corrosive.

(*c*) Another considerable drawback is that in each pass the conversion of the cyclohexane carboxylic acid is very low, *viz.* about 50-60 per cent, so that this main product has to be recycled.

(*d*) A quantity diagram, in moles, of this process is presented in figure VI.

The amounts of auxiliary materials — nitrous gases, sulphuric acid, and ammonia — required in the process are about the same as in the process *via* phenol-anol-anone. The yield is 4.5 tons of ammonium sulphate per ton of caprolactam.

3. *Toyo Rayon process (photochemical nitrozation)*

The essential feature of this process is the photochemical conversion of cyclohexane into oxime with NOCl. The first patent specifications date from 1944. It is the only process in which the activation of the six-ring of cyclohexane and the introduction of the nitrogen (in the form of NOCl) take place simultaneously. The gross reaction equation is as follows:

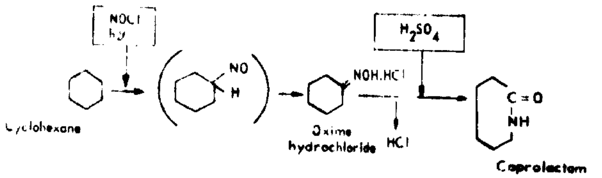
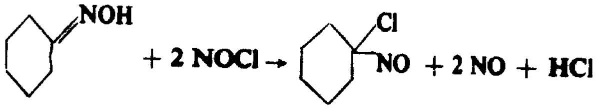


Figure VII. *Caprolactam by photonitrozation*

Caprolactam by photonitrozation

Reaction with the excess of HCl yields the hydrochloric acid salt of the oxime, which, after the reaction, separates out as an oil. The non-converted cyclohexane has to be recycled.

An undesired side-reaction is the formation of 1,1-chloronitrosocyclohexane:



$$C_6H_{10}{=}NOH + 2\,NOCl \rightarrow C_6H_{10}(Cl)NO + 2\,NO + HCl$$

The Japanese firm of Toyo Rayon, one of the largest lactam producers in the world, has developed the process to the stage of technical realization and is now applying it on a commercial scale.

The most important auxiliary material required is NOCl, which is prepared as follows:

(*a*) Combustion of NH_3 to nitrous gases:

$$NH_3 \rightarrow NO + NO_2\,(= N_2O_3)$$

The degree of oxidation needed is 50 per cent, i.e., 1 mole of NO to 1 mole of NO_2.

(*b*) Absorption into H_2SO_4:

$$N_2O_3 + 2\,H_2SO_4 \rightarrow 2\,NOHSO_4 + H_2O$$

(*c*) Introduction of HCl and formation of gaseous NOCl:

$$NOHSO_4 + HCl \rightarrow NOCl + H_2SO_4$$

This is a rather laborious way of preparing the mixed acid anhydride NOCl ($N_2O_3 + 2\,HCl \rightarrow H_2O + 2\,NOCl$).

Either H_2O will have to be removed from the sulphuric acid in a separate step by evaporation at a high temperature (Cl-ions present), or this dilute sulphuric acid is processed into ammonium sulphate. Extensive measures will have to be taken to prevent corrosion, both in the nitrozation proper and in the preparation of NOCl. In practically all steps of the process the presence of Cl_2 and Cl-ions has to be reckoned with.

The data available a year ago justified the expectation that the yield would be 200 g of oxime (= lactam) per kWh and that it would be possible to use 10-kWh lamps; this would mean a daily production of 48 kg per lamp. For a production of 24 tons per day an installation comprising 500 lamps would be needed. Although it would seem that the power of the lamps can be increased, some hundreds of lamps will still be needed in a plant with a capacity of some tens of tons per day. The principle of the nitrozation is shown in figure VIII.

Photochemical nitrozation

The conclusions to be drawn with regard to this process can — with some reserve — be formulated as follows:

(*a*) The difficulties in the purification of the end product are very probably not as great as those in the Snia process. There is, however, a great chance that traces of chlorinated lactam will get into the end product. The splitting off of HCl during the polymerization, may cause formation of unsaturated compounds, which may give rise to discolouration. Moreover, the HCl set free may attack the equipment.

(*b*) The number of stages in which the process is carried out is small, *viz.* three stages if benzene is used as starting product (hydrogenation, nitrozation and rearrangement), and two stages if the process is started from cyclohexane. It would be expected that the capital expenditure involved is small. This is not true, however, because the installations to be used in the photochemical part of the process are very costly. These costs will, moreover, increase proportionally to the capacity of the plant.

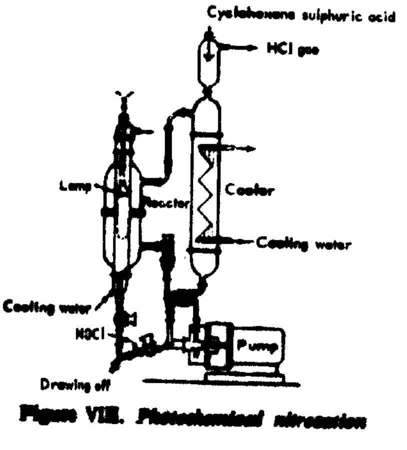


Figure VIII. *Photochemical nitrozation* (*c*) Also in this process nitrous gases, sulphuric acid and NH_3 are needed as auxiliary materials. As no hydroxylamine is made, the amount of ammonium sulphate formed as a by-product will be smaller, viz., 2 moles per mole of lactam, i.e., 2.3 tons per ton of lactam.

(*d*) The yields will very probably be high, and it will not be required to recycle any of the main products with the exception of cyclohexane and HCl.

The quantity diagram, in moles, is as follows:

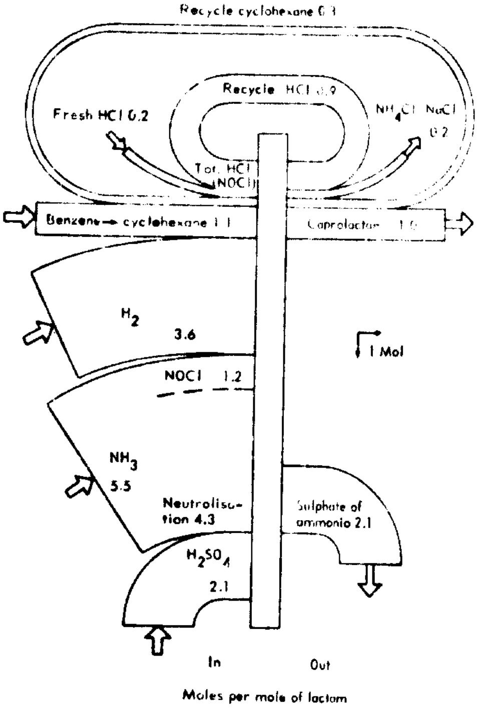


Figure IX. *Flowsheet Toyo Rayon process*

4. *The Du Pont process*

The first rumours about a new process for the manufacture of caprolactam developed by Du Pont started circulating in 1958-1959. Especially in the beginning, all kinds of conjectures were made as to the route followed. In the course of years, more data have become known, so that the reactions involved can now be indicated. However, it is not yet quite possible to make a comparative evaluation of the process, as has been done for the two previous ones. The process starts from cyclohexane, which is converted into nitrocyclohexane. The conversion is followed by a catalytic reduction yielding cyclohexanone oxime, which can be rearranged in the normal way with H_2SO_4.

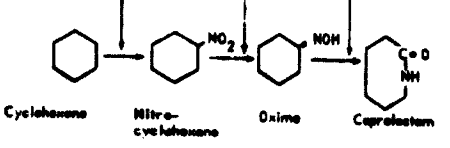


Figure X. *Caprolactam from nitrocyclohexane*

Caprolactam from nitrocyclohexane

The nitration of cyclohexane to the nitrocompound is not simple (explosion danger, corrosion, relatively low yield (65-70 per cent)), but the crucial step is the reduction of nitrocyclohexane to oxime. An extremely large number of patents have been granted for processes of this type, in which the most widely varying reduction agents and reduction methods are used: H_2S, Sn and Zn-compounds, ferrous salts, sulfites and hydrosulfites, CO + CH_3OH (Du Pont).

In most cases, the result is not encouraging: the yield is almost invariably below 80 per cent, while, furthermore, undesired products are formed because the reduction goes either just too far or not far enough: anone, cyclohexylhydroxylamine (R-NHOH), cyclohexylamine.

Du Pont, in one of their patent specifications, mentions about 8-10 per cent of amine as by-product at an 80-85 per cent oxime yield. Another characteristic of the process that can be given at the moment is the amount of ammonium sulphate formed as by-product, viz., 1.5-1.6 moles per mole of caprolactam.

5. *Cyclohexylamine route*

This last route in the diagram has not been associated with the name of a firm because I do not know of any firm which is applying the process on a commercial scale.

The most important step is the oxidation of cyclohexylamine to the oxime. This reaction is, as it were, the antipole of the reduction of a nitrocompound mentioned before. The difficulty encountered here is of the same nature, viz., stopping the oxidation right at the end of the oxime formation to keep out by-products.

In one of the publications, this is effected by bringing a threefold excess of the amine in contact with the oxidant H_2O_2. The oxime has to be separated from this amine excess by crystallization, whereupon the remainder of the amine has to be recycled (see i.a. BASF, Germ. Pat. 1,002,233 (14 February 1957), Holzverzuckerung (Inventa, Kahr Sw. Pat. 288,168), (Allied (U.S. Pat. 2,829,163)). The consumption of oxidant is more than 2 moles of H_2O_2 per mole of oxime, which normally means a prohibitive outlay.

C. FINAL CONCLUSIONS

In the foregoing, a discussion has been presented of the chemically characteristic features of a number of processes. For a technical, economical evaluation, supplementary economic data must be known as e.g., the investment costs involved; it goes without saying that difficulties will be encountered in collecting these data for processes applied by other firms. From what has been said before it can be concluded, however, that the various methods for preparing caprolactam, and the side-processes linked with them, show many points of resemblance. For instance, in all processes a hydrogenation has to be carried out in some stage or other, so that the over-all process must include production of hydrogen.

As a second example may serve the fact that in all processes ammonia is needed, which is employed as

TABLE 2. SURVEY OF ANALOGOUS OPERATIONS IN CAPROLACTAM PRODUCTION

	Operation	*Process*					
		Phenol	*Cyclohexane*	*Snia-Viscosa*	*Toyo Rayon*	*Du Pont*	*Aniline*
Main product	1. Hydrogenation	Phenol ↓ Cyclohexanol	Benzene ↓ Cyclohexane	Benzoic acid ↓ Cyclohexane-carboxylic acid	Benzene ↓ Cyclohexane	Benzene ↓ Cyclohexane	Aniline ↓ Cyclo-hexylamine
	2. Activation of the C-six ring	Toluene (benzene) ↓ Phenol (oxidation)	Cyclohexane ↓ Cyclohexanone (oxidation)	Toluene ↓ Benzoic acid (oxidation)	Photochemical activation ↓ (irradiation)	Cyclohexane ↓ Nitrocyclohexane (nitration)	Benzene ↓ Nitrobenzene (nitration)
	3. Production of lactam (rearrangement)	Virtually identical in practically all processes. In Snia-Viscosa combined with oxime production through application of nitrosyl sulphuric acid instead of sulphuric acid as in the other processes.					
	4. Lactam purification	Basically identical in all processes, but different in details, mainly as a result of the composition of the rearrangement products.					
Auxiliary materials and by-products	5 + 8. Production of active N-compound	Hydroxylammoniumsulphate $NH_3 \rightarrow NO + NO_2 \rightarrow$ $\rightarrow NH_4NO_2 \rightarrow NOH(SO_3NH_4)_2$ $\rightarrow (NH_3OH)_2H_2SO_4$		Nitrosylsulphuric acid $NH_3 \rightarrow NO +$ $NO_2 \rightarrow$ $NOHSO_4$	Nitrosylchoride $NH_3 \rightarrow NO +$ $NO_2 \rightarrow$ $NOHSO_4$ $\rightarrow NOCl$	Nitric acid $NH_3 \rightarrow NO_2 \rightarrow HNO_3$	
	6. Hydrogen production						
	7. Ammonia production	i.e. for neutralizing the sulphuric acid used in the rearrangement.					
	9. Sulphuric acid production	i.e. for the rearrangement; after neutralisation to be converted into sulphate of ammonia.					
	10. Sulphate of ammonia production	For production of ammonium sulphate fertilizer from $(NH_4)_2SO_4$ solution.					

starting product in the preparation of the auxiliary materials (NH_2OH, N_2O_3, $NOCl$, HNO_3) and for neutralization of the sulphuric acid used.

A survey of these analogous operations is given in table 2. This clearly shows the close similarity between the various processes, as regards the phase of manufacture of both the main product and the auxiliary materials and by-products.

Each process comprises ten different operations, viz: four in the lactam route proper, and six for the production of the auxiliary materials and the processing of the by-product ammonium sulphate. Comparing these operations, we can estimate the cost of investment. This procedure has been followed for three of the processes discussed, viz: the cylcohexane oxidation, the SNIA-VISCOSA route and the photochemical nitrozation.

In figure XI the result has been summarized for a 10,000 t/yr unit integrated in a large nitrogen-fixation plant. The investments in each of the process steps have been expressed in per cent of the total capital outlay, which for each process has been put at 100 per cent This has been done because at the above-mentioned production capacity the absolute amounts do not differ much.

The most important conclusion to be drawn from this summary is that the additional investments for the auxiliary materials amount to 40 to 50 per cent of the total. This important role played by the auxiliaries will have become clear already from the flow-sheets. Another conclusion is that a firm which has been using a certain process need not switch over to another process when expanding the production capacity, unless special circumstances should require this.

If production has to be started, however, the choice of the process will depend on factors which, for the greater part, do not bear any relation to the process itself, such as production capacity, raw materials position, special demands as to the amounts of by-product, etc. A factor which has not yet been mentioned, viz. the quality of the end product, might well be the decisive factor, but that is a subject in itself.

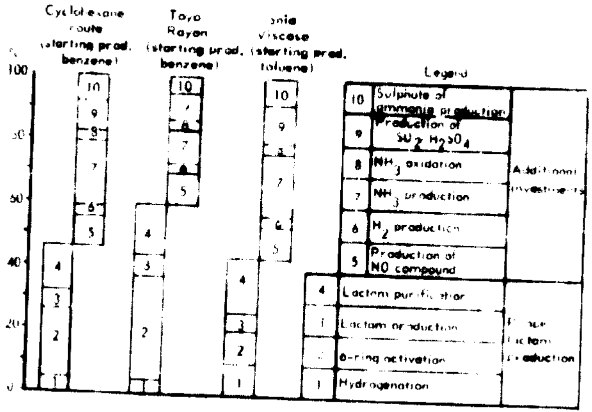
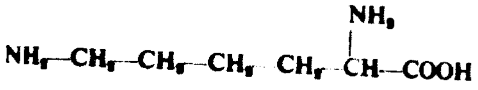


Figure XI. *Investments (in per cent) of the process steps of some caprolactam routes at an annual capacity of 10,000 tons*

III. Lysine

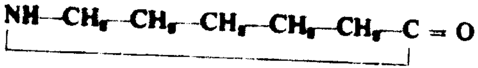
A. PREPARATION OF LYSINE FROM CAPROLACTAM

Lysine is an essential constituent of animal and vegetable proteins. These proteins are macromolecular products built up mainly of amino acids. Lysine is one of these amino acids. These compounds are indispensable for the growth and development of man and animal, and only some of them can be synthesized in the body from other nitrogen sources. The diet should therefore be so composed as to contain already a given amount of the various amino acids so that the proteins can be synthesized in the body. One of the most important amino acids for nutrition is lysine. The structural formula of lysine, or α — ε diaminocaproic acid, closely resembles that of caprolactam



$$NH_2—CH_2—CH_2—CH_2—CH_2—\overset{\overset{NH_2}{|}}{C}H—COOH$$

Lysine



$$\underbrace{NH—CH_2—CH_2—CH_2—CH_2—CH_2—C}=O$$

Caprolactam

Of the two optical isomers, i.e., the dextro-(d) and the laevorotatory (l) lysine, only the l-modification is assimilated in the body for protein formation.

Some years ago, Staatsmijnen succeeded in developing an entirely new synthesis for l-lysine on the basis of caprolactam. Introduction of an NH_2-group at the α-position is not simple to realise, and must be effected in an indirect way. Nevertheless, this route is much less laborious than other lysine processes used so far.

The principle is shown in the following diagram. Caprolactam is phosgenated and the reaction product converted to nitrolactam by reaction with nitrating acid ($NO_2{}^+$ $HSO_4{}^-$).

Hydrogenation yields aminolactam which, with an optically active acid as auxiliary material, is split up into the l- and d-modifications. After racemization of the d-aminolactam the racemate is returned to the process, whereas the l-aminolactam is hydrolyzed to l-lysine. The hydrochloric acid salt of the latter (l-lysine-HCl) is a crystalline product with excellent storing qualities.

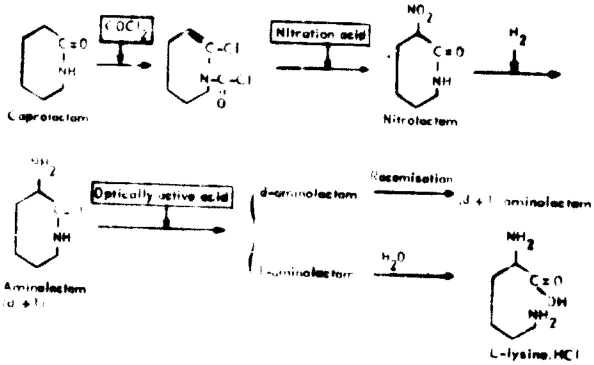


Figure XII. *Production of L-lysine from caprolactam*

The whole process has been run on a pilot-plant scale for a few years, and a production unit with an annual capacity of 3,000 tons is now under construction.

We have carried out an extensive study on the uses of lysine in feed and food. The results suggest that this product will come to play a very important role in the near future. The various applications that are possible will be discussed further below.

B. APPLICATION OF LYSINE

1. *Significance of amino acids in nutrition*

The report entitled *The United Nations Development Decade: Proposals for action*[1] contains a conclusion stating that, despite the considerable technological progress made over the past decade in the field of food and agriculture, one of the basic problems facing the world is the food situation.

It would be beyond the scope of this contribution to go further into the nature and extent of this problem. From the above-mentioned report and many other publications it can be concluded that in large parts of the world there is still a great shortage of protein, particularly of animal protein.

From table 3 it is seen that, whereas the differences in the consumption of vegetable protein are indeed small, animal protein consumption differs very widely from one area to another (see table 3).

All proteins, i.e., not only those in food and feed but also those in the body tissue, consist of polymers built of amino acids. In the body of man and animal, this process is based on the amino acids formed by the decomposition of the food protein. Of the approximately twenty different amino acids needed, some can be synthesized in the body, whereas the others cannot. The latter

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[1] United Nations publication, (Sales No.: 62.II.B.2), p. 46.

TABLE 3. CONSUMPTION OF PRODUCTS OF ANIMAL ORIGIN (ACCORDING TO MITTENDORF 1964 [a])

	Milk	Meat	Eggs	Fish	Protein		
					Animal	*Vegetable*	*Total*
			grammes per capita — *per day*				
High-income countries							
North America	850	248	55	26	66	27	93
Australia and New Zealand	574	312	31	22	62	32	94
La Plata countries	460	318	22	10	63	38	101
Europe	494	111	23	38	36	52	88
Average	573	152	30	34	44	46	90
Low-income countries							
South America [b]	204	67	9	20	19	42	61
Far East	51	24	3	27	8	48	56
Middle East	214	35	5	12	14	62	76
Africa	96	40	4	16	11	50	61
Average	79	30	4	24	9	49	58

[a] According to P. V. Sukhatme, *Food Supplies and Human Nutrition* (Stanford University Press, California, USA).

[b] With the exception of the La Plata countries.

— the indispensable or essential amino acids (about ten) — must therefore be present in the food in a sufficient amount to ensure optimum nutrition.

Lysine can be considered as the most important of these, because in many food proteins there is a deficiency of this product; in other words, lysine is in many cases the first deficient amino acid.

The difference between vegetable and animal protein is very often to be ascribed to a difference in lysine content. This appears, e.g., in figure XIII, which shows the content of eight essential amino acids in meat and wheat proteins.

It is known that animal protein in general possesses an amino-acid pattern which comes up near to nutritional requirements so that it has a high nutritional or biological value. Wheat protein, being deficient in lysine, has a much lower nutritional value, which value is determined by the degree of this deficiency. The same holds for most other proteins of vegetable origin.

It has been shown by several investigations that a deficiency of one or more amino acids can be neutralized by supplementing the food by these compounds. The body is evidently capable of incorporating a synthetic product in the same way as an amino acid formed by digestion of natural proteins. This very important principle underlies the application of synthetic l-lysine. Especially in those areas with insufficient production and consumption of animal proteins, this opens the way for a considerable improvement of the nutritional value of food and feed.

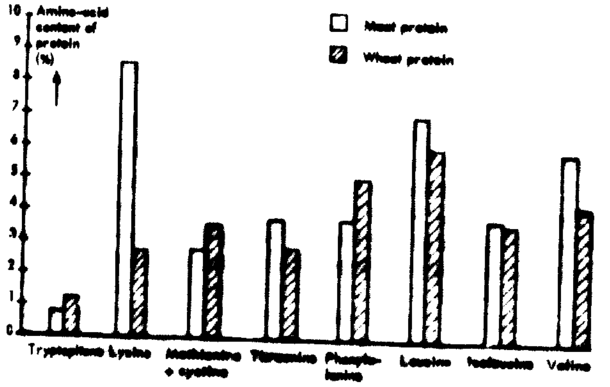

Figure XIII. *Amino-acid pattern*

2. *Some applications of synthetic lysine*

One of the possible applications of synthetic lysine is as a supplement to human food. Lysine deficiency in food can cause serious diseases.

Upon closer analysis, the food also of apparently well-fed population groups usually appears to be barely adequate as far as lysine is concerned. This holds particularly for the diets of pregnant and nursing mothers, children and aged people. The possible use of synthetic lysine will not be elucidated here because this field does not lend itself to making an economic evaluation.

The second field of application is that of animal nutrition, e.g., for pigs, broilers, layers, turkeys, fish, fur animals, etc. A few of these possibilities will be considered here: feed for pigs and poultry (broilers and layers). The main constituents of the feed in both cases are cereals which, although varying in lysine content from one species to another, and even from one crop to another, are invariably deficient in lysine.

The content of protein of the cereals (or mixture of cereals) is usually supplemented by addition of protein-rich nutrients. These may be of animal and/or vegetable origin; the former are generally rich and the latter poor in lysine. In many cases, however, the high price and scarcity of animal protein will be an impediment to its use in animal feed.

Addition of lysine to a lysine-deficient, but otherwise adequate ration, yields three advantages at the same time:

(*a*) Increase in production the growth-rate of the animals increases, the hens produce more eggs in a certain period; this can be achieved with the same amount of labour and the same accomodation which means lower depreciation costs,

(*b*) Decrease in feeding cost; less feed needed per unit product (meat, egg);

(*c*) Improvement in quality better lean/fat ratio, larger eggs and, hence, higher market values of these products.

Against these economic advantages there is of course the cost of the lysine addition. In various diets, these expenses are exceeded many times by the advantages that can be achieved, provided again the lysine is obtainable at a reasonable price.

(*a*) *Pigs*

In 1949 Mertz and co-workers were the first to prove that lysine is an essential amino acid for pigs. Since then, investigators throughout the world have performed hundreds of feeding experiments under very widely varying conditions as regards diets, feeding methods, accommodation, breed and age of the animals, etc. It would be beyond the scope of the present paper to give a comprehensive survey of this work. Therefore only a few examples will be given here. The first example may serve to illustrate the multiple economic effect of lysine addition[2]. A two-stage diet was used (14 per cent crude protein for pigs of 23-57 kg and 12 per cent crude protein for pigs of 57-91 kg), based on corn and groundnut meal (83 per cent and 14 per cent respectively for the 14 per cent protein ration). Both diets were fed unsupplemented and supplemented with 0.1 per cent l-lysine, to two groups of eight test animals each. The addition of 0.1 per cent l-lysine appeared to improve not only the weight gain (508 g/d → 640 g/d) but also the feed conversion (4.07 kg feed/kg gain → 3.65 kg feed/kg gain) and the carcass quality (e.g. higher killing-out percentage; 76.3 per cent → 78.0 per cent: more lean, less fat, etc.).

For given conditions and known price rates, these factors can be evaluated economically. Under the conditions existing in the Netherlands it can be calculated that an addition of 0.31 kg of l-lysine-HCl to the feed of a slaughter pig would yield a profit of approximately $7-8, i.e., approximately $2.0 through faster weight gain, approximately $2.2 through lower feed consumption (29 kg at approximately $0.036/lb) and approximately $3.6 through improvement of the killing-out percentage and the carcass quality.

A more complete economic evaluation depends on regional appreciations and price levels. In the following examples, therefore, attention will be given mainly to the decrease in feeding cost arising from the addition of lysine. This saving is expressed in a factor R which denotes how many kg of feed can be saved by addition of 1 kg of l-lysine-HCl. Consequently, this factor also gives the value ratio between lysine and feed.

For the sake of simplicity, the number of examples has been restricted. Only those tests have been chosen which were continued throughout the fattening period (approximately 20 kg-approximately 90 kg) while the abnormal diets (very favourable ones, and very unfavourable ones, such as those prepared with low-quality cottonseed meal) have been left out. So, these "average" diets were all more or less deficient in lysine (see table 4). Lysine addition invariably proved to give a feed saving of some tens of kgs per kg of lysine (approximately 40 R approximately 140 i.e., the equivalent value of l-lysine-HCl in these cases is 40 to 140 times the diet price).

(b) *Broilers*

The aspects of broiler fattening are approximately the same as those of pig fattening. Here again the advantages of lysine addition are of course particularly evident if the regional agricultural conditions are such that a sufficiently cheap feed is available which satisfies all demands to be made on it except with regard to the lysine content. This situation exists in many countries, e.g. in Eastern Europe, the Middle East and Africa, which have a sufficient production of protein-rich nutrients, such a sesame meal, sunflower seed meal, cottonseed meal, etc. These products are excellent feed constituents also for broilers, but are deficient in lysine. Several tests have shown that addition of synthetic lysine greatly improves these rations. Mention can be made here e.g. of the extensive study by Al-Azzawi[3] on the use of sesame meal in broiler diet This investigator concludes that for the Middle East, supplementation of lysine to feeds made up of home products like sesame meal should be preferred to other solutions, also economically. Another investigator (Van der Merwe)[4] used diets consisting of 60 per cent corn meal, 4 per cent lucerne meal and 30 per cent sunflower seed meal. These diets were fed without supplementation and supplemented with 0.15 per cent and 0.25 per cent of lysine; the corresponding feed conversion figures were 3.08 kg/kg, 2.88 kg/kg and 2.71 kg/kg. The calculated R-factors for the lysine preparation (probably L-lysine-HCl) were 46 and 55. This shows that also in the case of broiler rations, tens of kgs of feed can be saved by addition of 1 kg of l-lysine-HCl. Upon addition of 0.15 per cent and 0.25 per cent lysine, the weight gain moreover rose by 4 per cent and 7 per cent respectively.

(c) *Layers*

Supplementation of lysine to a given diet may also have a very favourable effect on egg production. As in the previous examples, this effect will be all the greater and the application of synthetic lysine all the more obvious when cheap, high-quality and lysine-rich feed components are not, or not sufficiently, available.

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[2] Magruder, Sherman and Reynolds, *J. Animal Science*, 20:573-577 (1961).

[3] Al-Azzawi, *Dissertatie* Wageningen (June 12, 1964).

[4] Van der Merwe, Proc. 12th World's Poultry Congress, Sydney (1962), pp. 254-258.

TABLE 4

Investigators	*Period (kg)*	*Chief constituents of basal diet (%)*	*Crude protein (%)*	*Lysine (%)*	*Amount of L-lysine-HCl added (%)*	*Feed conversion (kg of lysine)*		*Factor R*	*Notes*
						Basal diet	*Fortified diet*		
Clawson and co-workers	10-91	Corn 94.7/soybean meal 2.5	Appr. 10	0.26?	0.40	4.75	3.70	71	Averaged over 2 seasons 2 breeds; total 48 animals.
		Corn 84.2/soybean meal 5/cornsugar 8	Appr. 10	0.31?	0.40	4.27	3.57	49	Group feeding *ad lib.*
Vipperman and co-workers	15(-34-57)-91	Corn 78/Groundnutmeal 19.5	16-14-12	0.41-0.38-0.34	0.255 (average)	4.76	3.50	141	6 animals per diet. Group feeding *ad lib.*
Nielsen and co-workers	21(-57)-91	Barley 93/soybean meal 3 > 57 kg: no soybean meal	14-12	0.55-0.48	0.05	3.90	3.65	137	Test 26 (32 animals). Group feeding *ad lib.*
Magruder and co-workers	20(-57)-91	Corn 85/soybean meal 12 (crude protein = 12.5 %)	12.5-10.5	0.49-0.44		3.65	3.22	107	16 animals per diet.
		Corn 96/soybean meal 6 (crude protein = 11 %)	11 - 9	0.42-0.30	0.125	4.52	4.11	80	Group feeding *ad lib.*
		Milo corn 87/soybean meal 10 (crude protein = 14 %)	14 -12	0.55-0.40		4.19	3.69	108	
		Corn 79/Groundnutmeal 14 (crude protein = 14 %)	14 -12	0.50-0.39		4.07	3.65	92	
Brooks and co-workers	18(-34-60)-91 26-(90)	Corn 79/Groundnut meal 19 (crude protein = 16.6 %)	16.6-14-12	0.56 (crude protein = 16.6 %	0.285	4.13	3.35	84	7 animals per ration.
		Corn 73/Groundnut meal 20/Lucerne meal 5	17.4	0.55	0.625	5.13	3.00	114	Group feeding *ad lib.*
Hale and co-workers	26-85	Milo corn 72/Cottonseed meal (high quality B)	17	0.64	0.125	4.07	3.64	95	8 animals per diet. Individual feeding *ad lib.*
Hogedoorn	30-90	Cereals 75/soybean meal 5/Sunflowerseed meal 7/Banana meal 8	18	0.65	< 50 kg : 0.075 > 50 kg : 0.125	3.76	3.37	87	8 animals per diet. Restricted individual feeding.
Suerley and co-workers	19(-50)-90	Milo corn 85/soybean meal 12.5 (< 50 kg) Milo corn 93/soybean meal 4.5 (> 50 kg)	15.2-12.3	0.62-0.46	0.125 0.25	3.81 3.81	3.64 3.45	37 41	20 animals per diet. Group feeding *ad lib.*

In evaluating the results obtained with layers, not only egg production but also egg quality, in particular egg-size, should be considered.

Pepper and co-workers[8] compared *inter alia* the results obtained with diets which, beside a 50/50 wheat/corn mixture, contained only little soybean meal (5 per cent), without and with supplementation of lysine (0.25 per cent). The results are given in table 5.

Lysine supplementation gave an improvement of egg production, egg size, feed consumption and weight gain.

If, for simplicity, only the feeding cost is considered, it appears that the saving in feed is 360 kgs per ton of eggs; against this stands the consumption of 7.1 kg of lysine. The value ratio of lysine to feed (R) is consequently 51; for l-lysine-HCl with 80 per cent l-lysine, R = 41.

3. *Conclusions*

In the foregoing, attempts have been made to demonstrate that addition of lysine to animal feed can yield

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[8] Pepper, Slinger and Sibbald, Proc. 12th Worlds' Poultry Congress (1962), Sydney, pp. 240-247.

TABLE 5

	Basal diet				Basal diet + 0.25 % lysine			
Productivity (eggs/hen/day)	52.7 %				65.6 %			
Feed consumption (g/egg)	174.6				161.8			
Egg size distribution	42.5 - 49.6 g	49.6 - 57.6 g	56.7 - 63.8 g [a]	> 63.8 g	42.5 - 49.6 g	49.6 - 56.7 g	56.7 - 63.8 g [a]	> 63.8 g
	8.7 %	47.3 %	36.0 %	8.0 %	3.2 %	33.6 %	48.7 %	14.5 %
Mean egg weight	54.4 g				56.7 g			
Feed consumption (g feed/g egg)	3.21				2.85			
Weight gain of hens (g/36 weeks)	63 g				216			

[a] Standard size.

several important advantages. The relative importance of these advantages will, of course, depend on the conditions in the various countries. In principle, however, it is possible to find out by calculation how far addition of lysine is attractive; in most cases sufficient data are available concerning the amino-acid content, the feeding standards, etc.

An important datum is the price of lysine. The aim of a chemical industry, like that of Staatsmijnen, is to make products such as caprolactam and lysine in large quantities. As a result, lysine need never become a costly luxury.

Although the prices of agricultural products in the various countries are not known exactly, it may be stated that preliminary calculations have proved that lysine offers very important and interesting prospects, also from an economic point of view.

There is no point in giving economic considerations with regard to human food. Consequently, this subject has not been worked out further. It is obvious, however, that also the nutrient value of human diets consisting predominantly of vegetable protein (e.g. rice, lysine deficiency 56 per cent) can be considerably increased by addition of lysine. The attractiveness of lysine, in the case of both food and feed, consists in that:

(*a*) Only small amounts of it are needed, so that the cost of transport is not high;

(*b*) It is a chemical compound with a salt character and good keeping qualities under varying climatological conditions;

(*c*) The addition is not, by itself, a complicated technological operation; the only condition is that the lysine should be distributed homogeneously;

(*d*) Lysine does not affect the taste of the food and feed. The existing feeding habits need not be altered, provided there are no other circumstances that make this necessary.

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8. ACRYLIC FIBRES

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I. Introduction

Acrylonitrile, the raw material of acrylic fibres, was first synthesized in 1893 by a Frenchman, Moureu, by a process of dehydrating acrylamide or ethylene cyanohydrin. It was more than forty years later that acrylonitrile was commercially produced and the Badische Anilin u. Soda Fabrik, a member of I. G. Farben, officially announced its synthetic rubber "Buna N", a copolymer of butadiene and acrylonitrile.

Until about 1950, the industrial process of manufacturing acrylonitrile had been generally an indirect process by which ethylene cyanohydrin was produced from ethylene oxide and hydrogen cyanide and then dehydrated. This was followed by the development of a direct process consisting of the addition of hydrogen cyanide directly to acetylene, which was used industrially in many countries as the preferred process. In 1960, in the United States, the Standard Oil Co. of Ohio (Sohio) successfully industrialized a process of manufacturing acrylonitrile by animo-oxidation of propylene. Because this process uses propylene, which is readily available from oil refining or naphtha cracking, low-cost acrylonitrile can now be made and this process is being adopted in many countries. Acrylonitrile which was initially used for manufacturing synthetic rubber, is now largely used for synthetic fibre manufacture. The development of synthetic fibre based on acrylonitrile as a raw material was started by H. Rein of I. G. Farben around 1931, at about the same time that similar research work was started on synthetic rubber. Since polyacrylonitrile does not melt on heating, it must be dissolved for fabrication purposes. However, polyacrylonitrile cannot be dissolved in a common solvent, and therefore, one goal of research on acrylic fibres has been to find a suitable solvent for this polymer.

TABLE 1. MAJOR ACRYLIC FIBRE PRODUCERS IN THE WORLD

Country	*Name of producer*	*Trademark*	*Year production started*	*Estimated capacity in 1963 (t/y)*	*Remarks*
United States	Du Pont	Orlon	1950	58,000	
	Monsanto Chemical	Acrilan	1952	27,000	
	American Cyanamid	Creslan	1959	12,000	
	Dow Chemical	Zefran	1958	7,000	
	Union Carbide	Dynel	1949	4,000	Modacrylic fibre
	Tennessee Eastman	Verel	1957	4,000	Modacrylic fibre
Japan	Asahi Chemical	Cashmilon	1958	11,000	
	Japan Exlan	Exlan	1957	7,000	American Cyanamid licence
	Mitsubishi Vonnel	Vonnel	1959	7,000	Monsanto (Chemstrand) licence
	Toho Beslon	Beslon	1959	4,500	
	Toyo Rayon	Toraylon	1959	1,000	
	Kanegafuchi Chemical	Kanekalon	1956	7,000	Modacrylic fibre
United Kingdom	Courtaulds	Courtelle	1957	14,000	
	Courtaulds	Teklan	1962	200	Modacrylic fibre
	Chemstrand	Acrilan	1959	9,000	
Federal Republic of Germany	Bayer	Dralon	1954	27,000	
	Phrix	Redon	1952	5,000	
	Sueddeutsche Chemiefaser	Dolan	1952	4,000	
France	Crylor	Crylor	1955	5,000	
	Courtaulds France	Courtelle	1961	4,000	Subsidiary of Courtaulds
Italy	ACSA-Applicazioni	Leacril	1959	6,000	Monsanto (Chemstrand) licence
	Societa ANIC	Euroacryl	To be started soon	6,000	Asahi Chemical licence

TABLE 2. CHANGES IN WORLD ACRYLIC FIBRE PRODUCTION
(In thousands of tons)

	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963
Japan	—	—	0.5	0.6	2.8	12.5	22.0	23.0	27.4	36.0
United States	15.9	28.1	38.5	48.5	47.6	67.1	65.3	65.8	76.7	93.9
United Kingdom	—	—	—	0.5	0.5	1.8	7.1	7.3	9.3	17.2
Federal Republic of Germany	0.5	1.4	1.9	4.1	5.0	8.3	13.2	15.1	24.0	25.4
France	—	0.1	0.1	0.9	1.4	2.2	3.1	3.6	7.0	11.3
Italy	—	—	—	—	—	0.5	0.8	1.5	3.6	6.9
WORLD TOTAL	16.6	29.9	42.2	56.2	59.4	90.3	112.9	123.8	169.6	Approx. 220.0

As solvents for polyacrylonitrile, many types both organic and inorganic, have been discovered. H. Rein found for the first time that highly concentrated aqueous solutions of such inorganic salts as zinc chloride and sodium thiocyanate are usable as solvents, but their use was dropped for a time because problems such as degradation of the polymer and discoloration could not be satisfactorily solved, and the search for organic solvents was carried on intensively. As a result, almost simultaneously, Du Pont discovered various types of organic solvents, such as dimethyl formamide, and I. G. Farben a series of organic solvents containing γ-butyrolactone, dimethyl formamide, etc.

In addition to said discovery of solvents, research in polymerization methods and copolymerization reactions, made progress. In the closing days of the Second World War and the period immediately following, research on the manufacture of acrylic fibre was accelerated. In 1944, Du Pont announced Fibre A and started its commercial production in 1950 under the trade-name of "Orlon". This was followed by production of this fibre by many companies each using different solvents. Table 1 shows acrylic fibre producers of the world and their capacities.

Table 2 shows the changes in world acrylic fibre production. Production of acrylic fibre has continued to expand for the past several years and acrylic fibres have become one of the three major synthetic fibres along with polyamide fibres and polyester fibres. In view of the fact that the raw material is available at a low cost, incentives are great for further improvements of the properties of this fibre and its production processes.

II. Process for producing acrylic fibres

A. TYPES OF FIBRES

Most of the synthetic fibres based on acrylonitrile are not homopolymers of acrylonitrile (polyacrylonitrile), but are produced from copolymers for the purpose of improving the properties of the fibre. Such fibres spun from copolymers are classified into fibres whose acrylonitrile content is 85 per cent or more, and fibres whose acrylonitrile content is less than 85 per cent. The former are called acrylic fibres and the latter modacrylic fibres.

Acrylic fibres are the main product among synthetic fibres which are produced from acrylonitrile. Acrylonitrile content varies with the manufacturer, but in many cases the content is more than 90 per cent. The comonomers used for preparing a polymer are chiefly methylacrylate and vinyl acetate. Some of these fibres are terpolymers, with a third monomer added. The third monomer is usually a vinyl compound containing functional groups, such as sulfonic groups, carboxyl groups, pyridine rings, etc., which influence the dyeing properties of the fibre.

Comonomers used for the copolymers of modacrylic fibres manufactured at present are vinyl chloride, vinylidene chloride and vinyl acetate, which are added in equal or nearly equal mole ratio to acrylonitrile monomer. Such a copolymer is acetone soluble and has the disadvantage of having poorer resistance to heat, chemicals and solvents.

Since a stable molten phase cannot be obtained with either acrylic fibres or modacrylic fibres, it is impossible to use a melt spinning process. Therefore, the polymer is dissolved in a solvent as mentioned above, and then the prepared spinning solution is spun by a dry or wet spinning process to produce fibres. Figure 1 shows an example of such a production process.

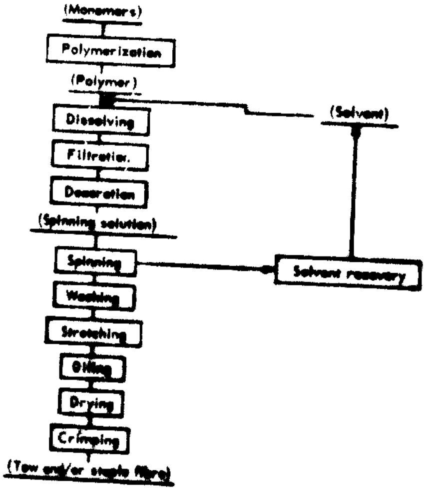


Figure 1. *Brief process flowsheet for acrylic fibre production*

B. PRODUCTION OF POLYMER

(a) *Catalyst*

Acrylonitrile is polymerized by means of light, γ-rays or various catalysts and gives a linear high polymer. The catalysts used are such inorganic substances as hydrogen peroxide, potassium persulfate and such organic substances as benzoyl peroxide, azo-bis-isobutyronitrile. Further, in industrial production, the following redox catalysts having high polymerization velocity are also used: (*a*) potassium persulfate or ammonium persulfate in combination with sodium bisulfite, (*b*) hydrogen peroxide in combination with ferrous salt or cuprous salt, (*c*) potassium persulfate in combination with amines, (*d*) sodium perchlorate in combination with sodium sulfite.

Acrylonitrile polymerizes so easily that a polymerization inhibitor such as hydroquinone or methylene blue is used in order to prevent polymerization during storage or transportation. It is preferable to remove the polymerization inhibitor prior to the polymerization process, but it is even possible to use acrylonitrile containing inhibitor without substantial trouble in the polymerization reaction provided the catalyst quantity is adequate.

(b) *Polymerization methods and systems*

The methods generally used at present for the polymerization of acrylonitrile, are suspension polymerization in a medium of water, and solution polymerization in a solvent for the polymer to be produced.

In suspension polymerization, the above-mentioned monomers, an aqueous solution of catalyst, and water, are fed into a polymerization reactor in a specified ratio.

Figure II shows the polymerization process diagrammatically.

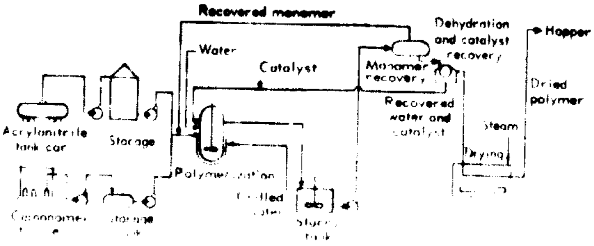


Figure II. *Polymerization process of acrylonitrile*

Acrylonitrile is soluble in water to an extent of 7 per cent at 0°C and 8 per cent at 40°C, so that polymerization is started in aqueous solution by a water-soluble catalyst. But, when polymerization proceeds and polymer is formed, it is separated from the water.

Most of the polymerization reactors used are glass-lined and are equipped with a stirrer. Through the jacket is passed cooling water in order to remove the heat of polymerization and maintain a specified polymerization temperature. Polymerization of acrylonitrile is an exothermic reaction, as is the case with other vinyl compounds. The heat of polymerization is reported to be 17.3 ± 0.5 kcal/mole. After a specified polymerization time, the polymer yield reaches over 90 per cent. When the polymerization is finished, the slurry formed is transferred to a vacuum tank, and after unreacted monomer has been recovered, the polymer is separated out by means of a filter. Since the filtered polymer would become coloured if exposed to too high a temperature, it is dried at a temperature of 50 to 80°C. The aqueous filtrate is circulated and reused as water for polymerization.

On the other hand, solution polymerization is a method in which the monomers and the catalyst, such as potassium persulfate or hydrogen peroxide, are fed into a solvent for the polymer, such as dimethylformamide or a concentrated aqueous solution of zinc chloride. In solution polymerization, unlike suspension polymerization, the formed polymer is not separated but is dissolved in the solvent, and the prepared solution can be used directly as spinning solution. Therefore, this method has the advantages that the equipment and the polymerization and spinning solution preparation steps can be simplified and the plant construction cost, as well as man-hours and steam consumption for polymer drying, can be reduced. On the other hand, it also has disadvantages: the polymer yield is not so high as in suspension polymerization and a considerable amount of unreacted acrylonitrile must be recovered; the polymer concentration cannot be made so high on account of the limit to the solution viscosity required for operational reasons; the selection of comonomer is restricted, depending upon the solvent; production of uniform polymer is difficult, and to cope with this difficulty, strict control of polymerization conditions as well as, in some cases, corrective treatment of the spinning solution or the fibre is required.

In the polymerization reaction in general, such factors as monomers, medium, quantity of catalyst charged, polymerization temperature, polymerization time and metallic impurities generally cause delicate changes in the degree of polymerization of the polymer and its distribution, and in the composition of the polymer and influence the viscosity of the spinning solution, coagulation in the spinning process and stretchability of the fibre, all of which have further great influences on the mechanical properties and dyeability of the fibre.

(c) *Necessity of copolymerization*

As already mentioned in brief in the description of the different types of fibres, acrylic fibres are generally copolymers, and some of them even contain a third monomer.

Generally, copolymerization is used as a means of thermoplasticity to acrylic fibres and improvement of their dyeability. The aforementioned monomers, methyl acrylate and vinyl acetate, are used mainly for the purpose of imparting thermoplasticity.

The fibre manufactured from 100 per cent polymer of acrylonitrile (polyacrylonitrile) is not sufficiently thermoplastic, so that heat-stretching and crimping of such fibre is rather difficult. Even if such a fibre is heat-stretched to some extent, it is set in such a stretched state, and it would not shrink noticeably when higher temperature is applied later. At present, 5 to 10 per cent of methyl acrylate or vinyl acetate is copolymerized with acrylonitrile monomer for the purpose of imparting adequate thermoplasticity to the polymer by disturbing the crystal structure of polyacrylonitrile. Therefore, the fibre produced from such copolymers has a potential shrinkage of 10 to 30 per cent, when the fibre is heat-stretched at a certain temperature and stretch ratio range. On the other hand, when the fibre has not undergone such heat-stretch treatment, it has no potential shrinkage. These two types of fibres, one having shrinkability and the other no shrinkability, are mixed to produce a high-bulk yarn which will be described later.

The thermoplasticity resulting from such copolymerization is created at the sacrifice of the resistance to heat and also means a reduction of the resistance of the fibre to solvents. However, it contributes to the improvement of the dyeability of the acrylic fibre. The structure of the polyacrylonitrile fibre is so dense that dyes penetrate into such a fibre at a low speed. In the case where a comonomer having little affinity to dyes, e.g. methyl acrylate, is copolymerized, the dyeable points of the fibre are not increased, but the structure of the polymer is disturbed and the speed of dye penetration is increased. Therefore, disperse dyes can be applied to the acrylic fibre produced from such a copolymer.

However, these comonomers do not improve the dyeability to basic dyes very much. In redox polymerization with potassium persulfate and sodium bisulfite as catalysts, the sulfate and sulfonic groups are attached to the ends of the polymer chains. Accordingly, the polymer shows affinity to basic dyes to some extent, but these groups are not sufficient to dye such a polymer in deep colours.

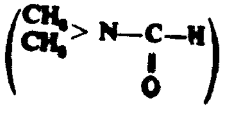
In order to improve the dyeability of acrylic fibre distinctively and control such a dyeability, a third monomer as mentioned above which has affinity to dyes is added and terpolymer is produced. Generally, styrene sulfonic acid, vinyl sulfonic acid and acrylic acid are used as comonomers with affinity to basic dyes, and vinyl pyridine is used as a comonomer with affinity to acidic dyes.

C. SOLVENTS

A polymer with a high acrylonitrile content cannot be melted by heating, Such a polymer is spun by dissolving it in a solvent. Solvents used for this purpose are classified into organic solvents and inorganic solvents.

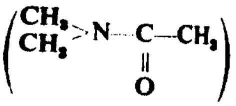
(a) *Organic solvents*

Organic solvents for producing acrylic fibres are many compounds such as amide compounds, nitro compounds and amino compounds. Of these, the representative solvents are

N, N-dimethyl-formamide 

$$\left(\begin{matrix}CH_3\\CH_3\end{matrix}> N-\underset{\underset{O}{\parallel}}{C}-H\right)$$

and

N, N-dimethyl-acetamide 

$$\left(\begin{matrix}CH_3\\CH_3\end{matrix}> N-\underset{\underset{O}{\parallel}}{C}-CH_3\right)$$

as amide compounds and

dimethyl-sulfoxide $\left(\begin{matrix}CH_3\\CH_3\end{matrix}> S = O\right)$

as a sulfoxide compound.

There are other solvents used for production of modacrylic fibres, which are obtained from a copolymer prepared by addition of vinyl chloride, vinylidene chloride or vinyl acetate in an equal or nearly equal mole ratio to acrylonitrile. Such solvents are acetone and acetonitrile. A modacrylic fibre has been developed as a copolymer which is soluble in common solvents.

(b) *Inorganic solvents*

Inorganic solvents are concentrated aqueous solutions of salts and aqueous solutions of inorganic acids.

As already mentioned, H. Rein was the first to find out that concentrated aqueous solutions of salts are usable as solvents for polyacrylonitrile. Later, G. W. Stanton made extensive investigations of the ability of acqueous solutions of salts to dissolve polyacrylonitrile. The results of his studies are shown in table 3.

TABLE 3. ORDER OF SEPARATION OF POLYACRYLONITRILE FROM SOLUTION

Increasing order of effectiveness	*Decreasing order of effectiveness*
K^+ Fe^{+++} Pb^{++}	
NH_4^+ Cd^+ Al^{+++}	SCN^-
Na^+ Ba^{++}	I'
Ca^{++} Li^+ Mg^{++}	Br^-
Ga^{+++} Sb^{+++} In^{++} Tl^{+++} Sn^{++++}	Cl^-
Zn^{++} Ag^+ Ni^{++} Co^{++} Mn^{++}	NO_3^-
	SO_4^{--}

Table 3 shows the order of effectiveness of cation and anion, by which it can be easily found out whether or not a certain aqueous solution of a salt is a solvent for polyacrylonitrile. Referring to this table, take an anion of some salt as an example. If the cation of that salt is found below the group (or line in the table) to which the anion belongs the concentrated aqueous solution of that salt can be used as a solvent for polyacrylonitrile, but if this condition is not fulfilled, the aqueous solution is not a solvent.

At present, concentrated aqueous solutions (50 to 60 per cent) of sodium thiocyanate (NaCNS) or of zinc chloride ($ZnCl_2$) are used in industrial production.

As for aqueous solutions of inorganic acids, aqueous solutions of adequate concentrations of nitric acid (HNO_3), sulfuric acid (H_2SO_4), phosphoric acid (H_3PO_4) and perchloric acid ($HClO_4$) are usable as solvents for polyacrylonitrile.

At the initial stage of development, however, it was found that breaks of the chains of polyacrylonitrile and hydrolysis of nitrile groups took place in such solutions of inorganic acid and the fibres produced by using such solvents did not have satisfactory properties. Therefore, these inorganic acid solvents were regarded as only solvents and were not used as solvents for producing fibres.

Later, it was confirmed in Japan with respect to nitric acid that if impurities such as nitrous acid are removed from nitric acid by purification and the purified nitric acid is used at a low temperature, it becomes chemically inert and if polyacrylonitrile is dissolved in such nitric acid, the polymer undergoes no substantial chemical change. Thus nitric acid has come to be used industrially. A nitric acid of more than 65 per cent is used; this is a very good solvent and dissolves polyacrylonitrile even at a low temperatures.

As a summary of the above brief explanation of organic and inorganic solvents for polyacrylonitrile, it may be said that a suitable solvent should fulfil the following conditions: (*a*) it should be capable of forming good fibres; (*b*) there should be no corrosion or other operational troubles; (*c*) recovery should be easy; (*d*) it should be of comparatively low cost.

D. SPINNING AND DRAWING PROCESS

There are three methods of spinning of synthetic fibres, namely: melt spinning, dry spinning and wet spinning. But as mentioned above, the melt spinning process cannot be used for producing acrylic fibres. Therefore, the dry or wet spinning process must be used. In the following, explanation will only be made regarding the manufacture of staple fibres because most of the acrylic fibres currently produced are staple fibres.

(a) *Spinning methods*

1. *Dry spinning*

Du Pont's "orlon" and Bayer's "dralon" are manufactured by the dry spinning process using dimethylformamide as solvent. As dimethylformamide has high hygroscopicity and forms amines upon decomposition, only dimethlyformamide entirely free from impurities is used for this purpose. First, the polymer weighing [illegible] to 30 per cent of the solvent is dispersed in the solvent, and then heated to 80-100°C for complete solution. The polymer solution is filtered by a filter press to be isolated from foreign matters and then is deaerated under reduced pressure so that yarn breakage is prevented in the spinning step. Thus, the spinning solution is prepared.

The spinning solution is heated to 80-150°C, sent through the constant volume gear pump, and passed through the candle filter to reach the spinneret. The spinneret used here is made of stainless steel and has from 200 to 600 holes. The spinning solution forced through the spinneret enters the spinning chamber. Since the boiling point of dimethylformamide is as high as 153°C, the spinning chamber is thermally insulated and receives air heated to 230-260°C. The spinning solution forced through the spinneret permits the dimethylformamide to evaporate while travelling down the spinning chamber, solidifies into filamentary form, passes over 3 godets, and is reeled up at a rate of 100 to 300 metres per minute. The filament thus obtained has not had its molecules sufficiently oriented yet and lacks adequate physical properties as a fibre, so that it must be subjected to the drawing process which is described later.

Modacrylic fibres can be dry spun by substantially the same method as described above using acetone as solvent. As acetone has a boiling point of 56°C, there is no need for using such a high temperature. However, caution should be exercised to prevent loss of acetone.

2. *Wet spinning*

The spinning speed in the wet spinning process is very low as compared with the dry spinning process. Due to such low spinning speed, however, this process has a merit that all the after-treatments including drawing (stretching), heat treatment, crimping, and cutting can be performed as a continuous operation. As to the spinneret to be employed, one having from several thousand to 20 to 30 thousand holes can be used in the wet spinning process. Therefore, it is generally more advantageous to use the wet spinning process as far as the production of staple fibres is concerned.

From the technical standpoint, the most important factors for the wet spinning are the selection of the solvent and the coagulant to be used and the setting of coagulating conditions. The qualities of the product are largely influenced by these factors. If coagulation is not carried out properly, the fibres obtained will be coarse and porous in structure. In the worst case, the fibres will get a milky white colour. This phenomenon occurs when the coagulation speed is too high for the filament, undergoing coagulation to acquire a closely packed structure or when the speed is so low that the filament, before acquiring a sufficiently set structure, is sent to the next steps of washing and heat drawing.

When dimethylformamide is used as solvent, the spinning solution is prepared by practically the same method as in the dry-spinning process, but it does not have to be heated during the spinning operation. As coagulants are suggested various substances including water, lower alcohols such as glycerine and butanol, and the aqueous solution of calcium chloride. For example, when water is used as the coagulant, the coagulation bath is prepared as about 50 per cent aqueous solution of dimethylformamide, and the coagulation is effected at 20-30°C. If glycerine is used as the coagulant, the concentration of dimethylformamide in the coagulation bath is about 10 per cent, and the coagulation temperature is suitable in the range of 110°C to 120°C.

The rate at which the filament is sent through the coagulation bath is generally between five and twenty metres per minute. The coagulated filament coming out of the coagulation bath may be heat drawn either directly as it is or after it has been stretched slightly and freed of the solvent content by washing. When such organic solvents as dimethylformide, dimethylsulfoxide, and dimethylacetamide are used, drawing can be carried out more easily and the product offers better yarn quality if the coagulated filament is heat drawn without being freed of the solvent content completely.

As an example of inorganic solvents, use of nitric acid will be explained. Nitric acid is required to be of very high purity as stated previously. Before use, it must be purified so as to be free of impurities such as nitrous acid. Aqueous solutions of a concentration of more than 65 per cent of nitric acid dissolve polyacrylonitrile very rapidly even at low temperatures. The aqueous solution of purified nitric acid and the polymer are continuously weighed and delivered to the dissolver, where solution is effected at a temperature of 0 to 5°C. Subsequently, the resultant solution is filtered and deaerated to become the spinning solution.

Figure III shows manufacturing of spinning solution and spinning process diagrammatically.

The concentration of the polymer in the spinning solution is in the range of 15-20 per cent. The spinning solution is forced through the spinneret into the coagulation bath by means of the constant volume gear pump. The coagulation bath used here is about 30 per cent aqueous solution of nitrate acid, and the temperature of the bath is in the neighbourhood of 0°C. Coagulation is performed under substantially no draft condition. As the coagulated filament still contains a large quantity of nitric acid, it is washed with water. The filament is introduced into the heat drawing step immediately after being washed with water.

When concentrated aqueous solutions of zinc chloride or sodium thiocyanate are used as solvents, the solution of the polymer should be performed at elevated temperatures, because polyacrylonitrile has not such a high solubility in these solvents as in nitric acid. In the coagulation step, the diffusion velocity of these solvents contained in the filament into the coagulation bath is lower than that of nitric acid. Therefore, the time in which the filament is held in the bath must be increased. The washing must also be carried out at elevated temperatures.

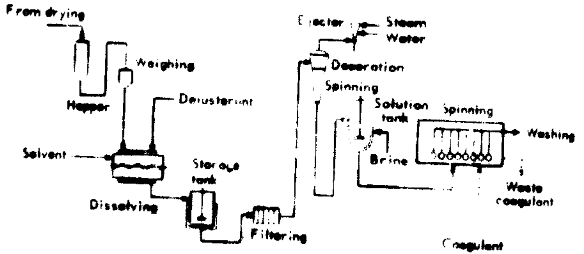


Figure III. *Flowsheet of a manufacturing spinning solution and spinning*

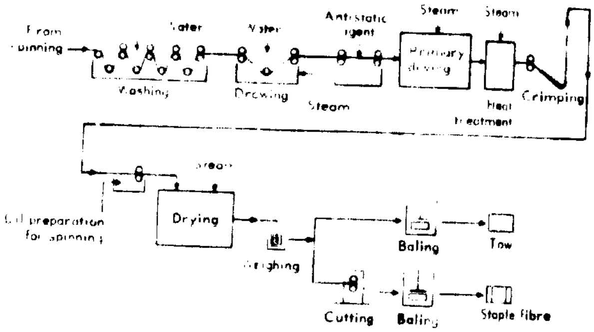


Figure IV. *Flowsheet of finishing and after-treatment*

As an example of modacrylic fibres, the equimolal copolymer of acrylonitrile and vinyl chloride is dissolved in acetone, and the spinning solution is spun into hot water, in which it is coagulated. In this case of coagulation, there is less chance of obtaining a milky white colour. The filament is usually coagulated while being stretched slightly, and sent into the dryer. In the dryer, acetone and water are evaporated. The filament thus dried, although containing no water and solvent, has thermoplasticity, and can be heat drawn in the dried state.

(b) *Drawing process (stretching process)*

1. *Dry heat drawing*

The filaments obtained by the dry spinning process or by the wet spinning process using an organic solvent and then dried, both contain the solvent by about 10 per cent, and they can be drawn merely by heat. These filaments are drawn four to ten times of stretch ratio by being heated to 80-110°C with heated air or heating rollers.

2. *Wet heat drawing*

The filament obtained by the wet spinning process can ordinarily be drawn with wet heat. There are two types of wet heat useful for this purpose; one using steam and the other using hot water. In either case, the temperature of the filament is about 70 to 100°C, and the draw ratio is usually four to ten.

Heat drawing serves to orient the molecules in the filament in its axial direction. To prevent electrostatic charge accumulation and impart good spinnability, the heat drawn filament is coated with an oil preparation before being sent into the drying step.

Figure IV shows a diagram of steps of finishing and after-treatment.

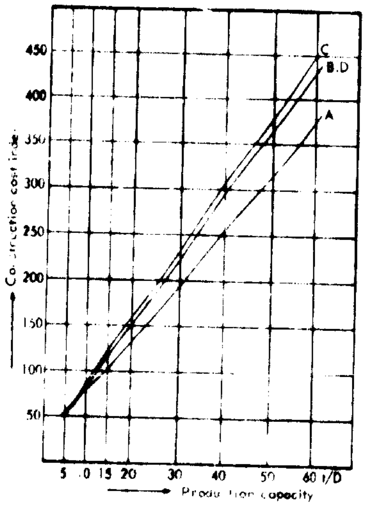


Figure V. *Plant construction cost shown in index and its relation to capacity*

III. Economics

A. Construction cost *vs.* production capacity

The relation between plant construction cost (for battery limits) of acrylic fibre A, B, C and D and production capacity is shown in figure V.

Drying, crimping and cutting

The tow of acrylic is obtained by drying the drawn filament and the staple fibre is obtained by cutting it. During the drying, the tow is held substantially tensionless. The filament shrinks by 5 to 20 per cent upon drying, although the percentage varies with the type of polymer, method of spinning, and spinning conditions.

The dried tow is provided with necessary crimping for spinning purposes. At present, tows having denier numbers up to 500,000 are handled. The tow is forwarded into the crimper of the stuffing box type by means of a pair of rolls.

The staple fibre is manufactured from this tow by being cut in desired length.

The construction cost index is estimated taking construction cost of 15 tons per day (t/D) plant of A as 100.

For making the relation between the construction cost and the production capacity clear, index per unit plant construction cost is used. Such unit construction cost is shown as the construction cost per t/D, and its index is estimated taking unit construction cost of 15 t/D plant of A as 100. This relation is shown in figure VI.

From figure VI it might be realized that, for each of A, B, C and D, the minimum economic production is in the neighbourood of 15 t/D.

B. Relation between the acrylic fibre manufacturing cost and production capacity

Figure VII shows the subject relationship. The index is 100 for the manufacturing cost of 15 t/D plant of A and is based on whatever other plants are estimated. A comparison of this figure VII and table 4 will convince us that the cost of solvent is an important factor in the manufacturing cost of acrylic fibre.

The following table shows the breakdown of the manufacturing cost of acrylic fibres A, B, C and D of 15 t/D capacity.

Table 4

	A (per cent)	*B* (per cent)	*C* (per cent)	*D* (per cent)
Raw material cost	58.6	48.9	48.3	53.7
Solvent cost	4.0	13.7	14.9	10.1
Other costs	37.4	37.4	36.8	36.2
Total	100	100	100	100

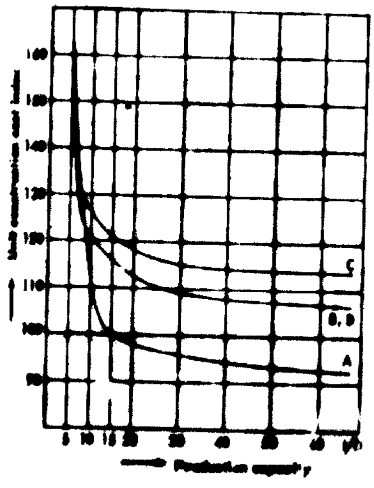


Figure VI. *Unit construction cost index and its relation to capacity*

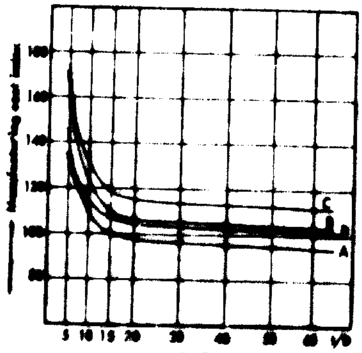


Figure VII. *Manufacturing cost index and its relation to capacity*

C. UNIT REQUIREMENTS AND PRICES OF RAW MATERIALS AND CHEMICALS

The unit requirements are the secrets of producers. Therefore, they cannot be disclosed, but it can be assumed that they are in the following range. The unit used is for 1,000 kg of product (tow or staple fibre).

	kg
Acrylonitrile monomer	930-950
Comonomers	80-120
Solvent loss	100-200

Comonomers and ternonomers generally used are the following: methyl acrylate; vinyl acetate; vinyl pyridene; third monomer containing sulfonic groups. As solvents, the following chemicals are mostly used: nitric acid; zinc chloride; sodium thiocyanate; dimethyl acetamide; dimethyl formamide; dimethyl sulfoxide. The market prices of main raw materials and chemicals mentioned above are the following:

TABLE 5

	Prices in the USA (unit : ¢/lb)
Raw materials	
Acrylonitrile	17.0
Methyl acrylate	28.25
Vinyl acetate	11.5
2-Methyl-5-Vinyl pyridine	129.0
Chemicals	
Nitric acid	4.9
Zinc chloride	11.95
Sodium thiocyanate	36.7
Dimethyl formamide	30.0
Dimethyl sulfoxide	33.0

SOURCE : *Oil, Paint and Drug Reporter* (July 27, 1964).

IV. Properties and application of acrylic fibres

A. PROPERTIES OF FIBRES

As already mentioned, each acrylic fibre has different polymer compositions, solvents used, spinning processes and drawing processes, so strictly speaking, each acrylic fibre has its own characteristics. But there are no distinguishing differences of properties among them. Table 6 shows a comparison of representative properties of acrylic fibre with those of other synthetic fibres and table 7 properties of five kinds of acrylic fibres. In this table, properties of Orlon, Acrilan, Zefran and Creslan are reprinted from "1962 Man-Made-Fiber Chart" published by *Textile World* magazine and the properties of Cashmilon are what are measured by Asahi-Chemical Industry Co., Ltd.

The specific gravity of acrylic fibres being 1.16-1.18 or almost the same as that of nylon, may be said to be the lightest of all fibres, except polypropylene fibres. Their tensile strength is 2.5-4.0 g/d. This is kept at such level because they are staple fibres. In a case where tensile strength is required such as for filaments, it can be brought up to 5-7 g/d. Compared with natural fibres, present synthetic fibres generally have less hygroscopicity, and acrylic fibres have higher hygroscopicity than polyester but lower than nylon 6. Lowering of strength by heating is in the following order, i.e. polyester-polyacrylonitrile-nylon 6 by drying heating and polyacrylonitrile-polyester-nylon 6 by steam heating, which shows that acrylic fibres have good resistance to heating. However, acrylic fibres sometimes become less white by heating. They have strong weatherability or resistance to outdoor exposure, i.e., there is an instance in which 70 per cent of their initial strength had been retained even after they were exposed to weather for two years. Thus, weatherability of acrylic fibres is most excellent among all fibres, natural and synthetic.

They have strong resistance to chemicals, i.e., they are not affected by common solvents or by mineral acid unless it is of high concentration and at high temperature. But their resistence to alkali is low and they hydrolyse by strong alkali solution. Thus, since they have strong resistance to chemicals as mentioned above, bleaching agents hardly affect them. Dyeability varies, according to the comonomers and third monomer to be copolymerized. When the polymer can be dyed by basic dyes, it shows the highest degree of colour fastness as the colour is of the beautiful tone characteristic of basic dyes. This brilliant and fresh colour tone is a characteristic of this fibre.

B. HIGH BULK YARN PROCESS

Application of high bulk yarn is recognized to be the main factor for the success of acrylic fibres as seen today. This may be compared to the role of textured yarn in nylon. Generally, textured yarn of thermoplastic fibres, for instance that of nylon, is made by either twisting, false twisting, stuffing box or edge crimping processes. But bulk yarn of acrylic fibre is made on the basis of a principle entirely different from those processes. That is, when acrylic fibres are heat-stretched and set in the stretched state, they have a high shrinkability. When they are treated afterwards with hot water or steam, they shrink and revert to a staple condition. A mixed spun yarn is made from this highly shrinkable fibre and ordinary fibre, which is then treated with hot water or steam. Since the highly shrinkable fibre shrinks and the ordinary fibre bends outside to come out to the surface of the yearn, the entire yarn becomes bulky.

Practically, there are the following three processes for making bulk yarns:

(*a*) Process in which highly shrinkable staple fibre is used (by ordinary spinning process);

(*b*) Process in which highly shrinkable tow is used (by Pacific converter);

(*c*) Process in which ordinary tow is used (by Turbo Stapler).

TABLE 6. PROPERTIES OF VARIOUS SYNTHETIC FIBRES (STAPLE FIBRES)

Items / *Fibres*	*Nylon 6*	*Polyester*	*Polyacrylonitrile*	*Modacryl*
Tensile strength g/d Dry	4.7-6.7	4.7-6.0	2.5-4.5	2.5-4.5
Wet	3.9-5.7	4.7-6.0	2.0-4.5	2.0-4.5
Dry and wet strength %	83-90	100	80-100	80-100
Loop strength g/d	7.0-11.0	6.8-10.0	2.4-5.5	2.4-5.5
Knot strength g/d	3.7-5.5	4.0-5.0	2.0-3.5	2.0-3.5
Elongation % Dry	38-50	35-50	27-48	27-48
Wet	40-53	35-50	27-48	27-48
Elastic recovery (at 3 % elongation) %	95-100	90-95	90-95	90-95
Apparent Young's modulus kg/mm	80-250	310-620	260-650	260-650
Specific gravity	1.14	1.38	1.14-1.18	1.26-1.37
Water content 20°C 65 % RH	3.5-5.0	0.4-0.5	1.2-2.0	0.5-0.8
Heat effect: Softening point	180°C	238-240°C	190-240°C	150°C
Melting point	215-220°C	255-260°C	Not clear	210-240°C
Weatherability	Strength lowers, turns yellow	Almost no lowering of strength	No lowering of strength	No lowering of strength
Effect of acid	Soluble in mineral acid	Strong resistance	Strong resistance	Strong resistance
Effect of chemicals	Strong resistance	Strong resistance	Strong resistance	Good resistance
Dyeability	Dispersible acid	Dispersible, high temperature or carrier of naphthol vat dyes	Dispersible, basic, acid	Dispersible, basic, acid

TABLE 7. PROPERTIES OF VARIOUS ACRYLIC FIBRES

	Trade name				
	Orlon (staple and tow)	*Acrilan (staple)*	*Zefran (staple)*	*Creslan (staple and tow)*	*Cashmilon (staple and tow)*
Breaking tenacity (gpd)					
Std.	2.2-2.6	2.0-2.7	3.3-3.7	2.4-2.9	3.1-.3.3
Wet	1.8-2.1	80%	2.9-3.3	3.3	2.8
Std. loop	1.8-2.1			2.6-2.3	3.0
Breaking Elongation (%)					
Std.	20-28	36-40	30-38	42-56	30-38
Wet	26-34	44-40	30-35	32	31-41
Average stiffness (gpd)	10	7	10.5	4.3-6.9	10.7
Average toughness (gpd)	0.40	0.46	0.50	0.57-0.60	0.54
Specific gravity	1.16	1.17	1.18	1.18	1.17
Effect of heat	Sticks at 455°F	5 % shrinkage at 487°F	Sticks at 490°F	Sticks at 397 to 460°F	Sticks at 400-460°F
Effect of acids and alkalis	Good to excellent resistance to mineral acids. Fair to good resistance to weak alkalis and to strong alkalis of room temperature	Good to excellent resistance to mineral acids. Fair to good resistance to weak alkalis; moderate resistance to strong, acid solutions	Excellent resistance to acids. Fair resistance to alkalis; resistance to weak solutions	Generally good resistance to mineral acids and weak alkalis	Good to excellent resistance to mineral acids. Fair to good resistance to weak alkalis and to strong alkalis of room temperature

TABLE 7 (*continued*)

	Trade name *Orlon* (*staple and tow*)	*Acrilan* (*staple*)	*Zefran* (*staple*)	*Creslan* (*staple and tow*)	*Cashmilon* (*staple and tow*)
Effect of bleaches and solvents	Can be bleached with hypochlorite peroxide and other agents. Not harmed by common solvents	Good resistance to bleaches and common solvents	Good resistance to bleaches and common solvents	Unaffected by dry cleaning solvents	Good resistance to bleaches and common solvents
Dyes used	Cationic, disperse acid (Type 44), and selected vats and naphthols	Disperse, basic, neutral, premetalized, acid, chrome, and neutral	Wide range of colours with vat, naphthol, sulfur, after-treated direct, and neutral premetalized	Type 58 has excellent affinity for premetalized, chrome, direct, acid, disperse and basic dyes. Type 61 has affinity for basic and disperse dyes — not receptive to acid dyes	Cationic, disperse, acid and various dyes
Resistance to mildew, aging sunlight, abrasion	Excellent resistance to mildew and aging. Good resistance to sunlight and abrasion	Not attacked by mildew. (Material on the fibre may be attacked.	Not attacked by mildew. Good resistance to aging, sunlight, and abrasion	Excellent resistance to mildew, aging, sunlight, and abrasion	Not attacked by mildew. Good resistance to aging, sunlight and abrasion

Of these, we give here an outline of the bulk yarn process using Turbo stapler. Figure VIII shows the function of Turbo stapler diagrammatically.

Ordinary tow of 400,000-500,000 denier are arrayed thinly with the component filaments placed parallel to each other and after tension is made uniform, it is heated and stretched by 20-50 per cent while passing through the tow hot plates at the same time. The temperature of the hot plates is normally 100-190 °C. Immediately after coming out the heating section, the stretched tow is cooled down suddenly and temporarily set in the stretched state. This tow is sent to the stretch-break section comprising front rolls, middle rolls and breaker bars to be stretch-broken. This stretch-broken tow or sliver is then crimped by the crimper of stuffing box type. Of the slivers thus made, some are introduced into Turbo Fibre Setter to be heat-shrinked by steam of 100-120 °C.

Then, the unshrinked sliver and the shrinked sliver are mixed normally at the ratio of 4:3 to 3:2 by Attenuator. Thereafter, yarn is made by ordinary spinning process.

When the yarn made through the above processes is heated by hot water or steam as it is or after it is made into

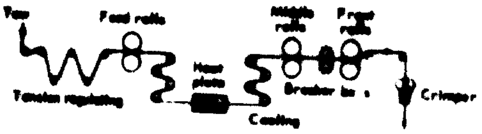


Figure VIII. Turbo stapler schematic

TABLE 8. END-USES OF ACRYLIC FIBRE IN JAPAN (1963)

For	*Quantity (ton)*	*Per cent*
Underwear (knit)	6,000	17.6
Sweaters (knit)	5,500	16.2
Jersey (knit)	7,000	20.6
Bedding	3,500	10.3
Woven fabrics	4,000	11.8
Export (staple fibre and yarn)	5,500	16.2
Others	2,500	7.3
TOTAL	34,000	100.0

TABLE 9. END-USES OF ACRYLIC FIBRE IN THE UNITED STATES (1963)

For	*Quantity (ton)*	*Per cent*
Sweaters (knit)	25,000	30.0
Pile fabrics	14,000	16.8
(Apparels)	(11,300)	(13.6)
(Scatter rugs)	(2,700)	(3.2)
Carpets	13,300	16.2
Blankets	6,300	7.6
Other knit goods	15,000	18.1
Other woven fabrics	8,600	10.3
TOTAL	82,300	100.0

knit goods, high bulk yarn or high bulk knit goods are obtained.

C. END-USES OF ACRYLIC FIBRE

The end-uses of acrylic fibre in Japan and the United States in 1963 are estimated in tables 8 and 9. It is clear from these figures that this fibre is mostly used in making knitted goods.

Acrylic fibres have no rivals in points of texture, softness, lightness and beauty, so that they are suited for applications requiring such properties. At present, almost all acrylic fibres are used as spun yarn and their main application is for bulk processed knit products such as sweaters, jerseys and underwear. They have other properties such as pleat retention and quick drying, so that they are mixed with wool, cotton and viscose rayon to improve their properties, and put to such uses as men's suiting, ladies' suiting and underwear. Acrylic staple fibre can be spun very smoothly by all spinning processes including wool spinning, both worsted and woollen, synthetic fibre spinning and cotton spinning. This is an advantage which cannot be seen in natural fibres and any other synthetic fibres. Especially, due to their soft feeling, they are most suitable for blankets, piles and man-made fur. They are also used as carpets and quilt wadding. Further, their resistance to chemicals and weatherability lend themselves to application such as tent-making and industrial material such as filtering cloth.

9. EXPERIENCES ACQUIRED DURING A STUDY FOR AN ACRYLONITRILE PLANT

Mario Galán-Gómez, President, Empresa Colombiana de Petróleos (Ecopetrol), Colombia

Colombia has one of the most developed textile industries in Latin America. Since the turn of the century this industry has undergone phenomenal growth, notwithstanding its traditional reliance on imported raw materials, such as wool and cotton. In fact, it was not until 1957 that Colombia, following an extensive cotton-development programme, became not only self-sufficient as a producer of this fibre but actually had small surpluses available for export. Wool, however, is still largely imported from abroad. The production of synthetic fibres began after the Second World War and developed appreciably, aided by a liberal import policy.

In 1963, coinciding with the start of ammonia production on the part of two private companies and the announcement by Empresa Colombiana de Petróleos (Ecopetrol) to the effect that the expansion of the Barrancabermeja refinery will include facilities for the production of ethylene and propylene, the idea was advanced of manufacturing acrylic fibres by direct synthesis from ammonia and propylene. Various private and semi-governmental entities joined Ecopetrol in exploratory talks designed to advance this project. To this end, different foreign organizations of recognized competence in this field were commissioned in 1963 to prepare market research and economic feasibility studies, which led to the following conclusions:

(*a*) It is estimated that by 1970 there will be in Colombia a market for some 4 million lbs. of acrylic fibres, provided that the fibre is priced competitively with wool.

(*b*) The potential Latin American market for acrylic fibre is estimated at 26 million lbs. by 1970. By that time, Argentina, Mexico and Brazil will unquestionably possess the capacity to produce acrylic fibres, so that there can be no expectation of Colombia capturing the entire Latin American market.

(*c*) If Colombia is to export a minimum of 5 million lbs. of the fibre in 1970, it will be indispensable for the members of ALALC (the Latin American Free Trade Association) to reduce their tariff on acrylic fibre to a maximum of 10 per cent which is the current rate of duty assessed by Colombia on wool imports. Similarly, the association members would have to introduce a common ad valorem duty of not less than 50 per cent as a barrier against possible dumping on the part of industrialized countries.

(*d*) The Latin American market for acrylonitrile destined for the production of fibre and plastics will be of the order of 30 million lbs. With suitable customs protection, Colombia would be in a position to capture a share in this market.

In the next few years, the price of acrylonitrile in international markets is expected to drop to $0.10 or $0.13 per lb. due to production stemming from large-size plants in major industrial countries. Under the circumstances, it is estimated that even with tariff protection, it would take a minimum capacity of 15 million lbs. for the plant to operate economically.

On the findings of these studies, Ecopetrol and the other sponsoring organizations have reached the conclusion that an acrylonitrile facility should not be established until such time as satisfactory arrangements have been finalized with the other members of ALALC for the interchange of this product.

Nevertheless, it is deemed convenient to set up a plant for the manufacture of acrylic fibre from imported acrylonitrile, with a yearly capacity of 4 million lbs. of fibre.

In conclusion, Colombia expects to take all measures necessary to ensure that at the forthcoming ALALC negotiations the Colombian Government obtain suitable tariff reductions and the inclusion of acrylonitrile in the "common list". The inclusion of acrylonitrile in the common list does not automatically ensure a gradual tariff reduction; rather, at the time of the forthcoming negotiations of national lists, Colombia will have to prevail upon the other ALALC members to reduce their tariffs on fibres and acrylonitrile to the levels of Colombian import duties on wood, or about 10 per cent.

Provided that Colombia is successful in these ALALC talks and that the indicated conditions are fulfilled, it is virtually certain that an acrylonitrile plant will be set up by 1970 with a capacity of 15 million lbs., since the country will be assured of adequate propylene and ammonia supplies at prices competitive in international markets. In this context, Colombia is very much interested in the opinion of Conference delegates and participants concerning the economic feasibility of producing acrylonitrile in plants with an annual capacity below 15 million lbs., and would welcome information and suggestions from countries which have evaluated comparable projects.

At the ALALC negotiations, both the Government of Colombia and Ecopetrol will use their best efforts to achieve a successful conclusion of their project in Colombia under conditions affording sufficient assurance of an export market within the Latin American Free Trade Area.

E. Synthetic rubbers

INTRODUCTORY SUMMARY

This introduction provides a background to, and notes some of the conclusions of, the papers on synthetic rubber which form this chapter and which were given at the Petrochemicals Conference under the same title.

Until the beginning of the Second World War, natural rubber had been predominantly in general use throughout the world. However, since then and especially in the post-war period, synthetic rubber has been gaining an increasing share of the total rubber market. This is due, *inter alia*, to improvement in the quality of styrene-butadiene rubber (SBR), cost reduction, as well as the production of various types of rubber other than SBR with specialized properties. The production of synthetic rubber has grown at a faster rate (11 per cent *per annum* since 1950) than that of natural rubber (about 1 per cent). By 1962, the share of synthetic in total rubber production exceeded that of natural rubber.

Synthetic rubbers include styrene, butadiene, chloroprene, butyl, nitrile, polysulphide, silicone, chlorosulphonated polyethylene, as well as the stereo-regular rubbers that include polybutadiene, polyisoprene, and ethylene-propylene rubbers.

SBR accounts for about 70 per cent of total synthetics. It is a versatile rubber, the oil-extended varieties of which are the cheapest rubber available. Oil-extended SBR is satisfactory for use in passenger car tyres. Butyl, chloroprene, and nitrile rubbers have established markets as speciality rubbers. Butyl rubber is relatively impermeable to air and has good resistance to heat and oxygen. Virtually all inner tubes in the United States and Europe are made from butyl rubber.

The high resilience and low heat build-up of the vulcanized polyisoprene rubber are among the qualities which make it a good substitute for natural rubber. In addition, it is easy to process, and it can be used in the manufacture of conventional rubber processing equipment.

Polybutadiene rubber is superior to SBR in that it has improved wear, heat build-up and groove crack resistance when used in treads of passenger-car tyres. The disadvantages are low resistance to chipping and difficulty in processing. In order to overcome these difficulties polybutadiene is being used in 1:1 blends with natural rubber in heavy-duty tyres, and in 1:3 blends with SBR in passenger-car tyres.

The properties of ethylene-propylene copolymers (EPR) appear at first sight to be similar to those of SBR but, in addition, EPR has a remarkable resistance to aging and ozone attack. It has been known that EPR is difficult to vulcanize. However, by including an unsaturated diene, vulcanizing could be carried out in the conventional way using sulphur.

The Chapter notes that investment requirement (grass roots plant) for the manufacture of SBR may be of the order of magnitude of $270 per annual ton capacity, assuming a 60,000 ton/year plant. This includes process units, utilities generation, tankage and laboratories. Additional investment is required when an integrated SBR plant is conceived to include production of butadiene and styrene monomers.

Further, the investment requirement for a stereo-specific polymerization plant has also been roughly estimated—at $400/ton of annual capacity for a plant size of 20,000 tons/year. This investment also includes start-up expenses, laboratories, initial catalyst and chemical charges and paid-up royalties. The high capital charges have been estimated at about 50 per cent of manufacturing cost in contrast to 10 per cent for labour.

1. THE PETROCHEMICAL INDUSTRIES : SYNTHETIC RUBBERS

Prepared for the United Nations Centre for Industrial Development by l'Institut français du pétrole, France

The demand for total new rubber has been increasing very rapidly while there is not and has not been the slightest possibility of increasing the production of natural rubber in time to meet such increased demand. For this reason, the balance of world rubber requirements must necessarily be supplied by synthetics.

However, as styrene-butadiene rubber (SBR) is still not available as a satisfactory substitute for natural rubber in all of its uses, the newer stereo-regular rubbers like polybutadiene (PB), polyisoprene (Pi) and ethylene-propylene copolymers (EPR) will find and maintain a large place among the general purpose rubbers of the future.

Styrene-butadiene rubber

SBR production predominates in the United States and in Europe; however, except for certain countries which have in the past been big importers of SBR and which can foresee sufficient justification to construct local plants, it is unlikely that new SBR plants will be built in western countries. In fact, because of the SBR technical limitations and over-capacity, producers are showing increased interest in the possibility of converting existing SBR plants for use in the making of other synthetics. Some plants have already been converted and are now producing stereo-regular polybutadiene.

Elements of operating cost for a 60,000 tons/year SBR plant are given below :

Investment (grass roots plant)	
Including process units, utilities generation, tankage and laboratories	MM $ 22
Raw material consumption	
	Tons/year
Butadiene	37,800
Styrene	11,800
Oils	9,000
Utilities requirements	
Electricity (10^6 kWh/year)	186
Steam (10^3 ton/year)	20,000
Cooling water (10^3 M^3/year)	1,980
Demineralized water (10^3 M^3/year)	720
Chemicals and catalyst ($/year)	3,000,000
Labour	
Men/shift	15
Men/day	7

Stereo-regular rubbers

One of the most important points about the newer synthetic rubbers is that they can be substituted for natural rubber in most of those applications where SBR cannot serve as a suitable substitute. Their addition to the list of available raw elastomers now makes it possible to replace natural rubber in nearly all its uses and still obtain products of adequate quality.

POLYISOPRENE (PI)

Extensive compounding studies have shown that polyisoprene rubber (PIR) gives vulcanizates very similar to those of natural rubber. The vulcanizates have high resilience and low heat build-up.

Moreover, it is a synthetic material of good processability : also, it can be used with but minor modification in formulation and recipe in conventional rubber processing equipment. PI has finally the potential of being of excellent uniformity and it is finding applications in areas previously held by natural rubber, particularly where good mould flow, excellent colour and purity of polymer are of importance. Oil extended polyisoprene is a good prospect on economic grounds, while latexes may well prove to be one of the most important outlets for polyisoprene.

This synthetic rubber whose qualities equal those of natural rubber is expected to go into mass production during the next few years. For example, by 1965, six times more PI will be produced in the USSR and the socialist countries of Eastern Europe than polybutadiene.

POLYBUTADIENE (PB)

Great confidence has been expressed in the future for PB, and proof of this lies in the large number of plants that are planned all over the world. In the United States of America, there is great interest in the commercial production of this new elastomer.

Compared with 100 per cent SBR, PB has better wear, heat build-up and groove crack resistance. The only falling off is noticed in resistance to chipping. This is only a problem in off-the-road tires and may well be improved as the knowledge of the compounding of PB advances. Also, one of the problems presented by PB rubbers has been their processing difficulty. One expedient which has been used to avoid these difficulties is to use these materials as extenders for natural rubber and SBR. As a result, PB is being used in 50/50 blends with natural rubber in heavy duty tires and in 25/75 blends with SBR passenger tires.

ETHYLENE-PROPYLENE COPOLYMERS (EPR) AND PROPYLENE-DIENE TERPOLYMERS (EPT)

The properties of EPR appear at first sight to be similar to those of SBR, but in addition EPR has a remarkable resistance to aging and ozone attack. In the latter respect, it may well be a competitor for butyl rubber.

It has been known for some time that EPR is difficult to vulcanize. However, by including an unsaturated diene, vulcanizing could be carried out in the conventional way using sulfur. The low monomer cost would be a great advantage and could make the production of this terpolymer attractive.

CHOICE OF POLYMER

From an economic standpoint the choice among the different rubbers for any particular application now depends to a much greater degree on price and cost considerations only.

This should not be taken to mean that identical results are always obtained regardless of whether natural rubber or a synthetic substitute is employed. There are always certain differences, sometimes in favour of the synthetic rubber.

For example, PB shows up to particular advantage in passenger car tire treads; PI is the best known to use in tire side walls and in footwear; PI and natural rubber are required to obtain the best results in aircraft tires, cut thread, and heavy duty tires.

None of these advantages of PB or PI are sufficient to command a significant premium if the superiority of one or other rubber is not less then 1 US cent per pound.[1]

In these circumstances, the choice of any particular rubber will obviously depend on considerations of strict competitiveness and of economic considerations resulting from raw material availability, monomer synthesis cost, and processing difficulties.

ECONOMICS OF STEREO-REGULAR RUBBERS MANUFACTURE

Monomers manufacture

Economics for styrene, butadiene, ethylene and propylene have been studied elsewhere, the economics of isoprene production, based respectively on propylene feed-stock and isobutylene-formaldehyde feed-stocks will be studied below.

Isoprene manufacture

Elements of operating cost for a 20,000 tons/year isoprene plant starting from propylene and isobutylene respectively are given in table 1.

Manufacturing cost and derived selling prices for the two routes are presented in table 2.

Stereospecific polymerization

Polymerization manufacturing cost is quite similar for the three stereo-regular rubbers: PB, PI and EPT. Table 3 presents the elements of the operating cost for a 20,000 tons/year plant starting from butadiene or isoprene or ethylene and propylene.

The manufacturing cost for such a plant, including profits and taxes, is given in table 4. Polyisoprene and polybutadiene selling prices may be estimated as follows:

Monomer selling price (isoprene or butadiene)	\$220/ton or ¢/lb 10
Polymerisation manufacturing cost including profits and taxes at 50 per cent	\$265/ton or ¢/lb 12
Polymer selling prices	\$485/ton or ¢/lb 22

TABLE 1. 20,000 TONS/YEAR ISOPRENE PRODUCTION BASED RESPECTIVELY ON ISOBUTYLENE AND PROPYLENE FEED-STOCKS

Elements of operating cost

	Isobutylene route	*Propylene route*
Investment in million \$	5.6	8.6
Raw materials balance (tons/year)		
Isobutylene in C_4 cut	21,800	Propylene 31,000
Methanol [a]	19,800	
By-products residols [b]	(9,200)	
Utilities Requirements		
Electricity (10^6 kWh/year) . . .	6,350	\$135,000/year [c]
Steam (tons/year)	208,000	
Cooling water (10^3 M^3/year) . .	2,780	
Process water (M^3/year)	64,000	
Fuel produced (10^6 kcal/year). .	(1,600)	
Catalyst and chemicals (\$/year) . .	150,000	90,000
Labour (men/shift)	7	7

[a] Including formaldehyde production starting from methanol.

[b] Used in phenolic and polyesters resins.

[c] Including electricity, cooling water and fuel requirements and taking into account fuel by-product and valorized at \$1.5/10^6 kcal

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[1] SOURCE: Dr. Cake, Vice President of the US Rubber Coy, Conférence internationale sur le caoutchouc (14-18 May 1962) Paris (France).

TABLE 2. 20,000 TONS/YEAR ISOPRENE PRODUCTION BASED RESPECTIVELY ON ISOBUTYLENE AND PROPYLENE FEED-STOCKS

Manufacturing cost [a] and selling price

	Unit cost ($)	Isobutylene route		Propylene route	
		Annual quantity	Annual cost (10^3 $/year)	Annual quantity	Annual cost (10^3 $/year)
Variable charge					
Raw materials					
Isobutylene (tons)	24	21,800	520		
Methanol (tons)	50	19,800	990		
Propylene (tons)	50			31,000	1,550
By-products residols (tons)	10	(9,200)	(− 921)		
Utilities					
Electricity (10^3 kWh)	10	6,350	63		
Steam (tons)	1.6	208,000	333		
Cooling water (10^3M^3)	6	2,700	17		
Process water (M^3)	0.2	64,000	13		
Fuel produced (10^6kcal)	1.5	(1,600)	(− 2)		
Catalyst and chemicals			150		90
Labour					
Salaries and wages (men/year)	5,000	28	140	28	140
Supervision at 25 % of salaries and wages			35		35
TOTAL VARIABLE CHARGES			2,167		1,950
Fixed charges [b]			1,290		1,970
MANUFACTURING COST			3,457		3,920
Selling price					
Net cash flow at 20 % of total investment			1,120		1,720
Depreciation provides			700		1,070
Net income after taxes			420		650
Net income before taxes at 50 %			840		1,300
Manufacturing cost			3,457		3,920
Isoprene sales			4,297		5,220
Isoprene selling price $/ton			215 or ¢/lb 9.8		260 or ¢/lb 11.8

[a] Royalties not included.

[b] Including : depreciation at 12.5 per cent of total investment, interest at 3.5 per cent, maintenance at 4 per cent, general plant overhead at 2 per cent, taxes and insurance at 1 per cent.

TABLE 3. 20,000 TONS/YEAR STEREOSPECIFIC POLYMERIZATION PLANT

Elements of operating cost

Investment (MM $) 8

Including : start-up expenses, laboratories, initial catalyst and chemicals charges and paid-up royalties

Utilities requirements	
Electricity (10^3 kWh/year)	25,300
Steam (Tons/year)	136,000
Cooling water (10^3M^3/year)	7,300
Process water (M^3/year)	450,000
Nitrogen (10^3M^3)	8,600
Chemicals and catalyst ($) consumption	1,260,000
Labour (men/shift)	20

TABLE 4. 20,000 TONS/YEAR STEREOSPECIFIC POLYMERIZATION PLANT

Manufacturing cost, including profits and taxes

Unit	*Unit cost ($)*	*Annual quantity*	*Annual cost (10^3 $/year)*
Variable charges			
Utilities			
Electricity (10^3 kWh)	10	25,300	253
Steam (tons)	1.6	136,000	218
Cooling water (10^3M^3)	6	7,300	44
Process water (M^3)	0.2	450,000	90
Nitrogen (10^3M^3)	2	8,600	17
Chemicals and catalyst			1,260
Labour			
Salaries and wages (men/shift)	5,000	80	400
Supervision at 25 per cent of salaries and wages			100
TOTAL VARIABLE CHARGES			2,402
Fixed charges [a]			1,840
MANUFACTURING COST			4,242
Net cash flow at 20 per cent of total investment			1,600
Depreciation provides			1,000
Net income after taxes			600
Net income before taxes at 50 per cent			1,200
Manufacturing cost			4,242
Manufacturing cost including profits after taxes at 50 per cent			5,442
Manufacturing cost [b] including profits ($/ton)			272 (or ¢/lb) 12.3

[a] See table 2 for distribution.

[b] Manufacturing cost for a 40,000 tons/year plant is estimated at 11 ¢/lb.

2. THE NEWER SYNTHETIC RUBBERS

Tuhin K. Roy, Scientific Design Company, Inc., New York, USA

Thirty years ago automobile tires and tubes were all made of natural rubber, and chloroprene rubber was the only commercially available synthetic material. Today, the planners of a developing country, having decided to build a synthetic rubber facility have to choose between a dozen or more synthetics. Of the many commercially available synthetic rubber polymers, mention may be made of the following types: styrene-butadiene chloroprene, butyl, nitrile, polysulfide, silicone, chlorosulfonated polyethylene, cis-polybutadiene, cis-polyisoprene, ethylene propylene terpolymer, poly-acrylates, and urethane elastomers. These synthetics now account for more than 55 per cent of new rubber consumption in the world and their share is increasing steadily. The current consumption pattern, and the prevailing price in the United States of America, of the synthetic rubbers mentioned above, are given in table 1.

In almost all the developing countries, pneumatic tires and tubes are the largest consumers of rubber. In India, for example, about two-thirds of the total new rubber consumed in 1963 went into tires and tubes for automobiles and bicycles. Again, of the total new rubber consumed for tires in India, about two-thirds was required for the manufacture of large truck and bus tires. Therefore, any planning effort for a large synthetic rubber plant in India should take into account the requirement for giant on-the-road tires. This situation holds for most of the developing countries.

Various rubber-carbon black compounds are used in the different parts of an automobile tire to obtain the optimum result. Tread compounds are formulated to obtain high abrasion resistance, while sidewall compounds must have resistance to scuffing, weather, flex, and age cracking. On the other hand, the rubber compounds used in the carcass or casing of the tire must have good flow properties, good tack between the tire fabric and vulcanizate, and good resilience. Camel-back compounds used for retreading should not only have high abrasion resistance, but they must also have good storage property and high cure rate.

SBR AND OTHER CONVENTIONAL RUBBERS

Of the estimated world production in 1964 of about 2.7 million metric tons of synthetic rubber, styrene-butadiene rubber (SBR), will account for about 70 per cent. Brazil and India – the only two producers of synthetic rubber among the developing nations, except mainland China – selected SBR for their first synthetic rubber plants. SBR is a versatile rubber, the oil-extended varieties of which are the cheapest rubber available. Oil-extended SBR is quite satisfactory for use in passenger car tires. It is also used widely for footwear, conveyor belts, cable insulation, hose, and foam products.

At the present time, most United States tire manufacturers use either all SBR or SBR blended with a small proportion of cis-polybutadiene for passenger car tires. The main difficulty with SBR tire compounds is high heat generation under dynamic conditions. These compounds also have poorer hot-tear resistance than natural

TABLE 1. PRICE AND CONSUMPTION (IN THE UNITED STATES OF AMERICA) OF PRINCIPAL TYPES OF SYNTHETIC RUBBER

Type of rubber	*Classification*	*Typical list price ($/lb)*	*Estimated consumption (long tons)*	
			1963	*1964*
SBR	Cold polymer unextended	0.23	960,000	920,000
Butyl rubber	Unsaturation (1.5-2%), staining	0.25	70,000	70,000
Chloroprene rubber	Sulphur modified, staining	0.41	90,000	92,000
Nitrile rubber	Acrylonitrile content, 28-34 %, non staining	0.50	38,000	40,000
Urethane rubber		1.50	2,500	3,500
Silicone rubber	Gum (not compounded)	3.68	4,200	6 500
Polyacrylate rubber		1.34	1,500	3,000
Polybutadiene	90-95% cis-content, non-staining	0.25	92,000	130,000
Ethylene propylene rubber	EPT – diene, 3 wt. %	0.30	9,000	45,000
Polyisoprene	95-96 % cis- content, staining	0.25	20,000	25,000
Polysulphide	General-purpose solid polymer	0.74	5,000	6,000

rubber compounds. With the increase in tire thickness and size, releasing tires from moulds during manufacture and dissipation of heat in the running of the tires become difficult problems. For that reason, virtually 100 per cent natural rubber has been used universally in the production of on-the-road heavy-duty tires.

In the developing countries, where the greatest use of rubber is for large bus and truck tires, SBR is not a suitable substitute for natural rubber. Even in industrially advanced countries, SBR appears to have reached its peak. During 1964, the consumption of SBR is expected to decrease in the United States of America by about 40,000 tons to make way for the newer synthetic elastomers.

Of the conventional synthetic rubbers, butyl, chloroprene and nitrile rubbers have established markets as speciality rubbers, and their world consumption is still increasing. Butyl rubber, a copolymer of a small percentage of isoprene with isobutylene (and sometimes dicyclopentadiene), is relatively impermeable to air and has good resistance to heat and oxygen. Virtually all inner tubes in the United States and Europe are made from butyl rubber. However, butyl rubber has failed to command a sizable proportion of the tire market in the United States because of excessive tread wear. Butyl rubber requirements in the developing countries can be judged, roughly, from the current United States consumption of about 40,000 short tons of butyl rubber for inner tubes, out of a total consumption of 1.12 million tons of natural and synthetic rubbers used for tires and tire products.

Chloroprene rubber, or neoprene, has an established position as a speciality rubber because of its excellent resistance to oils, chemicals, sunlight and weather. A polymer of 2-chloro-1,3-butadiene, chloroprene rubber is expected to remain a speciality rubber because of its higher price. The high cost of this rubber is due to the relatively large capital investment required, and also to the relatively high cost of raw materials and catalysts. The major use of chloroprene rubber is in the sheathing of a wide variety of cables, where advantage is taken of its flame and weathering resistance. Considerable advance has been made in recent years in improving the storage property of chloroprene rubber and in developing new types for special applications. However, the market for these special types of chloroprene rubber is likely to be small in most of the developing countries.

Nitrile rubber, a copolymer of acrylonitrile and butadiene, also has a small but established position as a speciality rubber because of its resistance to solvents including aromatics, and fats and oils. This rubber processes well on conventional rubber equipment. The greatest use of nitrile rubber is for oil seals, gaskets, and O-rings in the automobile and aircraft industries. Another common use of nitrile rubber is for printers' rollers. Unit costs of this rubber are still high because of the higher cost of acrylonitrile and, therefore, it cannot be considered as a general-purpose rubber suitable for a developing country.

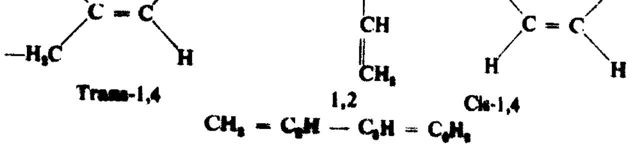
Similar considerations apply to other speciality rubbers such as polysulfide, silicone, polyacrylate, and chlorosulfonated polyethylene rubbers. These rubbers have a small but well-established market in the United States. For example silicone rubbers are resistant to extremes of temperature and are physiologically inert. These properties make silicone rubbers extremely useful in the aircraft industry, as well as for closures and seals used by manufacturers of food and pharmaceutical products. However, the demand for silicone gums, at the current market price of $3.50-4.00/lb. will be quite small even in a large country such as India or the United Arab Republic.

STEREO-REGULAR RUBBERS

During the last five years, three groups of stereo-regular synthetic rubbers have been developed and have already shown great potential for rapid growth at the expense of natural rubber and SBR. These are: cis-polybutadiene, cis-polyisoprene, and ethylene-propylene rubbers. It is estimated that the use of the first two cis-polymers in the Western world will climb to approximately 235,000 tons in 1964 – an increase of more than 50 per cent over 1963. In 1961, less than 2 per cent of the synthetic rubber consumed in the United States was polybutadiene and polyisoprene; this ratio increased to 5 per cent in 1962, and to 8.6 per cent in 1963. This year, the use of cis-polybutadiene and cis-polyisoprene will amount to approximately 11.5 per cent of the synthetic rubber consumption in the United States, while ethylene-propylene rubbers may be about 3 per cent. Within a few years, the stereo-regular rubbers are expected to account for 20-25 per cent of the synthetic rubber market in the United States, and the proportion may be even higher in some of the western European countries.

POLYBUTADIENE RUBBERS

Polymerization of butadiene has been studied by a number of workers for many years. The sodium polymer, Buna rubber, was studied extensively in Germany in 1927. It is primarily a product with 1,2-enchainment. Emulsion polymerization of butadiene results in a product where the trans-1,4 arrangement is the main structural feature. Lithium and organo-lithium compounds seem to be different from the other alkali metals and produce a polybutadiene with about 35 per cent cis-1,4 and 50 per cent trans-1,4 structure. Only after the introduction of the Ziegler-type catalyst (such as aluminum triethyl-titanium tetraiodide) was it possible to produce polybutadienes with more than 90 per cent cis-1,4 structures:



Trans-1,4 1,2 Cis-1,4

$$CH_2 = C_2H - C_3H = C_4H_2$$

TABLE 2. TYPICAL PROPERTIES OF SBR/POLYBUTADIENE VULCANIZATES [a]

Blends for tire treads of passenger cars

SBR 1712	137.5	103
Polybutadiene (budene 500)	—	25
ISAF black	68	64
Tensile strength (psi)	3,290	3,250
Elongation (%)	660	685
300 % modulus	1,100	1,000
Shore A hardness	62	62
Crescent tear strength (lb./inch)		
At 212°F	188	182
At 75°F	220	225
Goodyear ring abrasion (cc loss)	2.14	1.52
Rebound at 212°F (%)	70.1	70.7

[a] These compounds also contain conventional amounts of sulphur, zinc oxide, stearic acid, antioxidant, and accelerators.

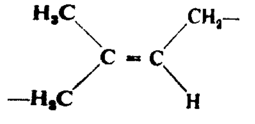
It was soon found that cis-1,4-polybutadiene rubber, when blended with SBR or natural rubber to the extent of 20-25 per cent, showed improved abrasion and crack resistance in tire treads. As a large quantity of butadiene monomer was already available in the United States, this finding triggered a very rapid growth of cis-polybutadiene production facilities there.

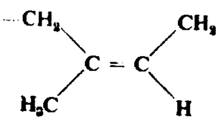
Cis-1,4-polybutadiene rubbers are characterized not only by high abrasion resistance, but also by good low-temperature properties, and good resistance to aging. Typical properties of cis-polybutadiene-SBR blends for tire treads of passenger cars, are shown in table 2. As polybutadiene by itself does not process well in conventional rubber mixing and curing equipment, it is always used in conjunction with SBR or natural rubber. Generally, cis-polybutadiene cannot be used effectively in blends beyond 50 per cent. Above the 50 per cent level, tread tearing and chipping becomes a problem. In a passenger-car tire, blending of polybutadiene with SBR above 50 per cent level may affect the ride quality and skid resistance of the tire. Most manufacturers of passenger-car tires find that blends of polybutadiene with SBR in the ratios of 20-25 per cent work best in the tread formulations.

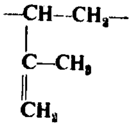
The major use of polybutadiene is in tire tread compounds. The potential market for this rubber in a country or region can be estimated, roughly, by assuming that about 25 per cent of rubber in all automobile tire treads can be cis-polybutadiene, and that tire tread constitutes about 60 per cent of the weight of the rubber in a tire. Thus, if 50 per cent of the new rubber consumed in a country goes into automobile tires, then not more than 8-10 per cent of the total new rubber market there can be assigned to cis-polybutadiene. Accordingly, the spectacular growth of cis-polybutadiene in the United States of America and Europe during the last three years does not necessarily mean that it will become a major tire rubber.

CIS-1,4-POLYISOPRENE

A great number of experiments were made, even in the nineteenth century, to see if high molecular weight polymers of isoprene could be produced which would duplicate the attractive properties of natural rubber. However, attempts to polymerize isoprene in emulsion with a persulphate initiation, as in the procedure for SBR manufacture, resulted in the trans-1,4-polymer as the main structural feature. Polymerization in bulk with benzoyl peroxide catalyst produced about 60 per cent trans-1,4 addition, 30 per cent cis-1,4 addition, and 5 per cent 3,4 addition. All these polymer products were different from natural rubber which is a highly stereospecific polymer, containing about 97-98 per cent cis-1,4-polyisoprene units.


Trans-1,4


Cis-1,4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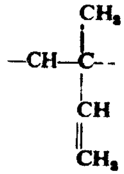
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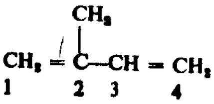


$$CH_2 = \overset{CH_3}{\overset{|}{C}} - CH = CH_2$$

Around 1956, cis-polyisoprene closely resembling natural rubber was obtained by polymerizing a solution of isoprene in solvent with either a lithium-based catalyst, or a Ziegler-type catalyst, such as aluminium trialkyl-titanium tetrachloride. Synthetic polyisoprene rubber became commercially available in 1961 when Shell Chemical Company put its first polyisoprene plant on stream. This was followed by Goodyear's Natsyn in 1962, cis-content of which is reported to be 95-96 per cent. Cis-content of Shell polyisoprene is reported to be 90-92 per cent.

Cis-polyisoprene rubber has excellent flow properties high resilience, low heat build-up, and high tensile strength. Table 3 shows a comparison of typical tire tread and carcass formulations with natural rubber and synthetic polyisoprene. (5) It can be seen that tensile strength, resiliency, and heat build-up properties of polyisoprene are comparable to those of natural rubber. These test results and reports of successful road tests indicate that stereoregular polyisoprene can replace natural rubber, either partly or wholly, in heavy-duty on-the-road tires.

TABLE 3. TYPICAL PROPERTIES OF POLYISOPRENE AND NATURAL RUBBER VULCANIZATES[a]

	Tire tread compound		*Carcass compound*	
Natural rubber (No. 1 smoked sheet)	100		100	—
Polyisoprene (natsyn 200)	—	100		100
HAF black	50	50		—
MPC black	—	—	30	30
Sulphur	2.25	2.25	3	3
Tensile strength (psi)	4,300	4,200	4,775	4,400
Elongation (%)	550	650	740	800
300 % modulus (psi)	1,800	1,300	675	475
Shore A hardness	68	67	55	54
Rebound at 212°F (%)	76.4	74.6	84.5	83.5
Heat build-up (°F) (Goodrich Flexometer)	54	54	29.0	30.5

[a] These compounds also contain conventional amounts of zinc oxide, stearic acid, antioxidants, and accelerator.

In the past, rubber bands, rubberized thread, and other miscellaneous rubber products requiring high gum tensile strength were dependent entirely on natural rubber because of the inherently poor gum strength of SBR and other conventional synthetic rubbers. Published test results indicate that polyisoprene is fully equivalent to natural rubber in such gum rubber formulations. While cis-polyisoprene is chemically identical with natural rubber and almost duplicates the compounded physical properties of natural rubber, it has the advantage of being cleaner and more uniform in quality than commercially available natural rubber. Synthetic polyisoprene bales can be directly charged to the mill or Banbury without size reduction or premastication, and usually require less mixing time than premasticated natural rubber.

ETHYLENE-PROPYLENE RUBBERS

The third group of stereo-regular rubbers which has attracted the attention of tire manufacturers during the past five years is ethylene propylene-rubbers. Ethylene-propylene copolymers (EPR) and ethylene-propylene-diene terpolymers (EPT) produced with Ziegler-type catalyst (4) differ markedly from stereo-regular polyisoprene or polybutadiene in that they cannot be blended with diene rubbers because of their high degree of saturation. They are cured by using a peroxide system in the cases of EPR, and higher levels of accelerators in sulphur-based curing systems, for EPT rubbers. The following discussion is limited to EPT rubber, as EPR is unlikely to break into the tire market because of the necessity for curing by peroxide.

EPT rubber contains 3-8 per cent of non-conjugated dienes such as dicyclopentadiene, 1,5-heptadiene or 1,4-hexadiene. These dienes form unsaturated side chains, which allow the polymer to be vulcanized with conventional sulphur cure. These dienes are relatively expensive, as is the solution-polymerization technique used, because of the high cost of the Ziegler-type catalyst. That is why the price of non-extended EPT is still high, although the major monomers, ethylene and propylene, are much cheaper than butadiene, styrene, or isoprene. However, EPT can be loaded with substantial amounts of carbon black and oil extenders.

TABLE 4. COMPARATIVE TEST DATA ON EPT AND PROPYLENE OXIDE RUBBER

	Natural rubber (No. 1 Smoked Sheet)	*EPT (Nordel 1040)*	*Propylene oxide rubber (Dynagen XP-139)*
Sulphur (phr)	2.5	1.5	0.8
Accelerator (phr)	0.5	2.0	0.6
Cure temperature (°F)	287	320	300
Tensile strength (psi)	4,150	2,800	2,675
Elongation (%)	530	430	580
300 % modulus (psi)	1,800	1,450	1,225
Shore A hardness	64	70	62
Tear strength (lb./inch)	500	110	350
Tear strength (lb./inch) at 212°F	275	65	215
Heat build-up (°F)	39	58	37
Rebound at 212°F (%)	77	68	76

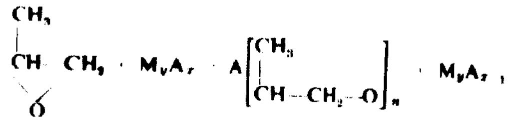
EPT rubber has shown outstanding weathering qualities and high resistance to ozone. However, it lacks adhesion and tack, and typical EPT-carbon tire compounds show lower tensile strength and tear resistance than natural rubber (see table 4). EPT rubber, therefore, cannot be considered as a replacement for natural rubber in heavy-duty truck tires. Its use, at least for the next three years, will be chiefly in the form of mechanical parts, weather-stripping, and body mounts for the automobile industry, in electrical cable sheathing, and household equipment. The market for such outlets is small in most of the developing nations.

PROPYLENE OXIDE AND POLYURETHANE ELASTOMERS

Polymerization of propylene oxide to low molecular weight polymers has been known for many years. These polymers require coupling with di- or poly-isocyanates to produce high molecular weight, rubber-like materials widely known as urethane foam or polyurethane rubber. Flexible urethane foam production has been increasing at a spectacular rate in the United States since this material was introduced in the cushioning market in 1954. The use of rigid and flexible urethane foam in the United States is expected to be well over 100,000 long tons in 1964.

Solid polyurethane elastomers combine high tensile strength with good resistance to oxygen, ozone and oil, and have good low temperature properties and high load-bearing capacity. Because of their high cost, however, the use of polyurethane rubbers has been restricted to engineering applications such as slow-speed sleeve bearings, diaphragms, and seals for ball-joint suspension and linkages. A small but fast-growing segment in this field is the manufacture of polyurethane elastic thread (spandex fibres), which is stronger than rubber thread and, unlike rubber, is oil-resistant and can be dyed to match nylon fabrics. Polyurethane rubbers will continue to be small-volume, speciality rubbers unless ways are found to reduce their manufacturing cost.

Polypropylene oxide rubber, made by copolymerization of propylene oxide and an unsaturated epoxide such as glycidyl acrylate or butadiene monoxide, represents something new in elastomer structure. Polymerization of propylene oxide to high molecular rubbers is generally carried out in a solvent using a co-ordination catalyst, such as ferric chloride :



Where,

M : metal atom or metal atom bonded to oxygen
A : Cl, H, R, OH, OR, — OM

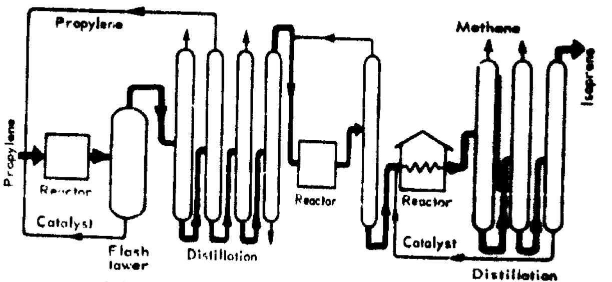
Unsaturated epoxides are added to incorporate some unsaturated groups along the polymer chain in order to produce a rubber that will vulcanize with conventional sulphur and accelerator systems.

Propylene oxide rubbers produced so far in developmental quantities have shown exceptional low-temperature flexibility, excellent dynamic properties, and good resistance to heat and ozone. (3) These properties are thought to be due to free rotation that occurs about the oxygen-carbon bond. Propylene oxide rubber bands easily on the mill and can be cured conventionally. In table 4, properties of typical compounds of propylene oxide and EPT rubber are compared with those of natural rubber. Each of the recipes contained 100 parts of polymer, 45 parts of ISAF black (intermediate super-abrasion furnace carbon black), 3 parts of zinc oxide, 1 part of stearic acid, and 1 part of antioxidant (nickel dibutyldithiocarbamate in the case of propylene oxide, and phenylbetanaphthylamine in the other three compounds), and was cured for thirty minutes. Sulphur and accelerators and curing temperatures used were chosen to give the best properties in each case. The results show that the tensile properties of both EPT and propylene oxide are much lower than those of natural rubber. Tear strength and heat build-up properties of propylene oxide compounds are much better than those of EPT, and approach those of natural rubber. This combination of properties in propylene oxide rubber, together with the possibility that propylene oxide will soon be produced by direct oxidation of propylene, leads one to predict a promising future for this newly developed rubber. However, it will be several years before utilization of propylene oxide rubber in tire compounding is tested and proven. Until then, therefore, propylene oxide rubber must be regarded as one of the speciality rubbers.

The intermediates required for the major synthetic rubbers discussed above are butadiene, styrene, isoprene, acrylonitrile, chloroprene, and propylene oxide. Olefins such as ethylene, propylene, and isobutylene are also used directly for EPT and butyl rubber production. Butadiene is often produced by catalytic dehydrogenation of n-butane or n-butylenes in the C_4 cuts available from a petroleum refinery. It is also produced as a by-product of ethylene manufacture by steam cracking of naphtha. Of the several methods proposed for the manufactur of isoprene, (1,2) two routes have been used commercially propylene dimerization (Goodyear-SD) and dehydrogenation of isopentane (Houdry or Shell). Of the other proposed routes, mention should be made of the isobutylene-formaldehyde and acetone-acetylene routes. Neither of these latter two proposed routes presently appears to have the potential of producing isoprene at a price which makes it competitive with butadiene.

The dehydrogenation process of producing isoprene from isopentane or isopentene is similar to the well-known dehydrogenation processes for butadiene production from n-butane or n-butene. Butane or butene, being structurally simpler, can be dehydrogenated to butadiene more selectively than isopentane or isopentene can to isoprene. Also, n-butane is more plentiful than isopentane. The isopentane route, therefore, is likely to produce isoprene at a somewhat higher cost than the n-butane-butene route for butadiene. In the Goodyear-SD process (see figure 1), propylene is dimerized to 2-methyl-1-pentene in the presence of tripropyl aluminum catalyst; 2-methyl-1-pentene is isomerized to 2-methyl-2-pentene, which is then cracked in the presence of a vapour-phase catalyst to obtain isoprene and methane. This crude mixture is then fractionated to yield a monomer of exceptionally high purity.

Goodyear-SD's three-step route to isoprene



1. Dimerize
Two propylene molecules are combined to make one molecule of hexylene

2. Isomerize
The double linkage between carbon atoms is shifted

3. Pyrolize
One carbon atom is cracked off to form methane and isoprene

Figure 1

Production cost estimates based on the current world propylene price of 1.5-2.5¢/lb show that isoprene can be produced from propylene to compete with butadiene, which is a well-established chemical currently selling at 11.0-13.5¢/lb in the United States of America and Western Europe. The ethylene-propylene-diene combination for EPT rubber is likely to cost 3-4¢/lb less than either butadiene or isoprene, but this is partially offset at least by higher accelerator cost. Propylene oxide at the current price of 14-17¢/lb, and acrylonitrile at 17-20¢/lb, are more expensive monomers. In view of the higher monomer cost and limited market, speciality rubbers such as nitrile polyacrylate, chloroprene, urethane and propylene oxide can be eliminated from immediate consideration by most of the developing countries.

The solution-polymerization technique for cis-polybutadiene, using a Ziegler-type catalyst, is very similar to the polymerization technique used for cis-polyisoprene or EPT rubbers. In a commercial stereo-regular plant, say, of 30,000 tons/yr capacity, the total capital investment for the polymerization plant may be of the order of $200 ton/yr of capacity, and the net mill cost of polymerization of the order of 4-5¢/lb. Thus, in the case of polybutadiene and polyisoprene, the monomer cost and the cost of polymerization are likely to be about the same. In the case of EPT rubber, the monomer cost is likely to be slightly cheaper but will be partly offset by the higher cost of curing. In the industrialized countries EPT as a tire rubber will have a further disadvantage, viz., its inability to adapt to high-speed tire-making machines. Furthermore, as the earlier discussion showed, EPT rubbers are not likely to be accepted for heavy-duty truck and bus tires, which consume a large part of the rubber in a developing country.

One may ask why a developing country should at all consider installing a stereo-regular polyisoprene or polybutadiene plant when it can buy natural rubber from other developing nations or, in some cases, grow rubber trees itself. The countries which have a sizable domestic or regional market for rubber products may be justified in considering such a project for the following reasons:

(*a*) The foreign exchange required for importing rubber, natural or synthetic, is saved or reduced if locally available raw materials can be used;

(*b*) A synthetic rubber project often helps in the economy of a petrochemical complex by providing a large outlet for one or more co-products from a naphtha cracker,

(*c*) A 30,000 ton/yr synthetic rubber plant is equivalent to about 110,000 acres of rubber plantation, and some of the developing countries cannot afford to allocate new areas for rubber plantation;

(*d*) A synthetic rubber like polyisoprene has a uniform, specified quality and does not suffer from frequent price fluctuations;

(*e*) Storing and processing costs for polyisoprene and polybutadiene rubbers are normally lower than those for natural rubber.

Recent technical advances made in the production of stereo-regular rubbers have enhanced the acceptability of synthetic rubber in areas where natural rubber has maintained a prime position. The major impact of competition from these rubbers has already been felt by SBR producers. While developments in polypropylene oxide rubber and polyacrylates need watching, it can be predicted that the future of the synthetic rubber industry in the developing countries will belong to the general-purpose stereo-regular rubbers. Cis-polyisoprene, being the only low-cost synthetic rubber that can be used interchangeably with natural rubber in heavy-duty on-the-road tires, is bound to receive increasing attention from all the countries that are planning to install new synthetic rubber plants.

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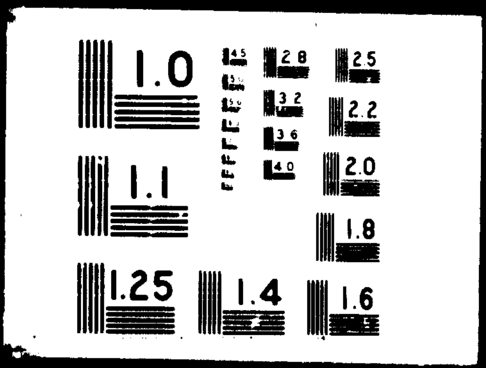

3. SYNTHETIC RUBBER—AS RELATED TO PETROCHEMICAL PRODUCTION IN DEVELOPING COUNTRIES

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The Second World War brought a tremendous demand for rubber. These demands could not be met by natural rubber, particularly in those countries which were cut off from the sources. Every industrial country tried to and did develop synthetic rubber from its own resources; and there has since been a continuous growth of synthetic rubber capacity.

In the United States of America, the success of these developments can be seen from the fact that synthetic rubbers now account for three-fourths of the total consumption, which amounts to over 2 million long tons for total rubber uses, of which about 1.6 million tons is synthetic. In 1954, for example, synthetics were only 48 per cent of the total United States rubber consumption, then much less than now. The present high level is the result of the continuous growth for each consecutive year over the last ten years, not merely in the volume 7 per cent of use for synthetics, but also in its percentage of the expanding total. This percentage of total consumption is expected to increase further in the next decade, although at possibly a somewhat slower pace. Some manufacturers of tires have already entirely eliminated natural rubber from passenger car tires, and can do the same, if necessary, in both truck and airplane tires.

In western Europe, the growth of synthetics in relation to the position of natural rubber has also been spectacular, as it has been in Japan. The tendency is for each country to try to become more self-sufficient.

Synthetic rubber is expected to account for some 53 per cent of the 1964 rubber consumption of 4,700,000 tons for countries with free market economies, and this is an increase from the 29.4 per cent or 2,517,500 tons reported for all rubber in 1964.

In peacetime, it is improbable that the use of all synthetics in the United States of America will go much above 80 per cent of total rubbers, because natural rubber is expected to decrease in price to meet competition, and will thus maintain its position.

The technology of rubber production, processing and utilization has changed radically in the last decade, and shows every indication of continuing to change. The making of synthetic rubber is still basically more of an art than a science; this is true especially in the compounding stages of the production. It is even more true in the making of finished rubber products than in the polymerization of resins for plastic use, or the compounding of resins with other added materials in the plastics field.

The many new types of synthetics which have been introduced have greatly magnified both compounding opportunities and compounding problems; and as a result, the production of synthetic rubber in final form is even more of an art than is that of natural rubber, if for no other reason than that the number of variables is so much larger since there are so many more synthetic rubbers with which to work.

Also, the fact that the boundary line between rubbers (elastomers) and plastics is rapidly disappearing becomes increasingly important as further emphasis is made continuously on thermoplastic materials, and relatively soft and flexible moulded objects — one important class being housewares, buckets, pans etc. In the immediate past, for example, products based on ethylene vinyl acetate have been introduced, which, in one composition with an appropriate set of compounding ingredients, are flexible "plastics", and with a somewhat different set of compound ingredients and a slightly different composition are "rubbers". Hybrid materials of rubbers and plastics can be expected to proliferate in the near future.

The total consumption of new rubber is considered to be an index of the degree of industrialization of a country because of its utilization in so many diverse consumer products and industrial products.

By these standards, the United States of America ranks first, followed by various countries in western Europe and Japan, in the same order as they would be classified as being "highly industrialized"; while the Federal Republic of Germany ranks first in plastics consumption *per capita*, probably because of the impetus given to the development of synthetic materials during the Second World War.

In developing countries, as in every other, it is, of course, necessary to provide consumers with rubber goods. To a very small extent these are at present imported; but as a country becomes more industrialized it will be necessary to produce synthetic rubbers in larger quantities. This industry must depend on raw materials and the technology for their conversion into synthetic rubbers. Some of the rubbers developed successfully in the industrialized countries will be indicated below; and these are probably the same ones which developing countries should produce, except that the problems of raw materials, technology, capital for investment and markets will bear somewhat different relations to the over-all economic problems.

The Second World War resulted in the large-scale manufacture of styrene-butadiene, chloroprene (called Neoprene in the United States of America), butyl and nitrile elastomers; and this compelled the rubber industry to enter into the production of chemicals, whereas, hitherto rubber itself was mainly an agricultural commodity, though somewhat exotic compared with corn or potatoes. This trend was further accelerated with the advent of the stereo-rubbers such as poly-butadiene, and poly-Isoprene, and the later development of the ethylene-propylene elastomers. Each of the basic synthetic monomers has a long history of expensive chemical and engineering research behind it.

The new chemical rubbers threaten to push some of the old = established agricultural rubber producers out of the market; and this trend will continue at an ever-increasing rate, depending on the costs of raw materials and specifications for products in the various markets

Today, a rubber processer has a choice of at least seven major elastomers, plus natural rubber itself, for large volume uses, and, in addition, there are some ten other speciality products, including silicones, urethanes, polysulfides, polyacrylates, chloro-sulfonated polyethylene, and, most recently, epoxide rubbers, which are based on propylene oxide, etc. The spectrum of his raw materials is thus increased; and he has wide latitude in his choice, depending on his skill and technology in obtaining and utilizing chemical raw materials in meeting specifications, in opening new markets, and in lowering production costs.

MAJOR SYNTHETIC ELASTOMERS AND CHEMICAL RAW MATERIALS

In the rubbers to be discussed below, it will be noted that there are available for compounding as the final materials, a group of six or seven principal elastomers — butyl rubber, styrene-butadiene, neoprene, polybutadiene, nitrile, polyisoprene and ethylene-propylene. In addition to these elastomeric materials, there are the usual compounding materials required — carbon black, various plasticizers and oils for rubber processing, rosin, stearic, and other higher fatty acids, styrene resins, zinc oxide and special chemicals such as accelerators, in addition to the old stand-by, sulfur.

The elastomers may almost all be made directly or indirectly from acetylene, olefins (including ethylene, propylene), butylenes, butadiene, benzene, ammonia, or hydrogen cyanide for the nitriles. Essentially all of these may descend from petroleum or its sibling, natural gas.

STYRENE-BUTADIENE RUBBERS (SBR)

This class of synthetic elastomers was initially known as "GR-S" in the United States, and may be regarded as a general purpose synthetic rubber. This type has by far the largest consumption. In the United States of America, in 1964, out of a predicted production of 1,683,000 long tons of synthetic rubbers, styrene-butadiene amounted to 1,140,000 long tons. The price is about 22¢ per pound.

While there have been various changes in the manufacture of SBR, the major amounts are still produced by emulsion polymerization of styrene and butadiene, giving a finished product of about 20 to 25 per cent of styrene.

In the original SBR process as developed and utilized to supply so much of the needs of the United States in the early 1940s, polymerization reactions were carried out in standard glass-lined reactors of slightly under 4,000 gallons capacity, at about 115°F. Since heat is given off, some cooling is necessary. About 550 BTU per pound of rubber must be removed. Also, in this process, approximately 75 per cent of the two monomers, butadiene and styrene, are converted to polymer in twelve hours, then the polymerization is stopped by the addition of a chemical such as hydroquinone. Unreacted monomers are removed by flash vaporization for the butadiene and by steam stripping for the styrene. Antioxydants are added to the latex; and the solid polymer is isolated by creaming the latex with brine and coagulating it with acid. The polymer comes as "crumbs", and is then compressed into bales, ready for compounding with sulfur, carbon black, zinc oxide, etc.

In recent years, the major improvement in processing has been the replacement of this former hot polymerization at 115°F by cold polymerization at 42°F with a concurrent reduction of polymerization cycle, from twelve hours to two hours. This advancement has been made by improvements in the types and amounts of the rather complicated chemical materials for accelerators and oxydizing agents which are used in relatively small amounts to the rubber itself, to speed the kinetics of the chemical reaction of polymerization.

The most recent development is solution polymerization of SBR, which is being pioneered in America. Solution polymerized SBR will be able to compete better with the newer stereo rubbers, and may change the outlook for SBR, the future growth of which has not been considered optimistic because of the competition of the newer materials.

Much remains to be learned about solution polymerization in its application to SBR, but the data which have been obtained show that this technique applied to SBR gives several important advantages, including better resistance to abrasion, lower build-up of heat in tires, and better low-temperature flexibility.

An important development from the standpoint of cost is the use of oil-extended SBR. If the SBR is from the cold process and extended with 25 pounds of oil per 100 parts of rubber, tire treads have more than 20 per cent increased wearing resistance than the standard cold rubber; and the cost is decreased accordingly because of the use of the cheaper oils.

For developing countries, it is obvious that, while SBR has been the "work horse" of the synthetic rubber business in industrial countries, it means the production of two rather sophisticated monomers; i.e., butadiene and styrene. The butadiene may come in any one of several ways learned in the United States with great effort and cost compressed into a very short time, and the styrene is usually made from benzene and ethylene, but both would require a rather developed petrochemical industry.

NEOPRENE

Neoprene was developed by the DuPont Company during the 1920s and early 1930s. In the United States of America, the production of Neoprene in 1964 will be 125,000 long tons by DuPont as the sole manufacturer. In Japan, there are two manufacturers, and Neoprene under the name of "chloroprene" is also manufactured in the Federal Republic of Germany. Its present cost structure is down from an introductory price of over $1 a pound in the low-price days of 1931 to 33 to 40¢ per pound now. It is not expected that the production of neoprene will increase without further price reductions, and the 1970 production is expected to decrease somewhat because of competition with other elastomers under present prices.

About 100 pounds of acetylene gives 135 pounds of neoprene; and next to vinyl chloride, it is the largest consumer of acetylene.

Neoprene has all the fundamental characteristics of natural rubber plus several properties not found in the natural material. What is even more important, it retains these properties when exposed to heat and cold aging, grease and oil, chemicals, oxidation, sunlight and weather.

Neoprene is not the best elastomer in all properties, but it is still the only major commercially marketed elastomer that is good in all properties. In view of this unique combination of properties, neoprene has been used to make more types of rubber compounds than any other synthetic. Neoprene compounds protect cables that are exposed to the baking rays of the sun or laid underground in salt marshes. They cover air hose and electric cords that are pulled over sharp rocks in quarries and, mines, and on construction jobs. They also do a great variety of jobs in the oil fields and throughout the oil industry. Neoprene is used as a jacket for service station fuel hoses that are constantly being dragged through oil and grease and over rough pavements. This versatile rubber lines many chemical storage tanks and pipelines.

Dissolved in solvents, neoprene can be applied like paint. It has proved to be an exceptionally durable protective coating for equipment and structural steel in chemical plants, plating shops, and other locations with corrosive fume-laden atmospheres.

Neoprene is particularly well adapted to use in conveyor belts. In many mines in the bituminous coal fields, the coal is mixed with layers of slate and rock. After mining, the products are separated and dropped on a giant conveyor belt. These belts have to withstand heavy loads of sharp, jagged rock and slate and, in the case of soft coal, a considerable amount of sulfur as well. One such neoprene belt is still almost as good as new after lifting 225,000 tons of refuse from one mine. Power transmission belts are also fabricated from neoprene elastomers.

Recently, manufacturers of telephone wires put neoprene in another form to equally difficult service. They jacketed telephone drop wires with this elastomer. Drop wires are subject to rubbing against trees and houses, and to severe weather conditions. They must stand up under rain, snow and sleet, and in the summer under temperatures that often exceed 100°F.

Neoprene is used as a jacket over electrical insulation. It protects the insulation on ignition wires in aircraft and autos, and is used to protect high voltage power lines. The elastomer is finding many other applications for electrical insulation purposes both at home and in industry.

Newer uses include covers for garden hose, jackets for the cord on electric irons, the coating of metal racks, and as impregnant in many fabric articles. In other forms, it is employed for playballs, and there is a special type of neoprene suitable for crepe soles on casual and work shoes. Neoprene bladders are widely used in volley balls, footballs, and basketballs, while soft balls are made with moulded covers of this synthetic.

Other household products made of neoprene now coming off the production lines are raincoats, weather stripping, and door seals. Neoprene seals in valves have made high performance records in locations where oil, hydraulic fluids, dust, mud, and grit are encountered.

Adhesive cements made of neoprene latex are used for attaching soles to shoes.

In hospitals, neoprene sheeting, surgeon's gloves, and medical appliances can be sterilized by steam. Natural rubber will not long endure sterilization by this method.

In a thousand ways today neoprene is serving industry and the home, making possible the fabrication not only of better products, but also of products that could not be made successfully from natural rubber.

The growth of neoprene is perhaps best illustrated by sales figures. When initial production started at the bottom of the economic depression in the United States — at a time when natural rubber was sold in New York at less than 5¢ per pound — the synthetic product was priced at $1.05 per pound. Even at that price, the nation's rubber processors gave immediate attention to neoprene because of its superior qualities. In 1932, the first year of production, less than 20,000 pounds of neoprene were sold — at some financial loss to the DuPont Company, the developers and commercializers of this unique synthetic elastomer.

Production each year from 1932 to 1940 more than doubled that of the previous year, except in the recession year of 1938, when a somewhat smaller increase was made. During that period, the price dropped to 65¢ per pound. Today, thanks to continual research and development, neoprene sells for 40-50¢ a pound — well under half the original selling price. The total quantity of neoprene elastomers marketed in 1963 exceeded 230 million pounds.

The future of neoprene synthetics must have been seen as most promising. Continued technological improvements and increased application development will no doubt help enhance the competitive position and wider participation in both existing and new markets of this uniquely versatile group of elastomers.

The basic steps of the neoprene process may be summarized as follows:

1. Acetylene polymerization to vinylacetylene;
2. Vinylacetylene hydrohalogenation to 2-chloro-1,3-butadiene (chloroprene);
3. Chloroprene polymerization to the rubber-like material, neoprene;
4. Isolation of neoprene from Latex.

Neoprene, like natural rubber, is used commercially in three different forms: (*a*) as a latex; (*b*) as a cement dissolved in solvents such as benzene, solvent naphtha or chlorinated hydrocarbons; and (*c*) as a plastic polymer which can be compounded, shaped, and vulcanized to an essentially non-plastic elastic rubber-like material.

The latices and cements are used for forming dipped goods, coating and impregnating a wide variety of objects, and as adhesives. The gelling of cements is said to be retarded by the addition of 3-5 per cent of camphor.

Plastic neoprene can be processed in much the same manner and with the same equipment as natural rubber. The vulcanizing differs from that of natural rubber in that the addition of sulfur is not required to convert the plastic into the elastic, non-plastic form, although sulfur does have an activating effect on many stocks. Uncompounded neoprene can be cured by the action of heat alone, but the physical properties of the vulcanizate are greatly improved by the use of certain metallic oxides and other compounding ingredients. While zinc oxide and magnesia are used to activate most neoprene stocks, the magnesia must be omitted and litharge used to obtain maximum water resistance. Wood rosin is used to improve the stability of carbon black-loaded stocks, and it functions also as a secondary vulcanizing agent.

The usual forms of carbon black and other loading materials used in natural rubber can be used in neoprene also. A considerable number of resins and synthetic materials have been suggested to improve certain properties. The plasticity, processing characteristics and stability of unvulcanized, compounded stocks can be improved by the use of many of the softening agents employed in compounding natural rubber and in plasticizing resins.

Ordinary rubber accelerators have found comparatively little use in the compounding of neoprene, although certain amines and aromatic hydroxy compounds have a definite accelerating effect.

Cured neoprene closely resembles vulcanized natural rubber in both gum and loaded stocks. The tensile properties of neoprene gum stocks at elevated temperatures are inferior to those of similar rubber stocks, but there is less difference in the case of carbon black-loaded stocks. The uses of neoprene depend upon its superiority to natural rubber in many respects, such as resistance to the action of light, heat, ozone, petroleum products, vegetable oils, animal fats and many chemicals, resistance to combustion and to the diffusion of many gases and liquids.

Neoprene can be bonded to natural rubber or to metals, and is also used as an adhesive or bonding material. While alone it is not suitable as a hard rubber, neoprene can be compounded with natural rubber and sulfur to yield a flexible hard rubber.

Neoprene elastomers have been manufactured continuously since 1931 in the United States on a commercial scale. The number of products which have been produced — initially under the trade name of DuPrene — is rather large. There are currently marketed ten neoprenes of the dry polymer type, as well as nine different latices.

All the commercial varieties of neoprene can be processed on conventional rubber equipment and by methods similar to those used in preparing corresponding products from natural rubber. For most applications, neoprene as supplied can be compounded directly without preliminary breakdown. If breakdown is required, however, it may be accomplished by mechanical working at low temperatures or by means of chemical peptizing agents. The latter are normally more effective at high temperatures.

Many metallic oxides affect the cure of neoprene. With the exception of litharge and red lead, however, which are used to produce vulcanizates having low water absorption, none of the other oxides alone or in combinations approach the desirable over-all balance of the zinc oxide-magnesia curing system.

The vulcanization of neoprene with sulfur is of comparatively minor importance. The reaction of this agent with neoprene is slow, even in the presence of accelerators. It is commonly used only in the presence of metallic oxide curing agents for the purpose of producing special properties in the vulcanizate. The metallic oxide curing system is sufficiently active for many, perhaps most neoprene compounds. Both speed of vulcanization and eventual state of cure can be favourably influenced, however, by the use of additional special accelerators.

Peculiarities of the chemical manufacture of neoprene require considerable knowledge and skill, which would have to be imported into a developing country. However, the simplicity of the basic raw material supply — acetylene and hydrogen chloride — is an attractive point for consideration. The general versatility of the products also is an important advantage.

The relatively high selling price is not necessarily a measure of its cost of production; and the large spread between the raw material costs and sales price probably includes a large profit after processing costs.

BUTYL RUBBER

Butyl rubber production in the United States is estimated at somewhat over 100,000 long tons in 1964, but it is expected to decrease by possibly 10 per cent during the next five years due to competition with other synthetic elastomers. Its price is about 2¢ per pound — competing with SBR.

The major use for butyl has been for inner-tubes for automobile tires because of the low permeability to gases. Competition with other materials makes this market problematical in the future. The advent of tubeless tires will also reduce the demand. Tires made entirely of butyl have had relatively little success. Butyl is also important in electrical insulation, especially for wires and cables; but polyethylene (which is much lower in price), as well as other plastics, have taken over much of this market. It has excellent strength and resistance to chemicals.

Butyl rubber (20 to 30 parts of isobutylene and 1 part isoprene) is usually made by a solution polymerization in methyl chloride as diluent at -90°C. From 1 to 2 per cent of butadiene allows vulcanization. The technology is quite advanced in spite of the fact (which has been known for many years) that the production requires quite careful attention, particularly because this copolymerization is highly exothermic. In the United States, for example, there is only one major producer - although others have indicated, from time to time, an interest in this and one may go into it.

Isobutylene may be produced along with other olefins as basic petrochemicals, and the isoprene may also be synthetically produced from acetylene and acetone by the new SNAM Process. However, with butadiene as a third basic material, the substantial background of chemical manufacture, the low copolymerization temperature, and the relatively narrow markets, make this a less desirable production route for a developing country than alternative processes.

NITRILES AND RELATED RUBBERS

Nitrile rubbers are formed by emulsion copolymerization of butadiene and acrylonitrile at about 50°F. The properties of the product are varied by changing from 40 to 80 per cent butadiene, with an average of about 70 per cent. This rubber has a high oil-resistance, which is larger with higher amounts of acrylonitrile. The increasing amounts of acrylonitrile decrease the flexibility at low temperatures. The main uses are as latex the treating of paper, leather, and textiles, and for mechanical goods moulding. The production in the United States is increasing slowly from its present value at about 50,000 long tons, under its present price range of 35-45¢ per pound.

Since acrylonitrile can be made either from acetylene (and hydrogen cyanide) or from propylene (and ammonia), there are two sources for this material. However, in both cases, relatively complicated processing is involved. Again, of course, another of the comonomers, butadiene, is a material which requires a substantial background of investment and operation for the chemical plant.

Closely related is the polyacrylate rubbers, also made from acrylonitrile as a major starting material, but with a copolymerization with various different materials, depending on those available and on the specifications of products, such as ethyl acrylate and 2-chloro ethylvinyl ether. In general, these are copolymers of acrylates and acrylonitrile. These are speciality rubbers, used mainly in the United States, in the automotive field. They have good resistance to hot oils, and also to air, (to oxygen and ozone) but are generally unsatisfactory below - 10°F. There are three manufacturers in the United States. The volume is small, but may increase. The price is relatively high, about $1 per pound.

STEREO RUBBERS

The commercial development of stereo rubbers may be said to date back to 1959, and comes as an outgrowth of the technology developed with the stereo-specific polymerization techniques, which have been so important in olefin polymerization. United States consumption is increasing, and amounted to roughly 112,000 long tons in 1963, but the capacity is more than twice this amount.

There are two stereo rubbers — polybutadiene and polyisoprene. There are five United States producers of polybutadiene rubber, and two United States producers of polyisoprene rubbers. These have large production capacity, which has not been fully utilized. This has the advantage, of course, that the single raw materials, the polybutadiene and polyisoprene, may, in each case, come from petroleum. The polyisoprene may also come from acetylene and acetone (from isopropylene). The price of polyisoprene is as low as 24¢ per pound; and polybutadiene is in this same price range. Thus they compete directly with SBR and butyl.

The main uses are directly competitive with natural rubber for tire cords, treads, blends with SBR, etc. Both are quite similar in properties, and have good abrasion resistance. The largest use is in tires for polybutadiene. The polyisoprene also goes into footwear.

Only a single monomer is required in each case, but either will require a somewhat sophisticated method of petrochemical production.

ETHYLENE-PROPYLENE RUBBER (EPR)

It should be noted that, for a developing country, EPR has major advantages in that it comes merely from the two olefins, ethylene and propylene, which come from naphtha-cracking operations or cracking operations for gasoline production, and hence would give a relatively simple raw material stock without requiring additional processing. Thus, EPR will be cheaper than other synthetic rubbers because the average cost of the monomeric raw materials will be less than 5¢.

The polymerization requires attention to developments which are only now being made; and there is required a specialized knowledge of the chemistry of polymerization, and skill in its practice. The equipment required is less complicated and less expensive than that for some of the other synthetic rubbers mentioned previously.

It is expected that this newer synthetic rubber will advance at a great rate in the industrial countries from its recent start; and it is thought that it will be an excellent material for consideration in developing countries.

There are two types of EPR being developed. One is EPR and the other EPT. EPR is the copolymer and cannot be cured by sulfur. It requires different organic peroxides. EPT can be a terpolymer, which can be cured with sulfur. In EPT the third ingredient is added in small amounts. Typical third ingredients are: dicyclopentadiene and

1,5-hexadiene. These are added in relatively small amounts to give an unsaturated condition during the curing process.

EPT has several outstanding properties: excellent resistance to aging, low cost, simple processing, the ability to be extended with large amounts of oils and still have good properties, etc. Thus, a very inexpensive product results. Also, EPR has excellent strength properties, and a wide temperature range of useful life — from comparatively low to comparatively high.

There are now two companies in production and two or three others in the United States of America may soon enter this field. The price will be competitive with SBR, but could be reduced. It may well be the cheapest, and may ultimately have the largest volume of all the synthetic rubbers because of the lower raw material cost. So far, it has not had major use in tires.

URETHANE ELASTOMERS OR RUBBERS

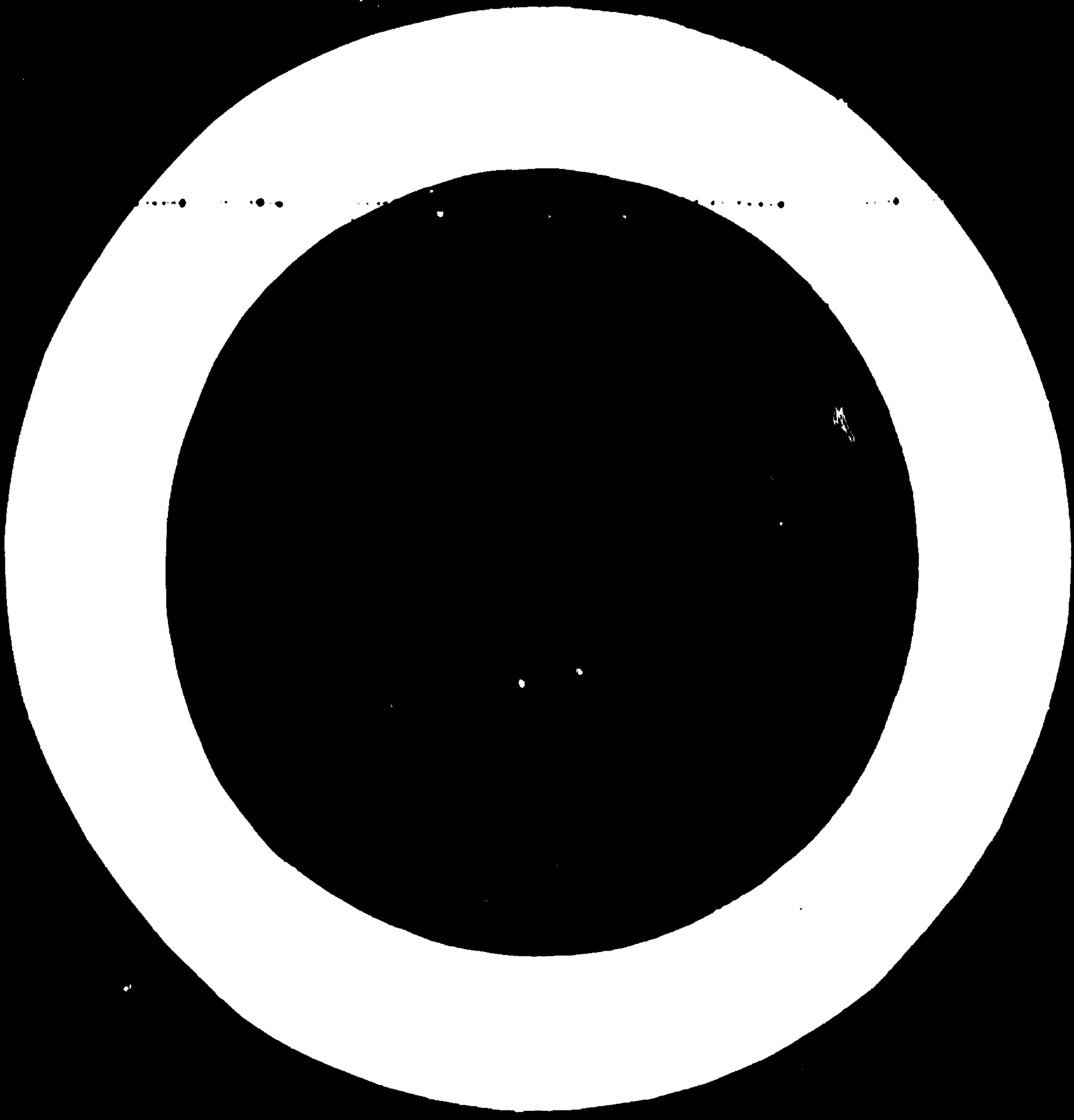
These are not important in volume produced. They are rather expensive and sophisticated in production and specialized in uses. They will probably not be important in the programmes for developing countries. Thus, production in 1963 in the United States was only 7,000 tons; and it is estimated that this volume will increase only to about 22,000 tons in 1970 in the United States. These are speciality products used in either casting or moulding in the major markets, as special tires, for flex and abrasion resistance in shoe products, for high abrasion resistance in mechanical goods, also in insulating wire and cable because of their excellent electrical properties.

These have certain disadvantages — poor heat aging and poor resistance to water and oil, particularly at elevated temperatures.

The raw materials are diisocyanates and polyesters or polyethers, all of which result from several intricate chemical manufacturing operations.

OTHER SPECIAL SYNTHETIC RUBBERS

Numerous elastomeric compounds are being produced for uses as special rubbers. Some of these may be regarded as falling into an elastomeric plastics classification. None will be of interest to a developing country because of the low volume or highly specialized uses, high cost, complicated chemical background of fundamental materials or chemical production. Among those which might be noted as representing this miscellaneous group are: fluro-chloro-elastomers, silicone rubbers, polysulfides, polyacrylics, propylene oxide rubber, and ethyl-vinyl-acetate elastomers.



F. Selected end-products

INTRODUCTORY SUMMARY

During this session, various economic and technological aspects of the production of some specific petrochemical end-products, namely sulphur, carbon black, detergents and methanol, were discussed. The importance of multipurpose reactors in the field of petrochemical industries was also mentioned.

1. SULPHUR

The petroleum industry has changed from a net consumer of sulphur in 1950 to a net producer since 1960. It was stated that in 1963, of the nearly 20 million long tons of sulphur consumed in Western Europe and North America, 19 per cent was produced from hydrogen sulphide found in sour natural gas or petroleum refinery gases.

The world-wide sulphur production sources at present were stated to be divided as follows:

	Per cent
Fresh sulphur	30
Sulphur from pyrites	34
Native sulphur	2
Sulphur from natural gas	18
Miscellaneous	16

The recovery of sulphur from natural gas is usually carried out in two steps:

First step. Desulphurization plant unit where H_2S is removed from the gas;

Second step. Sulphur plant where H_2S is burnt in order to give sulphur.

Industrial separation of H_2S from natural gas can be achieved in several ways, all based on selective absorption. The most common processes in this connexion were said to be the amine process and the hot potassium carbonate process.

The acid gases removed from the raw gas stream are regenerated from the absorbing solution by heat and/or pressure differences, then sent to the sulphur plant. In the sulphur plant, part of the H_2S is burned with air to form SO_2. This sulphur dioxide reacts with the remaining hydrogen sulphide, thereby producing sulphur, which is normally referred to as recovered sulphur. This process for the recovery of sulphur is known as the Claus process.

The cost of producing recovered sulphur varies considerably with such items as (*a*) quantity of raw gas to be treated, (*b*) per cent of acid gas in the raw gas, (*c*) per cent of hydrogen sulphide in the acid gas, (*d*) per cent of constituents other than carbon dioxide and hydrogen sulphide in the acid gas and (*e*) local factors, where the plant is to be established. The said items will not only affect the size and design of the gas scrubbing cycle, but also will affect the sulphur plant. Owing to the above variables, it is impossible to generalize a final recovered sulphur production cost versus sulphur production capacity.

Generally, the costs of purifying the raw gas and the sulphur plant are not allocated to sulphur alone. This is because the purifying process is normally needed to produce an economic sweet residue gas regardless of whether sulphur is recovered or not. If the sweet gas is not needed, then it is rarely economical to process the gas just to recover the sulphur.

Sulphur in general, however, is becoming very important for the developing countries where fertilizer plants are planned to be established.

2. CARBON BLACK

Chemically, carbon black is a pure elementary carbon with a small amount of chemisorbed hydrogen and oxygen and less than 1 per cent of ash. From the point of view of the applications properties, quality control, technical service and research required in its production, it must be regarded as a highly functional, upgraded material rather than a basic petrochemical, although it meets the formal requirements of a petrochemical.

The best raw materials for the production of carbon black are natural gas and highly aromatic rich fractions obtained from a petroleum refinery.

The various industrial processes for manufacturing carbon black from natural gas and oils are the channel process, the thermal furnace process and the furnace process.

Considering the minimum economic size of a conventional carbon black plant, it was stated to be in the order of 20-40 mm. lb/year, requiring a relatively high capital cost as well as export of a part of the output of the plant.

Because carbon black production needs a highly specialized operation requiring high capital, high technical skill, usually an imported material for construction and a small amount of labour, it is clear that it would not always be among the first petrochemicals to be considered for a developing country. However, carbon black may often be produced in developing countries by private enterprise or by the assistance of the Governments, before the local demand for carbon is large enough to make such an operation profitable. This is done to gain an early market position, looking several years ahead to larger local use, and to keep competitors out as long as possible. Thus, the introduction of carbon black production in the developing countries has tended to lead rather than to lag.

3. DETERGENTS

It is estimated that 75 to 80 per cent of the total demand is for household detergents. The remaining 20 to 25 per cent enter into the industrial detergents market in a wide variety of industrial applications.

Household detergents are mostly based on alkyl aryl sulphonate, fatty alcohol sulphates plus some non-ionics.

In the anionics market alky sulphonates are predominant, accounting for 45 per cent of the total. The main growth in detergents is presently in the non-ionics and in the liquid anionics formulations.

4. METHANOL

The production of methanol by high-pressure synthesis from gas composed "CO" and "H_2" was one of the earliest commercial petrochemical processes.

The main methanol production now is based on steam reforming processes for producing synthesis gas from naphtha or natural gas feedstocks. The conversion of the synthesis gas into methanol is carried out in a high pressure reactor like an ammonia converter.

MULTIPURPOSE REACTORS

The fact that petrochemical production and the demand for petrochemical products are expanding at an ever-increasing pace throughout the world, and that the larger primary petrochemical producers seldom serve the consumer directly, has created a need for utilizing multipurpose reactors where a variety of consumer petrochemical products are produced.

Multipurpose reactors are justifiable when, in a country, there is not a sufficient demand for the output of single-product units. The products in these multipurpose reactors are made from a wide variety of petrochemicals, all of which are available from either domestic production or imported petrochemicals. This type of reactor will greatly minimize the capital cost and, at the same time, the cost of production.

1. THE PETROCHEMICAL INDUSTRIES : SELECTED END-PRODUCTS

Prepared for the United Nations Centre for Industrial Development
by l'Institut français du pétrole, France

Methanol production

The production of methanol by high-pressure synthesis from gas composed of CO and H_2 was one of the earliest commercial petrochemical processes.

The main methanol production now is based on the steam-reforming process for producing synthesis gas from naphtha or natural gas feed-stock. The conversion into methanol is carried out in a high-pressure reactor like an ammonia converter.

The major portion of the methanol synthesized to-day is used in the production of formaldehyde, methyl methacrylate and DMT.

ECONOMICS OF METHANOL MANUFACTURE

The elements of the operating costs for a 30,000 tons/year methanol plant, built in Europe, and based on natural gas[1] feed-stock, are given in table 1. The manufacturing cost and the derived methanol selling price are presented in table 2.

TABLE 1. 30,000 TONS/YEAR METHANOL PRODUCTION
NATURAL GAS-BASED STEAM-REFORMING PROCESS
Operating cost elements

Investment [a] (MM$US)		
Process Units and off-sites, including tankage	3.00	
Initial charge of catalyst and chemicals	0.06	
Start-up expenses	0.14	
TOTAL INVESTMENT		3.20
Raw materials and utilities consumption		
Natural gas [b] (m^3/hr)	4,820	
Steam produced (tons/hr)	9.1	
Catalyst and chemicals requirements $US	45,000	
Labour (men/shift)	5	

[a] Royalties included.
[b] Including fuel consumption.

A lower selling price ($US50/ton) could be obtained in a higher capacity unit producing 60,000 to 65,000 tons/year methanol.

TABLE 2. 30,000 TONS/YEAR METHANOL PRODUCTION
NATURAL GAS-BASED STEAM-REFORMING PROCESS
Manufacturing cost and selling price

	Unit	*Unit cost $US*	*Annual quantity*	*Annual cost 10^3 $US*
Variable costs				
Natural gas	10^3 m^3	13	38,600	500
Steam (credit)	Tons	1.6	72,800	(−115)
Catalyst and chemicals				45
Labour				
Salaries and wages	Men/year	5.000	20	100
Supervision	At 25 % of salaries and wages			25
TOTAL VARIABLE CHARGES				555
Fixed costs				
Depreciation	At 12.5 per cent of total investment			
Interest	At 3.5 per cent of total investment			
Maintenance	At 4 per cent of total investment			
General plant overhead	At 2 per cent of total investment			
Taxes and insurance	At 1 per cent of total investment			
TOTAL FIXED CHARGES				735
MANUFACTURING COST				1,290

(Continued)

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[1] A similar evaluation based on naphtha feed-stock instead of natural gas will lead to approximately the same methanol selling price.

TABLE 2 *(continued)*

	Annual cost 10^6 $US
Selling price	
Net cash flow at 20 per cent of total investment	640
Depreciation provides	400
Net income after taxes	240
Net income before taxes at 50 per cent	480
Manufacturing cost	1,290
Methanol sales	1,770
Methanol selling price	
$US	59
¢/1b	2.7

Carbon black production

Chemically, carbon black is a purely elementary carbon with a small amount of chemisorbed hydrogen and oxygen and less than 1 per cent of ash.

Physically, it is composed of roughly spherical particles, of colloidal dimensions, ranging in diameter from 50 to 5,000 Å. The industrial properties for which carbon black is valued are associated with its fine state of division.

PRODUCTION AND USES

Carbon black capacity in 1963 is given in table 3 below. It is mainly used in:

Rubber industry, which consumes more than 90 per cent of the carbon black produced. Carbon black improves the physical properties of rubber, for instance: abrasion resistance, toughness, tensile properties.

Inks and paints as black pigment.

TABLE 3. CARBON BLACK CAPACITY
Unit: 10^3 tons/year

Process	*Oil furnace*	*Gas furnace*	*Channel*	*Total*
Europe [a]	380	9	20	409
Asia, Africa, Australia	148	9	19	176
America	908	283	121	1,312

[a] Eastern countries not included.

There are now on the market 16 main types of carbon black, the uses of which are variable, produced by three groups of processes. From these main types, ten are furnace blacks, four channel blacks and two thermal blacks. They differ in origin, colour and particle size.

MANUFACTURING PROCESSES

The principal processes are: channel, thermal furnace, furnace.

Channel process

Carbon black is collected by impingement of small natural gas flames on a relatively cool metal surface. The apparent density of this black is about 0.05 gr/cm³. Impurities are eliminated by cyclones, and density is increased in agitating tanks, where occluded air is removed; the apparent density increases to 0.2 gr/cm³ and handling becomes easier.

Thermal furnace process

Carbon black production is carried out in two phases: natural gas mixed with air is burned in an insulated furnace, filled with refractory. When refractory temperature reaches about 1,000°C, the combustion is stopped and gas alone is charged into the furnace. The heated refractory decomposes the natural gas into carbon and hydrogen. Cracked gases, with the entrained carbon, are cooled by a water spray. The carbon black is then separated from the gases in bag filters. When refractory is cooled, the cycle is repeated.

The manufacture of thermal blacks amounts to about 6.5 per cent of the total production.

Furnace process

Two raw materials are used: gas and oil.

Gas furnace

Natural gas and air are introduced simultaneously into a firebrick-lined chamber, in a predetermined ratio, through burners which distribute the air and gas in alternate parallel layers.

Combustion occurs at the air gas interface and supplies the heat necessary to crack the remaining natural gas to carbon and hydrogen.

The gaseous effluent containing entrained carbon is sent to a cooling tower, where water is sprayed, and is then passed into an electric precipitator. A part of the carbon black is removed, the remander is flocculated into loose aggregates which are recovered by cyclones.

Oil furnace

The operation is essentially the same as for gas. Liquid is introduced into the furnace by atomization or vaporization. Yields by the oil furnace process usually run between 50 and 60 per cent of the carbon content of the feed; the yield can be correlated with the feed aromaticity (very aromatic oils are the best feed-stocks).

ECONOMICS OF CARBON BLACK PRODUCTION

The elements of the operating cost for a 25,000 tons/year plant, based on furnace gas process, are given below:

	$ US
Investment (process units only)	5,000,000
Raw material and utilities requirements per ton of carbon black	
Natural gas. (m^3)	5,710
Electricity (kWh)	500
Cooling water (m^3)	68
Labour (men/shift)	15

Sulfur production

PRODUCTION AND CONSUMPTION

Because of the abundance of free acid in natural gas, the sour gases were not utilized and were burned during a long time. The increasing demand for natural gas in some countries and the improvement of sweetening techniques have developed gas acid uses after treatment, yielding in many cases by-product elementary sulfur. If the quantity of H_2S contained in the gas is low, sulfur is not recovered economically.

Sour natural gases may contain as much as 30 per cent of hydrogen sulfide. Sulfur is so extracted from refinery gases.

In 1960 there were 30 units in the United States producing sulfur from natural gas and as many processing refinery gas.

The petroleum industry changed from a net consumer of sulfur in 1950 to a net producer since 1960.

The world-wide sulfur production is divided as follows:

	Per cent
Fresh sulfur	30
Sulfur from pyrites	34
Native sulfur	2
Sulfur from natural gas	18
Miscellaneous	16

MANUFACTURING PROCESSES

Recovery of sulfur from gas is carried out in two steps:

First step. Desulfurization unit where H_2S is removed from gas;

Second step. Sulfur plant where H_2S is burned in order to give sulfur.

Industrial separation of H_2S from gas can be achieved by several ways, all based on a selective absorption. The most-known process uses solutions of amines which have the property to form with weak acids (H_2S) unstable components which can be broken by heating, thus regenerating the original solution.

The gases and the amines solutions are in contact in a counter-current column, working under pressure. A part of the H_2S reacts with amines, producing a salt. Another part is absorbed by dissolution in the amines. By heating the rich solution, the salts formed are broken; then H_2S is removed by flash.

Generally, the gas leaving the absorber is treated by caustic soda, which eliminates the last traces of acid.

Sulfur is produced from hydrogen sulfide by the Claus process. A part of the H_2S is burned. The sulfur dioxide produced is mixed with the remaining hydrogen sulfide. Sulfur is obtained in a liquid form.

$$2\,H_2S + 3\,O_2 \rightarrow 2\,SO_2 + 2\,H_2O \qquad (1)$$

$$2\,H_2S + SO_2 \rightarrow 3\,S + 2\,H_2O \qquad (2)$$

The reaction (1) is very exothermic. The recovery of the heat of reaction permits the production of a large amount of steam that supplies partially what is required by the absorption section.

ECONOMICS OF SULFUR PRODUCTION

The elements of the operating cost for a plant based on a natural gas composed of 15 per cent of hydrogen sulfide are given below.

Sulfur recovery/1,000 m^3 of natural gas treated: 0.203 tons

Utilities and chemicals requirements/1,000 m^3 of natural gas treated

	Amines washing and caustic scrubbing	*Sulfur plant*	*Total*
Electricity (kWh)	3.8	20.3	24.1
Steam (tons)	0.66	−0.36	0.30
Cooling water (m^3)	25	—	25
Process water (m^3)	0.02	0.5	0.52
Amines (kg)	0.05	—	0.05
Caustic soda (kg)	0.45	—	0.45

Investment and man-power required for a similar plant treating 220 million m^3 natural gas per year and producing 44,500 tons/year of sulfur are as follows:

	$ US
Process units cost	
Amines washing and caustic scrubbing	5,250,000
Sulfur plant	3,200,000
TOTAL	8,450,000
Man-power (men/shift)	5

Detergents

INTRODUCTION

Detergent is a group name attached to numerous products which are very different as to physical and chemical constitution, but which have all the common characteristic of deeply modifying the interfacial tension of liquids in which they are dissolved, especially of water.

Detergents are usually classified in three groups, according to the sign of the electrical charge of the specific hydrophobic group entering into the molecular structure:

Anionics (with a negative hydrophobic group) represent about 70 % (expressed in terms of 100 per cent organic surface-active ingredient) of total detergent production. In 1962, in the United States, benzene sulfonates, the best known among anionics, accounted for 46 per cent of total anionic production.

Below is given a list of main anionic detergents:

Alkylaryl sulfonates: basic materials are benzenes, propylene or normal paraffins derived from kerosene, and sulfuric acid or sulfur trioxide.

Alkyl sulfates: basic materials are olefins and sulfuric acid;

Fatty alcohol sulfates: fatty alcohols are prepared from natural fatty acids or synthetized with olefins, hydrogen and carbon monoxide.

Cationics (with a positive hydrophobic group) have little importance with only a 3 per cent share of the total detergent production. The most cationics are quaternary ammonium salts derived from fatty amines which may be obtained themselves from fatty acids and ammonia.

The last class of detergents are *nonionics* which do not ionize in water. They obviously represent 27 per cent of the total detergents production. Nonionic components are prepared by fixation of polyethylene oxide (or polypropylene oxide) and polyethylene glycol (or polypropylene glycol) to fatty acids (lauric, stearic, palmitic, oleic acids), tall oil acids, resinous acids, fatty alcohols (lauric and oleic alcohols), fatty amines, amines.

APPLICATIONS

It might be thought that detergents are only concerned with cleaning but, in fact, they are found in numerous industries under different names, such as emulsifiers or surfactants.

Various tests have been set up for defining detergent performances in order to employ them with regard to their best utilization; the most outstanding qualities are shown by emulsifying power, wetting power and detergent power. Roughly, it can be considered that products having good detergent power serve as household or industrial detergents, those having good emulsifying power promote dispersion of powder or liquid in a given medium and are used in the textile industry and for the preparation of lacquers, paints, waxes, pesticides, herbicides, pharmaceutical and cosmetic components; finally, those having good wetting power are used in textile and dyeing industries, in ore industry for flotation and dust removal, in the preparation of special concrete.

When considering again the distribution of detergents in anionics, cationics and nonionics, each group shows some specific properties:

Cationics are characterized by good wetting power and high germicide properties, for which they were originally used as disinfectants in many sanitizer formulations. A peculiar use was found in the drilling of oil wells in order to kill certain bacteria which cause plugging of the formation and corrosion of equipment. Cationics are also used for separation of ore by flotation; sometimes they are mixed with nonionics to impart their good germicide properties to the so obtained components.

Anionics, because of their excellent detergent power, serve as the major constituent in household and industrial detergents; about half the 885,000 tons of total synthetic detergents produced in 1962 in the U.S.A. were used in household products. Anionics are seldom used without mixing them with other ingredients in order to improve their properties or to add other properties.

For example, secondary alkyl sulfates, liquid anionic detergent types, are mixed with anhydrous sodium carbonate and other additives (sodium metasilicate, trisodium phosphate, carboxymethyl cellulose) and, if necessary, with water; the product obtained is crystallized and then crushed and sold as caustic lyes for industrial or domestic purposes. The detergent content, expressed in terms of 100 per cent organic surface-active ingredient, is never very important.

Alkylaryl sulfonates are well fitted for preparing clean hygroscopic powders. As mentioned before, detergents and additives (pyrophosphate, sodium polyphosphate, sodium metasilicate, carboxymethyl cellulose) are compounded into a viscous solution that is sprayed hot, and afterwards oxidants (sodium perborate) or dyes that would be damaged by heat, are added to the sprayed powder. Consideration should be given to the important share taken by the additives in the preparation of household detergents; the production of these additives involved a complementary industry to that of detergents. Anionics have found other applications in the textile industry, mainly for washing of cotton, and in paper and painting industries.

Nonionics have good detergent and emulsifying power but are more expensive than cationics; they are often mixed either with anionics or with cationics. Nonionics are employed as emulsifying agents for oil and waxes, in cosmetic, pharmaceutical and food industries. The production of a good tensio-active nonionic depends upon purity of raw materials, i.e. ethylene oxide or propylene oxide.

MANUFACTURING PROCESSES FOR DETERGENTS

Raw materials to make detergents are very numerous as previously outlined; therefore this study will be limited to the preparation of dodecylbenzene sulfonate and sodium secondary alkyl sulfates; then we will show the new trends to reach biodegradable detergents.

Dodecylbenzene sulfonate

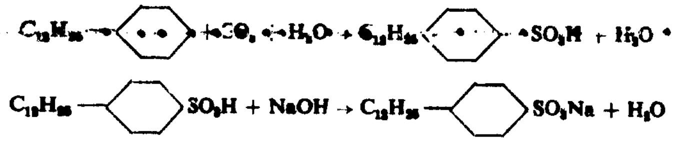
The two intermediates are propylene and benzene; the preparation is proceeded in three steps, illustrated by the basic reactions as follows:

Polymerization of propylene into tetrapropylene

$$(CH_2{=}CH{-}CH_3)_4 \rightarrow C_{12}H_{24}$$

Linking of tetrapropylene with benzene to form dodecylbenzene:

Sulfonation with oleum (or sulfuric acid, or sulfur trioxide) and neutralization with sodium hydroxide



(a) *Polymerization of propylene*

Propylene coming from a propane steam-cracking is charged into a reactor in which the catalyst is divided into several zones or put in tube. The polymerization reaction is very exothermic and occurs at a temperature of about 150-170°C and under slight pressure ranging from 40 to 60 atmospheres. The catalyst widely used is solid phosphoric acid and kieselguhr. The reactor effluent, after heat exchange with fresh feed, is passed through a depropanizer and tetramer freed of light polymers, which are recycled, and of heavier components in distillation columns.

(b) *Dodecylbenzene*

The condensation of tetrapropylene with benzene is carried out at low temperature with one of the following catalysts: hydrofluoric acid (HF), sulfuric acid (H_2SO_4) or aluminium trichloride ($AlCl_3$).

Tetramer and benzene feeds are dried and cooled before entering into the reactor. The effluent passes to a separating drum where the acid settles out and is recycled; then benzene is separated and also recycled in a distillation column. The products obtained after this operation contained light alkylates, heavy alkylates and dodecylbenzene suitable for sulfonation. All these components are separated and dodecylbenzene is withdrawn at the top of the last distillation column.

(c) *Sulfonation*

Sulfonation agent may be sulfuric acid (H_2SO_4), sulfur trioxide (SO_3) or oleum, i.e. a solution prepared by having SO_3 bubbled into H_2SO_4. The sulfonation reaction is not reversible and follows a smooth time-temperature curve until a maximum yield is reached. With SO_3 the reaction is nearly instantaneous and complete; the reactor capacity is minimum, but disadvantages are caused first, by high heat evolved which may decompose the products aimed at, and secondly, by high viscosity of the reaction mixture. With H_2SO_4 the previous statements are reversed; the reaction requires heat for completion and by-product formation is slight. Oleum has proved a practical compromise between SO_3 and H_2SO_4.

Dodecylbenzene and oleum are metered through a centrifugal pump which provides the first mixing step. Then the mixture is completed in a stainless steel reactor cooled by water for controlling the reaction temperature.

The dodecylbenzene sulfuric acid is removed and reacts with sodium hydroxide in a neutralizer. The slurry is sprayed and compounded with additives to form powder detergents.

ECONOMICS OF SODIUM D.D.B. SULFONATE MANUFACTURE

Elements of the operating cost for a 10,000[a] tons/year D.D.B. sulfonate plant based on propylene and benzene feed-stocks and including a dodecylbenzene unit (tetramer production and benzene alkylation) and a sulfonation unit, are given hereunder:

Manufacture of D.D.B.	
Investment[b] (Battery limit) (MM $)	2
Raw material balance (tons/year).	
Propylene	10,700
Benzene	4,400
By-products (light and heavy alkylation)	4,900
Utilities consumption	
Electricity (10^6kWh/year)	3,000
Cooling water (10^6M^3/year)	5,900
Fuel (10^6kcal/year)	60,000
Catalyst and chemical consumption ($)	4,600/year
Labour (men/shift)	10
Sulfonation (corresponding to D.D.B. production)	
Product: Sodium dodecylbenzene sulfonate detergent	
Capacity: 65,000 tons/year commercial detergent (20% sulfonate)	
Investment (MM $)	1.9
Elements of the operating cost ($/ton of end-product).	
Raw materials[c]	140
Utilities (including, fuel, electricity, steam, cooling water)	13
Labour	14
Maintenance	2
Fixed charges (including depreciation, interest, general plant overhead, taxes and insurance)	10
Profits and taxes (including sales promotion)	20
Detergent selling price ($/ton)	199

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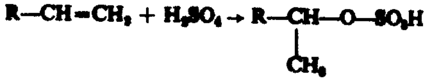
[a] Corresponding to a 65,000 tons/year commercial detergent production at 20% of active product.

[b] Including fees and paid-up royalties.

[c] Including dodecylbenzene, sulfuric acid, sodium hydroxide and products generally used as builders.

Sodium secondary alkyl sulfates

Sulfuric acid directly adds up to a double bond to form monoalkyl sulfuric acid, according to the sulfonation reaction



$$R—CH=CH_2 + H_2SO_4 \rightarrow R—\underset{CH_3}{\underset{|}{CH}}—O—SO_3H$$

Sulfation is more difficult to lead than sulfonation; the reaction is rapid and very exothermic; it is important to control it steadily to prevent side reactions supplying undesirable by-products. The mixture of reactants is held at the proper temperature by passing liquid propane through a tubular exchanger. Afterwards monoalkyl sulfuric acid is converted into sodium alkyl sulfate by reacting with sodium hydroxide in a neutralizer.

Both reactions, sulfation and neutralization, are proceeded in the same plant as those for sulfonation. The olefins which are employed usually originate from a high-temperature and pressure cracking of paraffins resulting from the refining of lubricating oils.

As for sulfonation, oleum is used rather than sulfuric acid of sulfur trioxide in the sulfation process.

Biodegradable detergents

The increasing amount of synthetic detergents used every day has put more emphasis on the problem of water pollution. Nowadays most detergents foam very much and this persists in waste water before being decomposed. Hence the interest shown by manufacturers to prepare products which will degrade adequately under proper sewage treatment and which will more easily break down by biological action; they have called them biodegradable or soft detergents as a contrast with non-biodegradable or hard detergents, qualifying the older ones. Facing the tricky problem of water pollution, some governments have regulated the utilization of non-biodegradable detergents.

Biodegradability of alkylaryl sulfonates depends upon the chain length between alkyl group and aryl radical attachment; the more numerous the carbon atoms are between the point of attachment of benzene ring and the end of the longest straight chain, the more the degradation rate increases.

To meet this requirement the sources available for biodegradable detergents are straight-chain olefins or normal paraffins (C_{10}-C_{14}):

The alkylation of benzene by straight-chain olefins presents no significant departure from processes developed to effect a similar alkylation with tetrapropylene.

The route to biodegradable detergents from n-paraffins is more attractive:

Development of the molecular sieve technique for the separation of straight-chain paraffin hydrocarbons (n-paraffins) from kerosene has made n-paraffins available at low cost.

N-paraffins may be dehydrogenated into straight-chain olefins and the end of the transformation into alkyl aryl sulfonates is similar to alkylation of benzene.

It is more likely that the conversion of n-paraffins on an industrial scale will be effected by the chlorination process according to the reaction.

$$RH + CL_2 \qquad RCL + HCL$$

The monochloroparaffin (RCL) may be used directly to alkylate benzene with aluminium chloride as the catalyst or may be dehydrochlorinated to straight chain olefins.

One aspect of the economics of detergent alkylate from n-paraffin lies in utilization of the by-product hydrogen chloride.

2. KERYLBENZENE-TYPE DETERGENTS FROM IRANIAN PETROLEUM FRACTIONS

By the Iranian participants, Iran

INTRODUCTION

Dodecylbenzene sulfonate has long been the detergent most widely applied for industrial and household use. However, due to the non-biodegradability of this product, attention has lately been directed toward new types of detergents. Intensive research has been carried out in different parts of the world for finding new biodegradable detergents. Although DDB is still the forerunner of all detergents on the market at the present time, various types of biodegradable detergents are catching up.

The use of kerosene, instead of propylene tetramer, to produce detergents has long been studied. However, since by using a suitable kerosene cut a biodegradable detergent might be produced, research in this field has been intensified.

Iran at the present time has no problem in using ordinary DDB, but as industries grow in size and number, the need for a biodegradable detergent might be felt in the very near future.

Thus research is being directed towards the production of a biodegradable detergent from Iranian crudes. The method under consideration is chlorination of suitable petroleum cuts and subsequent alkylation and sulfonation. While in this paper the trend of research in this field is presented, emphasis has been given on the chlorination and alkylation of different Iranian crude distillates.

LITERATURE SURVEY

Dodecylbenzene sulfonate, now the leading detergent in the market, is produced by alkylation of benzene with an olefin (having twelve or more carbon atoms) and consequent sulfonation of this product. Tremendous consumption of this detergent since the last decade has been responsible for the great variety of methods of preparation of this product. The alkyl chain is usually produced by polymerization of propylene to propylene tetramer. Alkylation is industrially carried out by using HF or aluminium chloride as a catalyst in liquid or gas phase. Sulfonation of alkylate is achieved by using oleum, chlorosulfonic acid or a mixture of SO_3 and SO_2 as the sulfonating agent. Consequent neutralization of dodecylbenzene sulfonic acid produces the desired detergent.

Alkylation of benzene by a long chain alkyl chloride and consequent sulfonation produces another type of detergent, known as kerylbenzene sulfonate because of the fact that the necessary alkyl choride is prepared from a suitable cut of kerosene. In contrast to dodecylbenzene, little attention has been paid to the kerylbenzene type detergent up to now, mostly because of its inferior properties compared with DDB. This kerylbenzene type detergent is partly biodegradable, and due to this particular characteristic attention has been directed recently toward this type of detergent and its method of preparation.

Actually a tremendous investigation into the preparation of different biodegradable detergents is being carried out in different parts of the world, and many different methods have been discovered. One method is by the action of ethylene on aluminium tribenzyl complex. The main difficulty in this procedure is the scarcity of the raw materials. Another method has been developed in which a suitable petroleum cut is cracked to produce a straight-chain olefin and the alkylation of benzene by this olefin produces the desired detergent. The main drawback of this method is the fact that the detergent produced is not completely biodegradable.

It has been discovered that alkylating benzene with a straight-chain normal alkyl chloride with eight to sixteen carbon atoms produces an alkylate which after sulfonation produces a biodegradable detergent. Since the best source of normal paraffin of this type is kerosene, investigation has been directly toward finding a practical method for separating normal paraffin from its isomers.

Two important processes have been developed — the urea process and the molecular sieve process. The urea process is based on the fact that normal paraffin forms a stable complex with urea. Therefore, addition of urea to a suitable kerosene cut produces a urea-normal paraffin crystalline complex which can be filtered out from the mixture. The quantity of urea necessary for this operation is 3.5 times that of the hydrocarbon. The temperature of the operation must be kept at 25°C in order that unreacted urea is dissolved in the medium. The crystalline complex is washed with pentane and decomposed in hot water.

The molecular sieve process is based upon the rate of adsorption of different hydrocarbons by sodium or calcium zeolite. In this case a suitable cut of kerosene is passed through an appropriate zeolite column at 100-300°C and 10-70 Kg/cm^2 pressure. For regenerating the zeolite usually normal heptane or hexane is passed through the column after the operation.

The normal paraffin which is obtained by one of the above processes is chlorinated to an alkyl monochloride. Chlorination is carried out in liquid phase or gaseous phase. Chlorination of normal hydrocarbon in liquid

TABLE 1. CHARACTERISTICS OF KEROSENES

Kerosene	*Cut, °C*	*Per cent of aromatics*	*Mol. wt.*	*Density, 20 °C*	n_D^{20}	*Aniline pt, °C*
From Ahwaz crude oil	200-250°	17	175.5	0.8100	1.4525	65.6
From Bahregansar (Asmari Horizon)	200-250°	16.5	176.6	0.8071	1.4512	66.3
From Alborz crude oil	200-250°	17	178	0.8092	1.4526	66.5
Commercial kerosene	200-250°	10.5	176.3	0.7961	1.4434	71.5
Commercial kerosene	190-230°	11	168	0.7887	1.4410	68.7

phase can be achieved at low temperature (25°C) in the presence of ultra-violet light or at high temperature (100-150°C). Chlorination in the gaseous phase is usually carried out at 250°C to 300°C. Alkylation of benzene monochloride is usually carried out by the known Friedel-Craft method. The catalyst usually used is aluminium chloride, and the reaction temperature is 40-50°C.

EXPERIMENTAL

(a) *Characteristics of raw materials*

Four different Iranian crudes were considered for this study. Except for the Alborz crude, which is paraffinic base, the others are considered to be of a mixed base. The petroleum cut (200-250°C) was used in each case in this research, except for commercial kerosene, in which both 190-230°C and 200-250°C was used.

The characteristics of these cuts in each case are given in table 1.

These fractions were chosen because the number of carbon atoms in this range is between eleven and fifteen. The aromatic content of these cuts should be separated prior to the chlorination. Therefore, these petroleum fractions were passed through a silica-gel column, care being taken to make sure that all the aromatics had been removed. The characteristics of the de-aromatized kerosene are given in table 2. The silica-gel was generated by washing it several times with ethyl alchohol and water and then dried in an oven at 150°C for three hours.

(b) *Operating conditions*

The chlorination was achieved by passing chlorine into kerosene at a temperature of 50-70°C under ultra-violet light. The apparatus consists of a reactor equipped with a stirrer and thermometer. The chlorine passes through a rotameter and a series of sulfuric acid traps. The dried chlorine passes through a flowmeter and then enters the reactor at a constant flow. The reactor is also equipped

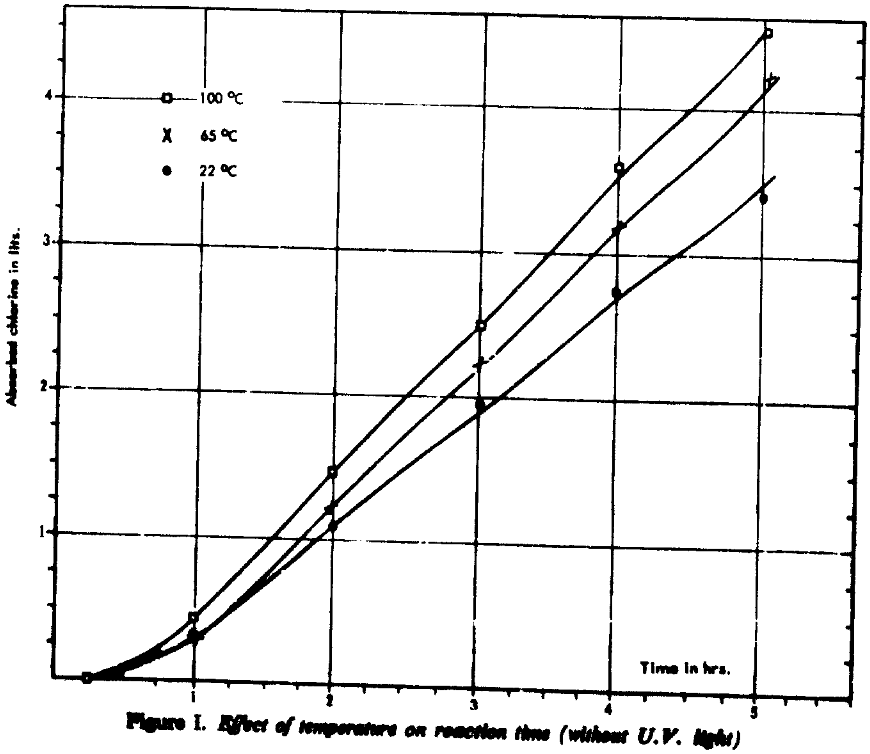


Figure I. *Effect of temperature on reaction time (without U.V. light)*

TABLE 2. CHARACTERISTICS OF DE-AROMATIZED KEROSENE

Kerosene	Cut °C	Per cent of aromatics	Mol. wt.	Density, 20 °C	n_D^{20}	Aniline pt. °C
From Ahwaz crude oil	200-250°	0	188	0.7871	1.4371	80.5
From Bahregansar (Asmari Horizon)	200-250°	0	184.2	0.7854	1.4362	80.4
From Alborz kerosene	200-250°	0	181.8	0.7875	1.4372	79.8
Commercial kerosene	200-250°	0	180.5	0.7821	1.4344	79.3
Commercial kerosene	190-230°	0	167	0.7759	1.4332	76.7

with a valve through which excess chlorine and hydrogen chloride produced in the course of the reaction are passed into a potassium iodide solution. By this system the rate of the chlorine flow is controlled.

Any excess chlorine which passes through the reactor is detected by the change in the colour of the potassium iodide solution. The reaction is also followed by taking samples from this potassium iodide solution in the course of the reaction and measuring the quantity of hydrogen chloride in it. By this system it is possible to follow the course of the chlorination reaction with great accuracy.

The effect of temperature on the rate of chlorination reaction was studied. The rate of chlorine absorption at different temperatures is shown in figure 1. Chlorination was achieved on four different types of petroleum cuts (200-250°C) under the same experimental conditions. In all these reactions ultra-violet light and catalyst were used for increasing the rate of the reaction. The rate of chlorine absorption in each case is shown in figure II. The characteristics of the chlorinated mixture are given in table 3.

After chlorination, the reaction mixture was fractionated and the characteristics of each fraction were determined. The properties of the chlorinated fractions of each crude are given in tables 4, 5, 6 and 7.

Different methods were used for determining the quantity of chlorine in keryl chloride fractions:

1. *Titration method*

In this method hydrogen chloride which was produced in the course of the reaction was titrated quantitatively by sodium hydroxide N/10. From the quantity of hydro-

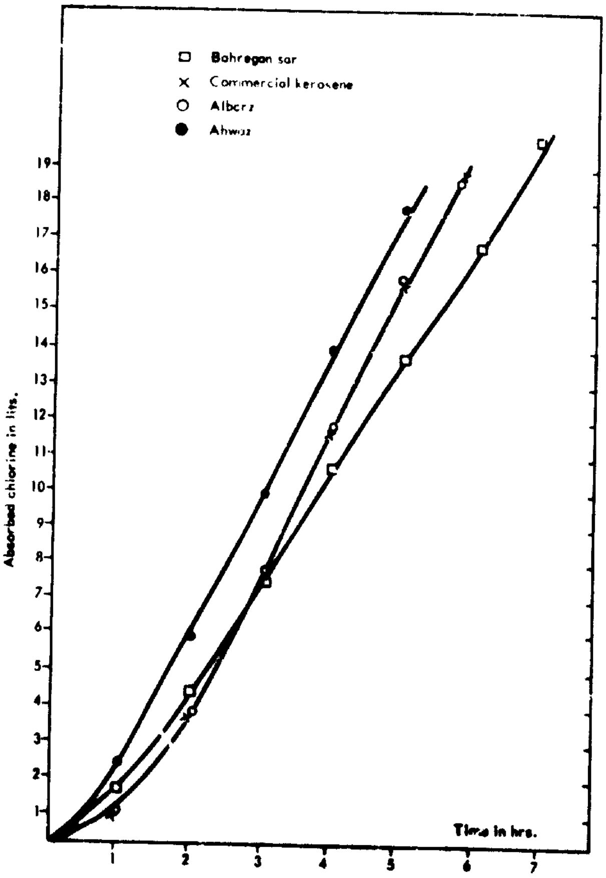


Figure II. *Behaviour of chlorine absorption by four different types of petroleum distillates*

TABLE 3. CHARACTERISTICS OF THE MIXTURE OF CHLORINATED KEROSENES

Kerosene charge					Chlorinated kerosene			Per cent of chlorine in chlorinated kerosene		
Origin	Cut	Volume, CC	Weight, G	Moles	Mol. wt.	Density, 20 °C	n_D^{20}	Titration method	Parr bomb method	Weight increase
From Ahwaz crude oil. . . .	200-250 °C	380	293.5	1.56	216	0.8909	1.4555	16.1	16.2	16.1
From Bahregansar (Asmari Horizon)	200-250 °C	400	312.8	1.70	212	0.8957	1.4545	16.3	15.8	16.0
From Alborz kerosene . . .	200-250 °C	400	307.8	1.69	212	0.8908	1.4551	16.0	15.8	16.3
Commercial kerosene	200-250 °C	400	310.1	1.71	210	0.8939	1.4533	16.0	15.8	16.1
Commercial kerosene	190-230 °C	400	308.5	1.84	198	0.8905	1.4519	16.1	16.4	16.5

chloric acid it was possible to calculate the chlorine content of the keryl chloride mixture.

2. *Parr bomb method*

A mixture of keryl chloride, sodium peroxide and anidon was placed in a bomb and heated until complete decomposition occurred. The mixture in the bomb was dissolved completely in boiling water. After filtration and acidification the chlorine in the mixture was measured by the Volhard method.

3. *Weight increase method*

The difference of the weight of kerosene before and after the reaction is obtained and used for determining the quantity of chlorine absorbed by the kerosene.

Alkylation was carried out according to the standard procedures. The apparatus consisted of a reactor, equipped with a stirrer, a thermometer, and a condenser. The catalyst used in this reaction was anhydrous aluminium chloride. The rate of the reaction was controlled by the quantity of hydrochloric acid which was produced in the course of the reaction. The temperature of the reaction was kept at 40-50°C and the reaction time was about one hour. The reaction mixture after washing and drying was fractionated. The characteristics of each fraction are given in table 8.

Alkylation cuts 290-360°C and 316-360°C were sulfonated by sulfuric acid (98 per cent). The apparatus consisted of a reactor, equipped with a stirrer and thermometer. The reaction temperature was kept at 40-50°C for two

TABLE 4. CHARACTERISTICS OF DIFFERENT FRACTIONS OF CHLORINATED KEROSENES USING AHWAZ CRUDE

Fractions, °C	*Weight, per cent*	*Density, 20 °C*	n_D^{20}	*Per cent of chlorine*	*Colour*
-200	0.59		4.4400	—	Without colour
200-210	0.68		1.4393	—	Light rose
210-230	5.95	0.8046	1.4390	2.2	Light rose
230-250	17.9	0.8119	1.4413	4.0	Light yellow
250-270	24.17	0.8585	1.4491	11.0	Light brown
270-289	35.7	0.9327	1.4625	18.8	Brown
Residue	10.32				
Loss	4.67				

TABLE 5. CHARACTERISTICS OF DIFFERENT FRACTIONS OF CHLORINATED KEROSENE USING BAHRGANSAR (ASMARI HORIZON) CRUDE

Fractions, °C	*Weight, per cent*	*Density, 20 °C*	n_D^{20}	*Per cent of chlorine*	*Colour*
-200	0.359		1.4400	—	Light rose
200-210	0.707		1.4395	—	Onion skin
210-230	7.72	0.8000	1.4387	1.8	Without colour
230-250	22.61	0.8142	1.4417	4.8	Light yellow
250-270	20.80	0.8645	1.4500	12.0	Yellow
270-391	35.06	0.9368	1.4624	21.3	Light brown
Residue	7.96				
Loss	4.78				

TABLE 6. CHARACTERISTICS OF DIFFERENT FRACTIONS OF CHLORINATED KEROSENES USING ALBORZ CRUDE

Fractions, °C	*Weight, per cent,*	*Density, 20 °C*	n_D^{20}	*Per cent of chlorine*	*Colour*
-200	1.23	—	1.4478	—	Without colour
200-210	0.88		1.4421	—	Without colour
210-230	9.63	0.7998	1.4390	1.2	Lemon
230-250	20.0	0.8161	1.4432	4.2	Light yellow
250-270	21.94	0.8634	1.4499	11.9	Light brown
270-290	32.61	0.9354	1.4625	20.4	Brown
Residue	9.33				
Loss	4.38				

TABLE 7. CHARACTERISTICS OF DIFFERENT FRACTIONS OF CHLORINATED KEROSENES USING COMMERCIAL KEROSENE

Fractions, °C	*Weight, per cent*	*Density, 20 °C*	n_D^{20}	*Per cent of chlorine*	*Colour*
-200	0.94		1.4372	—	Without colour
200-210	1.46		1.4354	—	Without colour
210-230	11.25	0.7893	1.4350	0.96	Light yellow
230-250	21.55	0.8209	1.4410	6.1	Yellow
250-270	27.49	0.8832	1.4415	14.9	Yellow
270-292	26.76	0.9593	1.4650	22.3	Brown
Residue	5.69				
Loss	4.86				

TABLE 8. CHARACTERISTICS OF DIFFERENT FRACTIONS OF ALKYLATES

Origin	*Fractions, °C*	*Per cent YL on based keryl. chl.*	*Density, 20 °C*	n_D *20*	*Mol. wt.*	*Aniline point, °C*
From Ahwaz crude oil	290-316	11.20	0.8870	1.4908	242	12.8
	316-360	27.20	0.8964	1.4988	255	12.7
From Bahregansar	290-316	6.16	0.8838	1.4910	239	9.5
(Asmari Horizon)	316-360	30.06	0.8899	1.4970	258	6.3
Commercial kerosene	290-316	12.36	0.8811	1.4908	239	11
	316-360	24.74	0.8987	1.5005	253	8.4
From Alborz crude oil	290-316	6.26	0.8838	1.4910	238	12.4
	316-360	28.75	0.8935	1.4988	256	10.5
Dodecylbenzene			0.8669	1.4878	242	11.7

and one half hours. The reaction mixture was purified and neutralized by 20 per cent sodium hydroxide solution.

DISCUSSION

In this study an attempt has been made to determine through a series of reactions the most suitable petroleum cut and the best experimental conditions for this process.

It was found that petroleum cuts below 160°C do not produce suitable keryl alkylates. The cuts above 250°C produce very heavy alkylates, the characteristics of which differ very greatly from those of dodecylbenzene. This change in characteristics depends greatly upon the number of carbon atoms in the paraffin. Usually the paraffins having less than eight carbon atoms do not produce suitable detergents and those having less than twelve carbon atoms have low foaming and wetting properties.

The effect of temperature on the rate of chlorination reaction was studied. It was found that the temperature has no noticeable effect on the rate of the reaction when ultra-violet is used as a photometric catalyst. However, in the absence of ultra-violet light the temperature has a definite effect on the reaction time. Chlorination of different types of petroleum cuts was carried out under ultra-violet light in the presence of a small amount of catalyst in this investigation.

One of the most important factors which has been considered in this investigation was the rate of the chlorine flow. Through the control of the chlorine flow it would be possible to produce mostly alkyl monochloride. We were able to adjust the flow of the chlorine in such a way that most of the chlorinated mixture consisted of alkyl monochloride.

A comparison of the rate of chlorination of different types of petroleum cuts indicates that Ahwaz Crude Fraction has the shortest reaction time and the highest yield of chlorinated products. However, it should be mentioned at this point that the quantity of aromatics in this crude in comparison to the commercial kerosene is high. Therefore, the removal of this high quantity of aromatics might produce some difficulty in the actual operation.

As far as the characteristics of alkylates are concerned, the alkylate cuts are a little heavier than that of the commercial dodecylbenzene and have a higher refractive index. This difference in characteristics is, of course, due to the fact that the keryl chloride used in alkylation consisted of a mixture of alkyl chloride having different numbers of carbon atoms.

Sulfonation of all these alkylates produces suitable detergents with characteristics comparable to those of dodecylbenzene sulfonate. It should be mentioned that these types of detergents are partly biodegradable.

CONCLUSION

The most important part of this study was the chlorination reaction. The chlorination was achieved under ultra-violet light at low temperature. The mechanism of this reaction is based on the chlorine-free radical produced by the action of ultra-violet light on the chlorine molecule. The chain reaction which follows the above initiation step can be stopped not only by the coupling of the free radicals which are present in the reaction mixture but also by a group of inhibitors such as sulfur or aromatic compounds. Therefore, the removal of these materials prior to the operation poses a very important problem. Fortunately the sulfur content of the petroleum cuts under consideration was very small and caused no particular difficulty, but the aromatic content of these petroleum cuts was high and the removal of these aromatics by chromotographic column was tedious and time consuming. However, we are able to de-aromatize these petroleum cuts very effectively in a reasonably short period of time.

Another important point in chlorination reaction that needed a great deal of attention was the rate of chlorine flow. Our aim was to produce monochloro compounds. Therefore, prevention of local concentration of chlorine in the reaction mixture depended greatly on chlorine flow and agitation of the reaction mixture. We were able to design a system in which the rate of chlorine flow and agitation were controlled in such a way that monochloro compounds of high quality were produced.

From the study of different petroleum cuts, it was found that Ahwaz cut 200-250°C was the most suitable raw material for this process. The kerylbenzene sulfonate which was produced from this fraction had good detergency characteristics and was partly biodegradable.

3. PETROLEUM — A MAJOR SOURCE OF SULPHUR

Gino P. Giusti, Texas Gulf Sulphur Company, United States of America

A. Introduction

Many countries of the world consume more sulphur than they produce. With the rising production of fertilizers in many of these countries, even more sulphur will be needed in the future. Therefore, many countries in the world, and especially the developing countries, are searching for indigenous sulphur sources. These indigenous sources may be any form or type of sulphur, however, the attention of this paper will be devoted mainly to sulphur from petroleum sources.

Sour natural gas and refinery gases are the two principal sources of sulphur from petroleum. The petroleum industry generally refers to this sulphur as a petrochemical; however, we in the sulphur industry prefer using the terminology "recovered sulphur".

B. Review of sulphur industry

Most of the world's sulphur is converted into the intermediate, sulphuric acid, before going into finished products. The major use of sulphuric acid is in the production of fertilizers, consequently, the largest single use for sulphur itself is for the production of fertilizers.

Any form of sulphur that can be converted into sulphuric acid may be the raw material. These raw materials may be sulphates, sulphides, oxides of sulphur, or the element itself. On basis of Western Europe and North America we find that in 1963 the total consumption of sulphur in its various forms was as follows:

	Western Europe and North American sulphur consumption (1,000 long tons)
Elemental	11,015
Sulphides	6,228
Oxides	1,983
Sulphates	396
Total .	19,622

The sulphates are gypsum or anhydrite which are converted into sulphuric acid or ammonium sulphate. The oxides result from roasting or smelting operations and generally originate from copper, lead or zinc sulphide ores. The sulphides generally are pyrites but also include a small quantity of hydrogen sulphide utilized directly to produce sulphuric acid. Elemental sulphur is made up of Frasch sulphur, which is sulphur mined by the hot water process, ores containing elemental sulphur, and recovered sulphur.

Of these various forms of sulphur, the form of primary interest to us today is elemental sulphur and, in particular, recovered sulphur. Again referring to the year 1963, Western Europe's and North America's consumption of the various types of elemental sulphur was as follows:

	Western Europe and North American elemental sulphur consumption (1,000 long tons)
Frasch	6,596
Recovered	3,735
Ores	688
Total .	11,015

The use of elemental sulphur in the world has grown considerably in recent years. This has been due to (*a*) a significant increase in the total consumption of sulphur, (*b*) the availability of large supplies of elemental sulphur, (*c*) the low cost of utilizing elemental sulphur and (*d*) the ease of using elemental *versus* other forms of sulphur. However, the most dramatic growth has been experienced by recovered sulphur.

In 1950 when Texas Gulf Sulphur Company installed the first large commercial sulphur recovery plant in the United States, Western Europe and North America was producing recovered sulphur at an annual rate of only some 150,000 long tons. In 1963, recovered sulphur production in Western Europe and North America was 4,038,000 long tons. Today, some 20 countries in Western Europe and North America produce recovered sulphur. In 1963 three countries — the United States, Canada and France — accounted for over 90 per cent of this production. In the United States there are now nearly 70 sulphur recovery plants producing a million long tons annually of recovered sulphur. Over one half of this amount originates from refinery gases whereas almost all of the recovered sulphur produced in Canada and France originates with sour gas.

From the petrochemical viewpoint, the production of commercial quantities of sulphur from petroleum refinery gases and sour natural gas requires considerable special equipment and capital. It demands marketing a new product, sulphur. It involves considerable equipment relating to the storage and handling of sulphur with costs exclusively devoted to sulphur. New sources of plant corrosion are encountered. It requires spending time and energy on what is generally the minor part of the plant.

C. POSSIBLE SULPHUR PRODUCTION FROM PETROLEUM SOURCES

Recovered sulphur is produced from the hydrogen sulphide contained in petroleum refinery gases and in sour natural gases. Therefore, the percentage of hydrogen sulphide in the raw gas stream as well as the quantity of raw gas treated will determine the recovered sulphur production rate.

In the production of sour natural gas, hydrogen sulphide appears as one of the constituents. However, the hydrogen sulphide appearing in petroleum refinery gases has been generated through processing the sulphur containing crude oil.

Most of the gas producing desulphurization processes yield hydrogen sulphide. Therefore, the practical quantity of sulphur that may be recovered in a refinery would be equal to the hydrogen sulphide produced during the refining steps.

The quantity of hydrogen sulphide evolved at a particular refinery is a function of (*a*) the quantity of crudes processed, (*b*) the quantity of sulphur in the crude, (*c*) the types of sulphur compounds in the crude, (*d*) the types of refining processes employed and (*e*) the quantity put through the various processes. In general, some 20 to 50 per cent of the sulphur entering with the crude oil is available as hydrogen sulphide; however, more extensive utilization of newer desulphurization techniques may increase this percentage in the future.

To aid in determining the possible sulphur production at refineries, figure I shows the approximate quantity of sulphur entering a refinery with the crude oil as a function of (*a*) barrels of crude oil processed daily and (*b*) sulphur content of the entering crude. For this chart, the specific gravity of crude oil was assumed to be a constant and equal to 0.9. As an example, one may see from figure I that the quantity of sulphur entering a refinery daily when processing 50,000 barrels per day of 2 per cent sulphur crude oil is 140 long tons. If we assume 50 per cent of this sulphur is transformed into hydrogen sulphide, then this refinery has the capability of producing some 70 long tons of sulphur daily.

D. RECOVERED SULPHUR PRODUCTION — BRIEF TECHNICAL DESCRIPTIONS

1. *General*

To produce recovered sulphur generally requires the removal of hydrogen sulphide from the raw gas stream in question (either sour natural gas or refinery gases) and then reacting part of the hydrogen sulphide with air to produce sulphur dioxide. The unreacted hydrogen sulphide chemically combines with the sulphur dioxide, thereby producing recovered sulphur in a very pure elemental form.

Many processes have been studied and developed for the removal of hydrogen sulphide from the sour or refinery gas streams, but two predominate. The one most often used is the amine process. In the absorption cycle of this process, either monethanolamine or diethanolamine forms a loose compound with hydrogen sulphide and carbon dioxide. The acid gases are released by depressuring and heating the absorbent solution to an elevated temperature. These gases are then sent to the sulphur plant and the regenerated amine solution is cooled and returned to the absorption cycle.

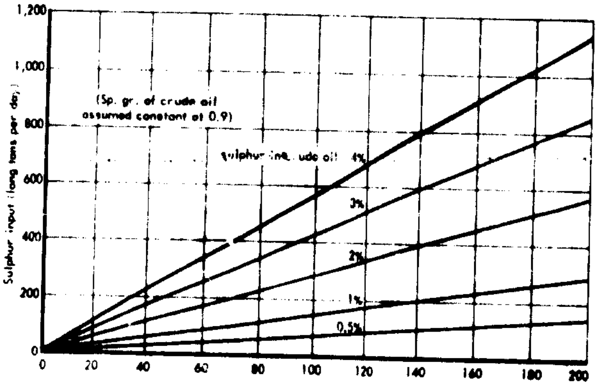


Figure I. ***Sulphur entering refineries with crude oil***

Another process commonly used for acid gas absorption is the hot potassium carbonate process. In general, this process is employed when treating gases at higher temperatures and pressures and when degradation of amine may occur due to certain constituents in the gas stream.

A more detailed description of both of these processes follows.

2. *Hot potassium carbonate process*

Sour natural gases containing carbon dioxide and low percentages of hydrogen sulphide can best be treated by a variation of the hot potassium carbonate process, provided complete removal of the carbon dioxide is not required. The amount of carbon dioxide present will determine the circulation characteristics of the absorbing solution. If very high carbon dioxide contents are encountered split stream circulation methods are frequently employed.

The hot carbonate process is best utilized at absorption pressures in excess of 250 psig with a sour gas stream containing between 5 and 50 per cent acid constituents, and when the residue gas specifications permit 0.1 per cent hydrogen sulphide or carbon dioxide. Major items of equipment consist of absorber, reactivator, circulating pumps and reboilers. The primary equipment advantage of the hot carbonate process is the absence of expensive heat exchanger equipment. In the carbonate process the acid gases are released from the rich carbonate solution by pressure reduction rather than heat input.

Figure II depicts the various arrangements that are usually encountered in the hot carbonate process. Sour gas enters the base of the absorber and is contacted with a counter-current flow of 30 per cent hot potassium carbonate solution. Residue gas leaves the top of the absorber while hot rich carbonate solution is withdrawn from the bottom of the absorber and is permitted to flash into a

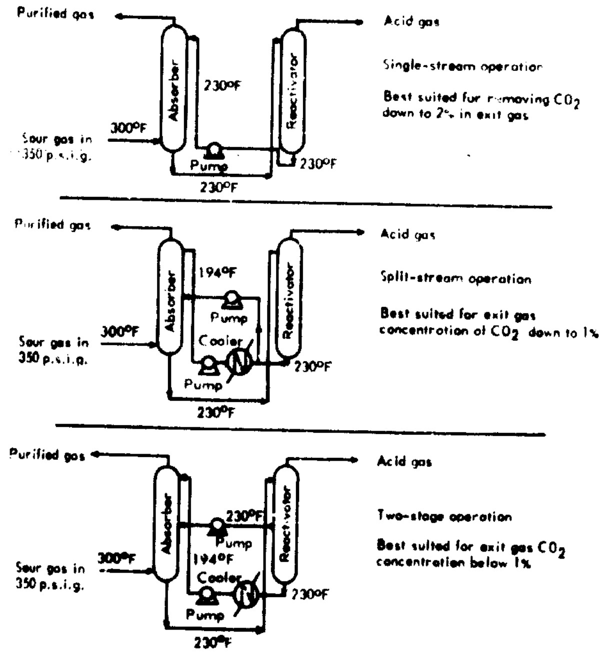


Figure II. *Hot carbonate process*

reactivator tower whose operating pressure is considerably lower than the absorber. Normally, steam heated reboilers maintain the carbonate solution temperature at the same level throughout the absorption and regeneration cycle.

Split stream variations, as illustrated in figure II, include the injection of two streams into the absorber. This split absorption stream may result simply from a division of the totally regenerated carbonate stream or in a second case it may involve withdrawing a partially regenerated stream from the reactivator and using this as a preliminary absorption stream in the absorber. Considerable emphasis has been placed upon the use of power recovery turbines to drive the solution pumps in this type of operation.

When sour gases are encountered with very high carbon dioxide and hydrogen sulphide contents, it may be beneficial to combine two gas cleaning operations. The hot potassium carbonate process has been used to pretreat these very sour gases and the monoethanolamine process has been utilized to rid the residue gas of its last traces of acid gas constituents.

3. *Amine process*

Of the two basic amine absorbents normally used in industrial practice, monoethanolamine or MEA was first used because it has a great absorption capacity for the acid constituents present in sour natural gas. However, a slight increase in the absorption of higher molecular weight hydrocarbons is encountered. For the treatment of refinery gases containing high precentages of these heavy hydrocarbon fractions, carbonyl sulphide, and carbon disulphide, diethanolamine or DEA was found to be a very effective absorbent.

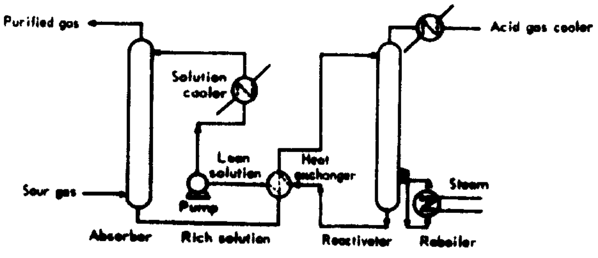
Figure III illustrates a typical aqueous monethanolamine flow diagram. Normally the MEA strength is between 15 and 20 per cent. The remaining solution is condensate free of normal soluble water salts to eliminate scale and corrosion. Depending upon the absorption pressure, the residue gas will contain from 1/4 to 1 grain of hydrogen sulphide per 100 cubic feet or less while the carbon dioxide content will be approximately 10 ppm.

Sour natural gas is admitted to the base of the absorber and is contacted by a counter-current flow of cooled regenerated amine solution (lean MEA solution). The resulting sweet gas is discharged at the top of the absorber. All acid constituents remain in the amine solution which leaves the absorber at the bottom. This solution is generally termed rich MEA solution. The rich solution passes through an amine solution heat exchanger and into the top of the reactivator.

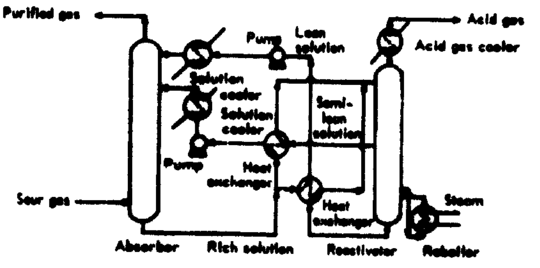
Reactivation of the rich amine solution is accomplished by means of steam heated reboilers. Here the amine solution is boiled and the resulting steam serves as a stripping medium in the reactivating tower. Hot regenerated (lean) amine solution having lost all of its absorbed acid gas, leaves at the bottom of the reactivator. The acid gas is released from the solution through the action of the heat stripping steam, and is removed at the top of the reactivator.

This gas stream is cooled and the condensed water vapour returned to the reactivating tower to serve as a reflux. Cooled acid gas is sent to the sulphur recovery plant for conversion to elemental sulphur.

The hot lean solution leaving the reactivator serves as the heating medium for the incoming rich solution as they pass counter currently through the amine solution heat exchangers. Immediately following the amine heat



Normal process



Split stream operation

Figure III. *Amine process*

exchanger the lean solution is further cooled to 100°F in the amine solution cooler. From here the lean MEA solution enters the absorbing tower to begin another absorption cycle.

A split-stream amine process has been developed to treat sour gases containing an excess of 40 per cent acid gas and yield a residue gas to meet the most strict residue gas specifications. Basically, the flow pattern is that of the normal amine operation with the exception of the addition of a semi-lean solution stream. This stream is withdrawn from the mid point of the reactivation cycle and is used as a feed to the first section of the absorber. A very thoroughly regenerated lean solution is used as a feed to the top of the absorber. The combined amine feeds are removed from the base of the absorber as one rich solution stream. Such a method tends to use a minimum amount of steam for amine regeneration.

The diethanolamine or DEA process utilizes roughly the same equipment and equipment arrangement as the MEA operation. The primary difference occurs in the type of sour gas to be treated. In purifying refinery gas or natural gas containing carbonyl sulphide and carbon disulphide the use of DEA may be considered to be more feasible than the use of MEA. Carbonyl sulphide and carbon disulphide react with the MEA and form degradation products of a very high molecular weight. These products represent a very corrosive material in the amine solution as well as a loss of absorbent. DEA will not react with carbonyl sulphide or carbon disulphide, thus eliminating the replacement of a costly absorbent and the formation of a serious corrosive solution.

Recent variations of the monoethanolamine process have produced a system that now permits the treatment of very sour natural gases containing high percentages of carbonyl sulphide, carbon disulphide, and the various mercaptans. Generally the resulting residue gas will meet specifications of 1/4 grain of hydrogen sulphide per 100 cubic feet, trace quantities of carbonyl sulphide, carbon dioxide and mercaptan.

4. *Sulphur plant*

The acid gases resulting from the regeneration of the absorbing solutions are next sent to the sulphur plant. Here a portion of the hydrogen sulphide is reacted with air to produce sulphur dioxide which in turn is reacted with the remaining hydrogen sulphide to produce sulphur. The process may be either split stream or partial combustion — this refers to burning all of a portion of the hydrogen sulphide to sulphur dioxide in the split stream or burning a portion of all of the hydrogen sulphide in the partial combustion process. Selection of the type of sulphur recovery unit to be used depends upon the chemical characteristics of the acid gas and the quantity of acid gas to be processed.

In general, the smaller sulphur recovery plants (less than 50 tons per day) tend toward the split stream design (figure IV). Also, it has been advantageous to utilize the split stream feature when the acid gas contains excessive quantities of carbon dioxide. Carbon dioxide volumes in excess of 60 per cent represent an acid gas that will not readily support combustion. It is difficult to control the oxidization of hydrogen sulphide to sulphur when excess quantities of carbon dioxide are present, therefore, the complete conversion of the hydrogen sulphide to sulphur dioxide is preferred.

Split stream operations involve the complete combustion of one-third of the acid gas stream as illustrated by equation 1.

$$H_2S + 1\tfrac{1}{2}O_2 \rightarrow SO_2 + H_2O \qquad (1)$$

The combustion products are then commingled with the remaining two-thirds of the acid gas stream in preparation for catalytic reaction as illustrated by equation 2.

$$2\,H_2S + SO_2 \rightarrow \frac{3}{x}\,S_x + 2H_2O \qquad (2)$$

Catalytic conversion of the hydrogen sulphide and sulphur dioxide to elemental sulphur is an exothermic

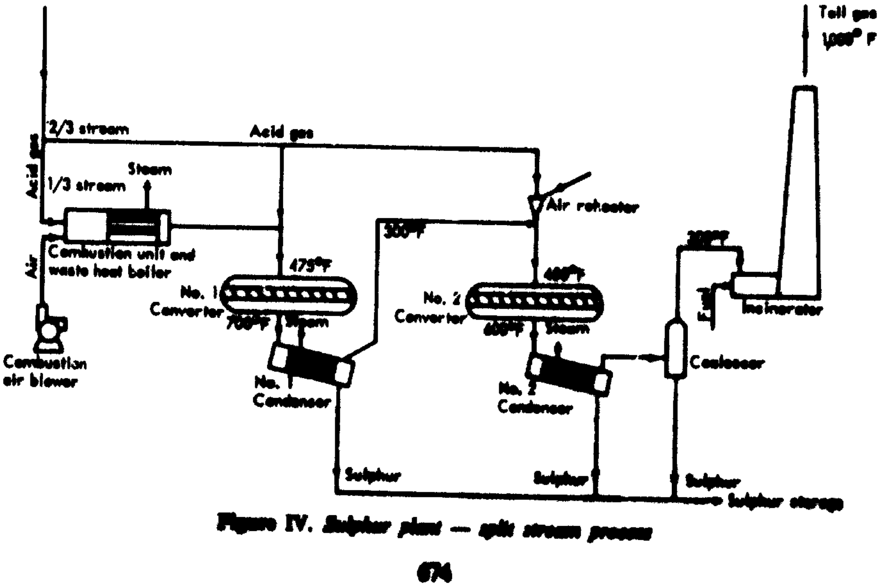


Figure IV. *Sulphur plant — split stream process*

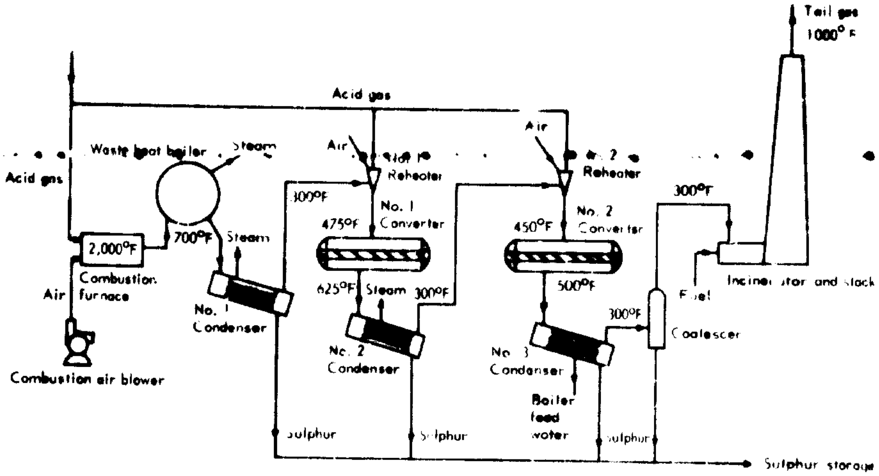


Figure V. *Sulphur plant — partial combustion process*

reaction, yielding considerable heat. The total gas stream from the first catalytic converter is then cooled so as to condense the vaporous sulphur. This condensation operation will yield waste heat that may be utilized in other sections of the processing plant. Normally, the acid gas stream after sulphur condensation would be in the neighbourhood of 280 to 330°F. It now becomes necessary to reheat this gas stream to approximately 400 to 450°F. This is accomplished by either of several heat exchange methods.

1. In-line gas fired reheater using acid gas or natural gas.
2. Heat exchange with the gas stream immediately after the first catalyst reaction.

Again, the catalyst reaction in the second converter yields vaporous sulphur. Immediately following the second converter a second sulphur condenser is employed to condense and remove the elemental sulphur formed by the second catalytic reaction.

In some instances the catalytic operation is repeated; however, the general practice has been to utilize only two such catalyst conversion steps.

Generally for the larger type sulphur plant and for acid gas streams containing over 50 per cent hydrogen sulphide, a partial combustion process is employed in the sulphur recovery plant (Figure V).

Acid gas is metered to a reaction furnace and an automatically proportioned stream of combustion air is supplied to produce partial combustion as illustrated by equation 3.

$$H_2S + \tfrac{1}{2}O_2 \rightarrow 0.7S + 0.8H_2O + 0.2H_2S + 0.1SO_2 \qquad (3)$$

Completion of the reaction leading to the formation of sulphur is limited to approximately 65 to 70 per cent and as the retention time in the combustion zone decreases the conversion also decreases.

The gases from the reactor furnace pass to a waste heat boiler. Here steam is produced as the gases are cooled and the vaporous sulphur condensed. To reheat the gas stream prior to catalytic conversion several heat exchange methods have been devised.

1. A slip stream from the hot section of the waste heat boiler may be by-passed and commingled with the total gas stream so as to adjust the temperature of the gas to the catalyst unit to approximately 450 to 500°F.
2. A second method that lends itself to excellent control by instrumentation is to utilize an in-line acid gas burner and heat the total acid gas stream to the desired temperatures by controlling the quantity of acid gas consumed in the burner. Here the very hot products of combustion are commingled with the main gas stream achieving maximum heat exchange.

The vaporous sulphur produced in the catalyst convertor is condensed and removed from the system by a second condenser which also acts as a boiler producing low-pressure process steam.

A second in-line burner reheats the gas stream prior to entering the second (and usually final) catalytic convertor. The gaseous reaction products then go to a third sulphur condenser-coalescer. The object of the coalescer is to remove fine sulphur mist by passing the gas through a finely divided mesh or screen.

Finally the total gas stream is passed through an incinerator to convert all the remaining sulphur and hydrogen sulphide to sulphur dioxide before admission to the atmosphere.

Sulphur condensed in the waste heat boiler, the condensers and the coalescer is pumped to liquid storage or is solidified in a block or vat for future shipment.

Sulphur recovered from sour natural gas or refinery gases generally is very bright in colour, however, excessive quantities of hydrocarbon (4 per cent or greater) will not only poison the catalyst but will also produce a dark sulphur product in the reactor furnace section. Therefore, it is highly desirable that the acid gas stream for processing contains a minimum quantity of hydrocarbon. If catalyst bed temperatures fall below the sulphur dew point, sulphur condensation will rapidly foul the catalyst section. Some catalyst deterioration will occur due to dusting resulting from thermal decomposition.

Recovered sulphur is normally over 99.9 per cent pure, it is free from objectionable metallic contaminants such as arsenic, selenium and tellurium, and, as stated above, is very bright in colour.

E. PRODUCTION COSTS

1. *General*

As indicated above, recovered sulphur may be produced in refineries that process sour crudes or in plants that treat sour natural gas. Also, as shown above, the removal of acid gases, and in particular hydrogen sulphide, from the sour gas produces a sweet gas. If the sweet gas has economic value, then part of the process and costs for producing sulphur, namely, the absorption cycle, is necessary regardless of whether sulphur is produced or not. However, in instances where there is no demand for the sweet gas, then it may not be worthwhile to produce the sour gas or treat the refinery gas at all except where atmospheric pollution may require it.

The chances are that most of the new sulphur recovery plants to be built in the world will be coincident with petroleum refineries rather than sour natural gas sources. However, if a refinery has no need for the sweetened refinery gases, then the entire cost of purifying the refinery gases and producing the sulphur must be borne by the sulphur alone.

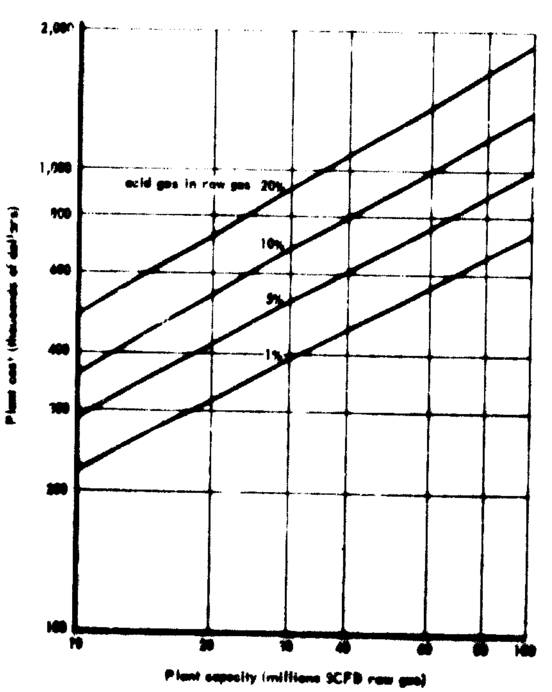


Figure VI. *Capital costs of amine plants*

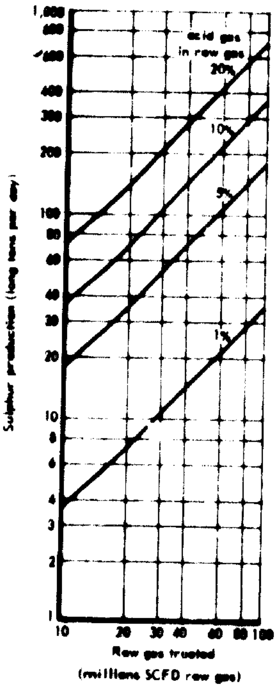


Figure VII. *Maximum sulphur production from raw gases (acid gas = 100 % H_2S)*

What are these costs? As implied earlier, they include much more than the capital and operating costs of the gas absorption-desorption cycle and the sulphur plant. They include provisions for maintaining adequate inventories, costs of loading equipment, acquiring proper transportation equipment, the cost of marketing and the like. However, we shall limit our discussion to capital and operating costs of an acid gas absorption plant and a sulphur plant.

2. *Acid gas absorption-desorption plant*

For this plant, it is assumed that a monoethanolamine system is used. Figure VI indicates the capital cost of such a plant as a function of (*a*) quantity of raw gas treated and (*b*) per cent of acid gas in the raw gas. In addition to these two parameters, the percentage of hydrogen sulphide in the acid gas is needed to determine the quantity of recovered sulphur production. Figure VII shows this sulphur production rate for an acid gas stream containing 100 per cent hydrogen sulphide. By multiplying the data obtained from this figure by the fraction of hydrogen sulphide actually in the acid gas, one obtains the expected sulphur production from the raw gas stream in question. Applying this technique to the data of figure VIII, one may determine the approximate amine operating costs per long ton of sulphur produced.

As an example we shall determine the absorption-desorption cycle costs for processing 50 million standard cubic feet per day of raw gas containing 5 per cent acid gases and whose acid gases are 75 per cent hydrogen sulphide. From figure VI we estimated the capital cost of such a plant as $665,000. Figure VII tells us that 0.75, 90, or 67½ long tons of sulphur would be produced daily from such a gas stream. Figure VIII indicates that the operating costs of this cycle would be 12.75/0.75, or $17 per long ton of sulphur. The acid gas is now ready to be sent to the sulphur plant.

2. *Sulphur plant*

The cost of producing sulphur is a function of (*a*) the quantity of acid gas processed and (*b*) the percentage of hydrogen sulphide in the acid gas. Figure IX presents approximate capital and operating costs of producing sulphur from an acid gas containing some 75 per cent hydrogen sulphide. Continuing with our example, one learns that the sulphur plant costs are as follows: capital costs — $75,000; operating costs $6.50 per long ton.

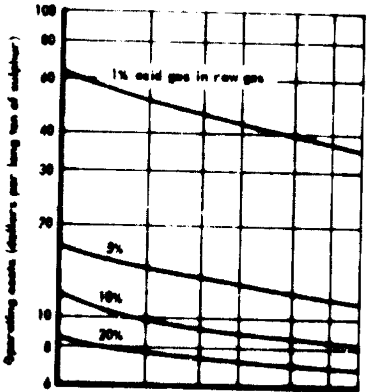


Figure VIII. *Amine operating costs per long ton of maximum sulphur production (acid gas — 100 % H_2S)*

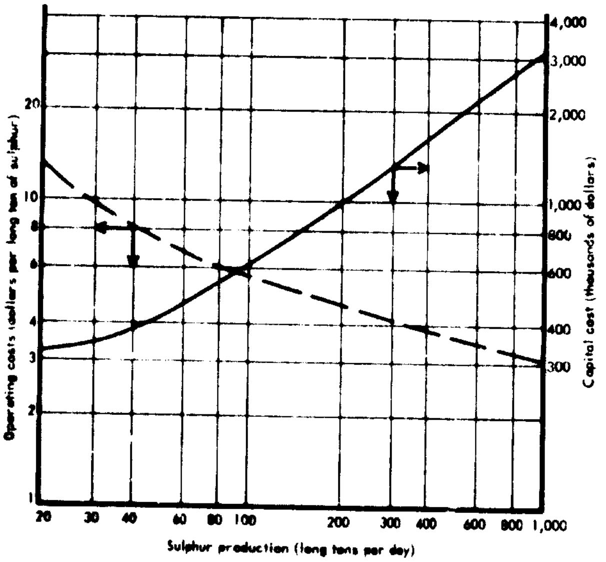


Figure IX. *Sulphur plants — capital and operating costs*

In summary, the costs of producing the sulphur in the example are:

	Amine plant $*US*	*Sulphur plant* $*US*	*Total costs* $*US*
Capital costs	685,000	475,000	1,160,000
Operating costs.	17.00/LT	6.50/LT	23.50/LT

F. Conclusion

This paper attempts to present data useful for appraising petroleum as a source of sulphur. Since many variables affect not only the costs of producing recovered sulphur but also the process to be employed, generalized conclusions are unwarranted.

4. CARBON BLACK PRODUCTION IN DEVELOPING COUNTRIES

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It is quite reasonable to begin by viewing carbon black as a petrochemical product. By far the largest percentage, at present close to 80 per cent, of the entire world's carbon black production is made from petroleum refinery fractions. Therefore, carbon black meets the first test of a petrochemical: it is a continuous processing plant using highly automated reactor systems which operate with a relatively small labour force. A flow diagram, a plant layout, and a photograph of a typical modern furnace carbon plant are shown in figures I, II and III. As the flow diagram clearly indicates, even the processing and packaging stages of carbon black manufacture have been modernized and reduced in labour requirements so that these operations are very efficient and low in cost.

Like other petrochemicals, carbon black production is characterized by a relatively low ratio of product sales value per dollar of investment when operating at full plant capacity. This ratio, which tends to be higher for carbon than for most petrochemicals, is typically 0.5 to 0.8. A tabulation (table 1) of those furnace carbon plants built outside of the United States since 1949 gives the relationship between capital costs and the annual capacity in the various producing locations. As noted in the two columns at the extreme right, the cost of new plants varies, in most cases, from 10 to 15 cents per annual pound of installed capacity. Plant expansions, on the other hand, average typically 40 to 60 per cent as much as a new grass roots plant of comparable capacity.

The capacity of United States carbon black plants is presented in table 2. It is clear that the average plant size is considerably higher within the United States than outside, a factor which favours the economy of United States plants over most foreign plants.

Finally, carbon black may be regarded as a petrochemical in that the production cost and sales price are each relatively low and net profit after taxes, in turn, is often a matter of a few tenths of a cent per pound except in larger plants that are also favourably situated with respect to fuel supply.

At this point, however, all similarity between carbon black and the usual petrochemicals ceases. Carbon black is a highly empirical product the properties of which are measured entirely on a functional basis, i.e., by end-use testing rather than by rigorous physical or chemical tests. The plant layout diagram (figure II) indicates the approximate proportion of a plant required for this function.

Another dissimilarity is that the manufacture of carbon black does not lead to by-products, co-products or next-stage derivatives as is normally expected for petrochemicals in general. The manufacture of one petrochemical tends to spawn a second generation of products and these in turn spawn several other generations of products. For all practical purposes carbon black has no use other then the manufacture of rubber goods; the amount used for pigmentary purposes of the order of 5 per cent of the total in a highly developed economy and perhaps twice this percentage in a less developed country. To justify carbon manufacture there must first be a substantial demand for rubber goods and a local rubber manufacturing industry. It would normally be quite uneconomical to produce carbon black in a non-consuming country with the idea of exporting all of it to other countries.

The fact that the product is almost pure carbon is simply coincidence. That it is made from petroleum fractions is purely a matter of convenience and cost. It can be made as well from coal tar by-products and no doubt processes could be devised to produce highly satisfactory carbons from vegetable oils and other materials containing a high content of chemically combined carbons. As a matter of fact, the ancient Chinese made excellent carbon for tinctorial use from vegetable oils.

From the standpoint of its applications properties and control of quality as well as from the standpoint of technical service and research required, carbon black is much more to be compared with a plastic material such as polyethylene than it is to be compared with a basic petrochemical such as methanol, benzene, butadiene, and the like. As mentioned, the successful operation of an isolated carbon black plant requires a complete rubber compounding and testing laboratory in order that the product be suitable for use when the customer receives it. Because it is so highly end-use oriented, carbon black must, therefore, be taken out of the category of the basic petrochemicals and be regarded as a highly functional, up-graded material requiring rather sophisticated technology both in manufacture and in applications testing for a successful business operation. These requirements tend to mitigate against small carbon black plants located far from highly industrialized areas. Table 1 shows how the build up of production outside of the United States since 1949 has been concentrated in Europe and Japan. The effect of this build up is shown in figure IV in terms of production. The world production is increasing at

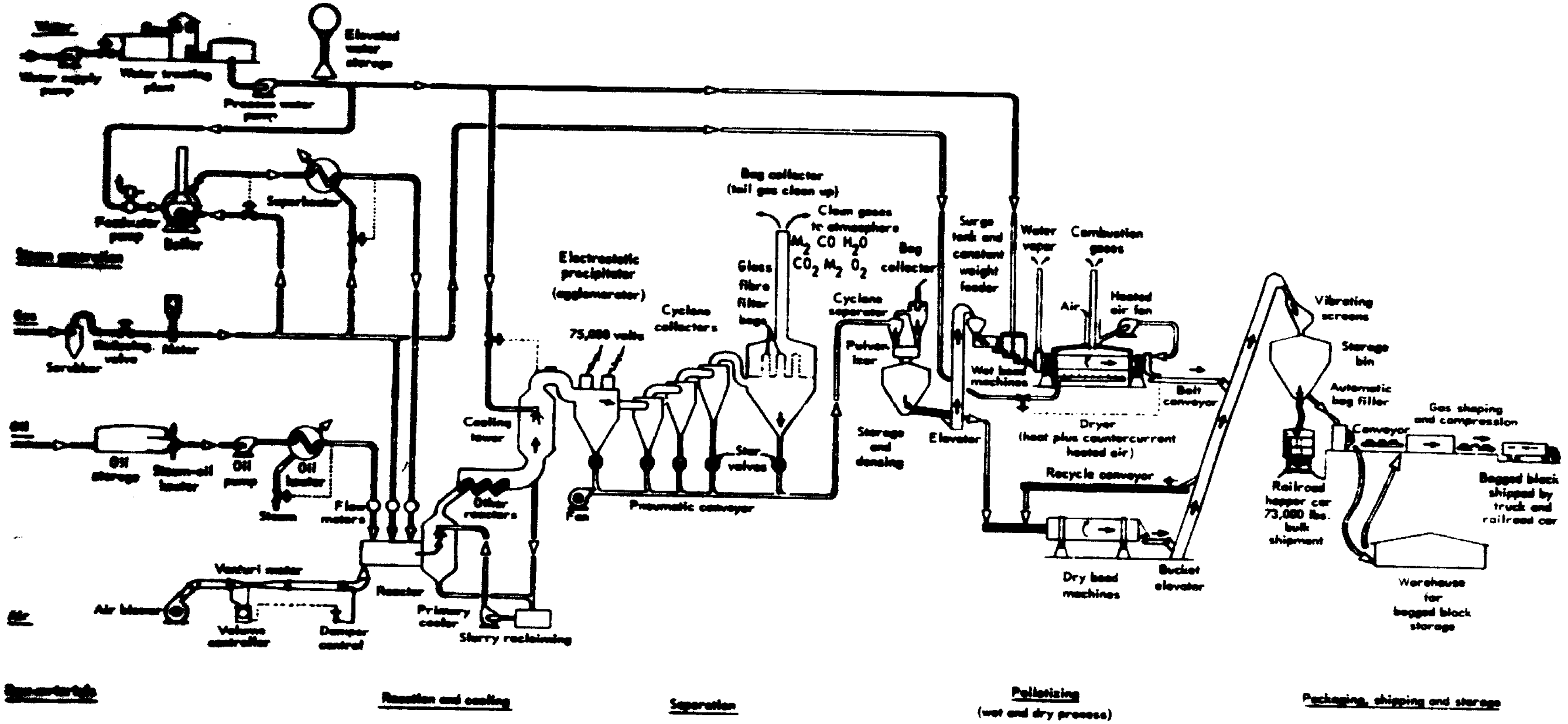

Figure 1. *Process flow diagram, oil furnace process*

TABLE 1. CAPITAL COST AND CAPACITY

(In carbon black plants built since 1949 outside of the United States)

Country	Owner(s) or Process licensee(s)	Capital cost MM $	Estimated annual capacity, millions of pounds	¢ per annual pound of capacity	Expansions, ¢ per annual pound added
Australia	Cabot-United	N.A.	58	—	
Brazil	Columbian	4.5	40	11	
	Phillips	N.A.	30	—	
Canada	Cabot	3.0	25	12	
	Cabot	3.5	60 (expansion)	—	6
UAR	Columbian	5.0	40	13	
		4.5	10 (planned for 1965)	Not significant	
France	Cabot	—	102	—	
	Phillips	N.A.	55	—	
	United	5.0	50	10	
Fed. Rep. Germany	Degussa	—	100	—	
India	Phillips	3.2	33	10	
	United	4.5	30	15	
Italy	Cabot	3.3	30	11	
	Phillips	N.A.	25	—	
	Columbian	5.0	60	8	
Israel	United	3.0	20 (completed 1963)	15	
Japan	Tokai Denkyohu & Cabot	N.A.	30	—	
	Phillips	N.A.	15	—	
	Mitsubishi Kasei & Columbian	N.A.	30	—	
	Continental	N.A.	13	—	
Mexico	Phillips	4.0	33	—	
Netherlands	Continental (Columbian)	2.5	30	8	
		1.8	30 (expansion)	—	6
	Cabot	—	60	—	
U. of South Africa	Phillips	N.A.	22	—	
United Kingdom	Cabot	2.4	20	12	
	Cabot	—	124	—	
	Phillips	—	140	—	
	United	N.A.	30	—	
Venezuela	United	3.0	20	15	
Argentina	Cabot	4.0	26	15	
Spain	Calvo Sotelo & Phillips	4.5	22	20	

a rate considerably higher than that of the United States reflecting both a more rapid increase in consumption and replacement of importation with local production. A key factor in bringing about the latter situation is the high cost of transporting carbon black due to the low density (20-28 #/cu.ft.) of even the most dense pelletized form. Transportation of the raw material, on the other hand, can be relatively cheap although there are many circumstances in which this is far from true.

It may be well at this point to look briefly at the nature of the raw material problem. The manufacture of carbon black to be economic with present day technology requires a specialized fraction from a petroleum refinery. This fraction must be high boiling and high in aromatic content. At the same time it must contain a minimum of sulfur and almost no amount of inorganic materials. Such a material has approximately the same handling properties as the usual grades of bunker oils. Carbon black raw materials of the required type are produced only in the larger refineries which stress the production of gasolene by catalytic cracking at the expense of heavy fuel oils and the lighter grades of fuel oils. Such deep cracking refining operations are relatively uncommon outside of North America. It is therefore not surprising to find that the first carbon black plants located outside the United States were started with fuels from the United States. A very large part of the carbon black manufactured in Europe is still made from petroleum raw materials imported from the United States.

Since in the less industrialized countries it is practically impossible to find a local supply of a suitable feedstock for carbon black manufacture, in planning for carbon black production in such countries one must start out with the assumption that the fuel will be brought from another country. The only practical method for shipping fuel from a cost standpoint is by tanker. This immediately means that sufficient tanks must be provided on the receiv-

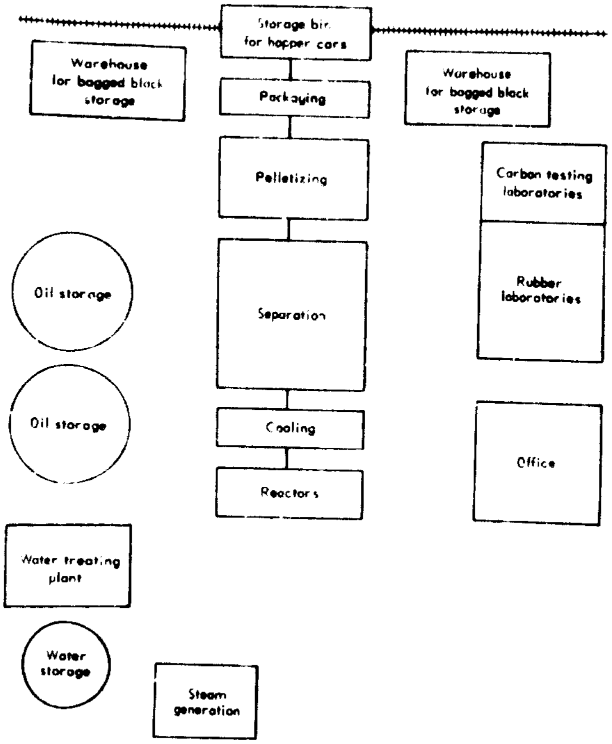

Figure II. *Carbon black plant layout*

ing end to unload an entire tanker or at least a half a tanker. Because of the relatively high cost of overland transportation, the fuel situation also dictates that the carbon black plant be located at the seaport, if at all possible.

Since the cost of raw materials is a high proportion of the total cost of making carbon black, especially under the circumstances common in the developing nations, one sees that the value added to manufacture is reduced by the excessive raw material cost unless the price of the product is artificially raised above the cost of imported carbon black.

If we now look at the broader problem of carbon black production in the smaller, less developed countries, it is clear that the following considerations need to be applied to their situation.

The basic purpose of developing the economy of a country is to bring about the accumulation of capital. Interestingly enough, this same result is sought regardless of the political ideology of the country in question. What we must know, therefore, is whether the use of a certain amount of scarce capital in the country in question will bring a sufficiently large return on that capital to bring about new capital accumulation at a rate which is significant compared to the best alternatives. Here is where the problem begins to get complicated. If the plant is too small, outside capital will not take any or all of the risk because the return is not sufficient.

Such risk is considerable. While no precise figures can be given, as a general rule it requires a production rate of 35 to 55 MM pounds per year in the United States of the higher grade carbon black for rubber in order to achieve a satisfactory operation from a competitive and economic standpoint. The cost of such a plant built abroad can vary quite widely from the range of costs that would prevail if built in the United States under United States standards. This United States range is between about $2-1/2 and $5 MM or 7 to 10 cents per annual pound, the variation being due to size and to the extent extra facilities are required in the plant, such as a rubber laboratory. As noted above, plants located in less industrialized areas require additional facilities in order to be

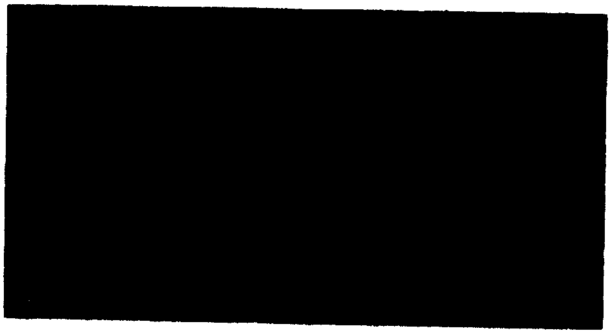

Figure III. *Modern oil furnace carbon black plant (Columbian Continental Europa — Italy)*

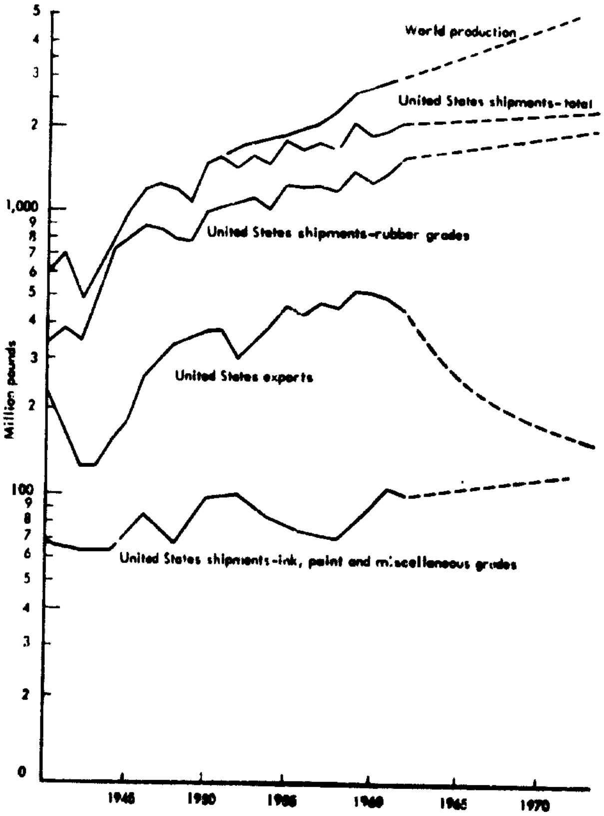

Figure IV. *United States carbon black shipments and exports and world production*

TABLE 2. UNITED STATES CARBON BLACK PLANTS

Producer	Location	Production capacity (millions of pounds annually)		
		Furnace	Thermal	Channel
Cabot	Big Spring, Texas	120		
Cabot	Franklin, Louisiana	170	110	
Cabot	Pampa, Texas	48		
Cabot	Skellytown, Texas			36
Cabot	Ville Platte, Louisiana	170		
Columbian	Conroe, Texas	111		
Columbian	El Dorado, Arkansas	87		
Columbian	Eola, Louisiana	70		
Columbian	Hickok, Kansas	52		
Columbian	North Bend, Louisiana	110		
Columbian	Seagraves, Texas	91		
Columbian	Seminole, Texas			40
Continental	Bakersfield, California	50		
Continental	Eunice, New Mexico			25
Continental	Ponca City, Oklahoma	75		
Continental	Sunray, Texas	60		
Continental	Westlake, Louisiana	70		
Huber	Borger, Texas	115		10
Huber	Eldon, Texas	115		
Phillips	Borger, Texas	290		
Phillips	Orange, Texas	60		
Richardson	Big Spring, Texas	50		
Richardson	Odessa, Texas			60
Shell	Pittsburg, California		15	
Thermatomic	Sterlington, Louisiana		120	
United	Aransas Pass, Texas	90		
United	Ivanhoe, Louisiana	145		
United	Johnson, New Mexico			30
United	Mojave, California	64		
United	Shamrock, Texas	100		
GRAND TOTAL		2,313	245	201

operable. Such additional facilities include utility producers, a complete rubber laboratory and often housing facilities for the workers. For this reason, and because of their generally smaller initial sizes, foreign plants cost typically 10-15 cents per annual pound as noted previously.

It would be difficult to state precisely what the unit production cost would be in such a plant and in addition to give such costs would reveal highly confidential information which no carbon black producer likes to do. On the other hand, it can be stated that raw material cost in foreign plants tends to run in the range of 15-25 per cent of the net sales value.

Because the technology is so specialized, and because the management it requires is considerable and of a highly technical nature, the fees which are charged by owners of carbon black patents and know-how are relatively high, ranging perhaps from 5 to 10 per cent of the selling price, depending upon the kind and amount of continuing services rendered by the licensor to the licensee.

If carbon prices are raised artificially within the country in order to provide a return on capital for outside investors, then the prices on rubber goods must rise accordingly. In many cases, an increase in the cost of rubber goods cannot be tolerated because such an increase will interfere seriously with the export sales from the country in question. Even if export sales are not important, an artificial increase in the price of rubber goods in order to pay a return on investment to an outside source of capital simply penalizes the rubber goods manufacturer so that he has less return on capital. If the price increase is passed on to the consumer then the consumer may consume less. According to the capitalistic theory of investment, there is no way around this dilemma. If the capital is taken away from the consumer or the rubber goods manufacturer in order to subsidize the foreign investor, there is very little if any gain in capital accumulation in the country.

If all local capital is used and the plant is of uneconomic size, the result in the long run is practically the same. Capital is used for one purpose which could be better used for another.

Very obviously a specific case must always be viewed as just that. There will always be special circumstances and special economics governing the production of carbon black in any given country. However, in summary it can be said for the general case that the manufacture of carbon black is a highly specialized matter requiring a high capital, high technical skill and usually an imported raw material and consuming a rather low amount of labour. It is not among the first petrochemicals that would be considered in the development of the economy of a smaller nation. On the other hand, carbon plants may often be put in developing countries by private enterprise before the local demand for carbon is large enough to make such an operation profitable. This is done to gain an early market position looking several years ahead to larger local use and to keep competitors out as long as possible. Government assistance to a potential producer may produce the same result. Thus the development of carbon black production in the developing countries has tended to lead the need rather than to lag behind it, a situation which is understandably encouraged by the local governments. Such early producing plants are usually built to be expanded later, a practice which further tends to lower the return on capital in early years but, at the same time, makes the cost of expansion relatively cheaper once the market begins to grow.

5. MULTIPURPOSE REACTOR FOR THE PRODUCTION OF SELECTED PETROCHEMICAL INTERMEDIATES AND END-PRODUCTS

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I. INTRODUCTION

Possibly petrochemical and polymer chemistry have influenced more personal lives and the establishment of more businesses than has any other field in modern chemistry. Dramatic advancements and development changes are continuing to provide a large variety of products. Every country of the world uses these products in a growing list of applications, and most countries produce portions of their own needs in one form or another. Countries who use petrochemicals as raw material for production are in a position to fully develop their own market using advanced technology available and have export potential as well. Countries having no petrochemical or a developing petrochemical industry can take advantage of the growing world supply of monomers to prepare finished products for their own consumption. When petrochemical plants are later established within their borders, they can integrate backwards to the then established source of material for production of finished products.

The large primary petrochemical establishment seldom makes products for use by the consumer. There have been many approaches to the intermediate step between the oil industry and the ultimate user. In many cases, single product plants are established such as a mill to produce polystyrene plastic for moulding and injection users. Another mill is set up for polyvinyl chloride and so on. In large countries with high-consumer demand, these operations have met with some success. In many areas, there is simply not sufficient demand to establish single product units.

There is an alternative available which can be described as the *multipurpose reactor* concept. This permits a manufacturer to establish his operation at minimum cost and with minimum risk. The products are made from a wide variety of petrochemicals, all of which are available from either domestic production or readily imported chemicals. The production covers a spectrum of industry and is not confined to a single segment within each industry. A company starting with a single reactor can grow in logical increments as their own market becomes established and grows. Research offers new and exciting compounds to accelerate growth. There is a critical need for multipurpose plants, particularly in developing countries. The production of selected petrochemical intermediates and end products will do much to relieve import exchange requirements and to promote accelerated industrial growth.

II. MULTIPURPOSE REACTOR

The heart of the multiproduct plant is the reactor. Reactors are not unique; as a matter of fact, the fabricators of such reactors offer them as standard units. This equipment is available in the United States, Europe, Japan, and in many other countries. In some instances, the reactor can be fabricated locally at a saving. The purchaser of the vessel advises the fabricator as to the location, number, and size of openings and piping. Any of the chemical products can be made in either stainless steel or glass-lined vessels.

The reactor specifications for multipurpose use are based on the requirements in manufacturing styrene butadiene copolymers (St/Bd) and polyvinyl chloride resin, as these products require pressure to 200 psi maximum. Most of the other products can be manufactured under normal atmospheric pressure. This reactor provides maximum flexibility and can make the full product mix.

REACTOR FOR THE MANUFACTURE OF STYRENE BUTADIENE TYPE POLYMERS AND POLYVINYL CHLORIDE RESIN

Vessel: Glass lined and/or 316 type stainless steel jacketed		
Design pressure, psi	300 to full vacuum ($21\ kg/cm^2$)	
Operating pressure, psi	150 to full vacuum ($11\ kg/cm^2$)	
Design temperature, °C	315	
Operating temperature, °C	120	
Hydro test, psi	325	($23\ kg/cm^2$)
Jacket: Steel clad or Inconel		
Design pressure, psi	275	($19\ kg/cm^2$)
Operating pressure, psi	180	($13\ kg/cm^2$)
Design temperature, °C	315	
Operating temperature, °C	120	
Hydro test, psi	300	($21\ kg/cm^2$)

REACTOR FOR THE MANUFACTURE OF STYRENE BUTADIENE TYPE POLYMERS AND POLYVINYL CHLORIDE RESIN *(continued)*

Heat transfer:

Heat of reaction (maximum for St/Bd and/or PVC) approximately 25 kcal per mole

Approximate usage:

	4,000-gal (15,000-litre) vessel
Steam, lb/hr, dry & saturated at 75 psig	3,600 (1,600 kilos)
Water, minimum, gpm, circulated	400 (1,500 litres)
Water, cooling, gpm at 50 psig at 25 °C	200 (750 litres)
	1,000-gal. (3,800-litre) vessel
Steam, lb/hr, dry & saturated at 75 psig	800 (360 kilos)
Water, minimum, gpm, circulated	100 (380 litres)
Water, cooling, gpm at 50 psig at 25 °C	40 (150 litres)

Whether a jacket alone is adequate for complete reaction heat removal depends on polymerization rate, amount of agitation, and the solution's physical properties (viscosity, specific heat, and thermal conductivity). Many low viscosity systems, such as low solids butadiene-styrene emulsions, are suitably handled by jacket heat transfer alone. In the more reactive or viscous systems, such as acrylates and vinyl acetates, heat transfer is handled by condenser as well as jacket-heat transfer.

The heat load can be materially reduced by continously feeding monomers or monomer emulsions to the reaction vessel during polymerization. Regulation of the addition of monomer controls mass reaction polymerization, implementing process control, regulated heat transfer, and safety.

Agitation

Agitation serves two purposes — it provides sufficient shear to disperse adequately the monomer in the water phase, and it provides sufficient movement of this liquid mass to insure good heat transfer to the jacket. Turbine agitators are satisfactory for low to medium viscosity emulsion systems (up to 5,000 cps.) such as acrylates, vinyl chloride, vinyl acetate, vinyl chloride copolymers, and butadiene-styrene. For these, moderate agitation is required, because excessive turbulence may cause too fine a particle size which, with corresponding increase of particle surface area, causes emulsifier starvation and subsequent reduction of mechanical stability resulting in excessive floc formation.

For low and medium-viscosity systems (up to 5,000 cps), 4- to 5-horse-power agitation for each 1,000-gallon reactor volume should be provided. For systems with a high viscosity (compounded products and sodium polyacrylates), the finished emulsion may be moderate (5,000 to 10,000 cps.). Turbine agitators of large diameter and slow speed are satisfactory for these systems. For even more viscous systems, low speed paddle, anchor, or gate-type agitators are necessary. A minimum of 10 horse-power per 1,000 gallons reactor volume is required for this type agitation.

Electricity

Single phase, 60 cycle, 110 volts and three phase, 60 cycle, 220/440 volts (adaptable to 50 cycles and 200-volt systems). Explosion-proof motors, drives, wiring, lighting, etc., are required.

Instrumentation

Batch temperature is the most important control, and the temperature bulb in the reactor should be properly located — away from dead spots and in an area of good circulation. Safe operation and cross-checking require an indicating and recording thermometer to measure reactor temperatures.

Batches run at reflux are not readily adaptable to automatic temperature control, since the throttling action of control valves is based on temperature settings. Flow of condenser cooling water is controllable by operating from condensate temperature readings.

Compressed air for instrumentation — 40 psig.

All other installations in the multipurpose chemical plant support the reactor function. A source of steam, power and water with delivery piping is required. Two make-up tanks of small capacity are used for supplementary materials added during polymerization in reactor. Facilities for incoming unloading and storage of monomers are necessary, the extent and volume determined by plant production capacity. In general, storage is provided in tanks (if convenient, placed underground). Pumps for monomer transfer from tank to reactor expedite material handling.

The stripping column is used for synthetic rubber latex manufacture. Traces of unreacted monomer are removed by this column. This could be done in the reactor, but the stripping column permits freeing the more expensive reactor equipment for increased production. This permits a shorter reactor cycle or increases the number of batches that can be run through the reactor in any given time period.

A blend tank receives the primary reactor product for temporary storage, and other additives or polymer blends can be incorporated prior to final product storage. When dry resins are produced, a centrifuge, dryer, pulverizer, and bagger are required. The type and capacity of this equipment are determined by the volume of production and product type. All of this equipment is of standard type requiring no special or extraordinary specifications and is widely available.

The plant construction should include warehouse space for incoming chemical and finished product storage. A small control and testing laboratory is a necessity. Other features are common to any operation such as office area, dock space for trucks, toilet facilities, etc. The entire plant, allowing room for future expansion, occupies about five acres (2 hectares) of land. Waste disposal facilities should be considered. A sewage connexion would be desirable, but inexpensive settling and clarification ponds can be used.

The Multipurpose Chemical Manufacturing chart summarizes the chemical products produced by the multipurpose reactor. The raw materials are the monomers shown on the chart plus other readily available commercial chemicals such as caustic soda, refined clay, solvents, sulfuric acid, and zinc oxide, to name a few of the larger volume items. The products are polymers, copolymers, and terpolymers that have wide trade application. By no means is the reactor complex limited to these specific chemical products. For example, many parts of the world require urea formaldehyde resins. These are readily manufactured. Once established, the chemical complex can meet local needs for many products which are sometimes not made in the United States due to economic factors.

Flow charts showing the processing sequence are shown in figures I through VII incorporated in this discussion. These charts cover a selected group of primary products. All of the chemical products specified in the Multipurpose Chemical Manufacturing summary can be made with a similar flow and using the illustrated equipment. A photograph incorporated in this discussion shows a typical reactor complex. Two reactors and a

MULTIPURPOSE CHEMICAL MANUFACTURING

Basic petrochemical	*Acetylene or ethylene*	*Acetylene or ethylene*	*Ethylene or ketene process*	*Benzene-ethylene catalytic dehydrogenation*	*Petroleum catalytic dehydrogenation of butylene*	*Ethylene or ethylene oxide with HCN*
Monomer . . .	Vinyl acetate	Vinyl chloride	Methyl, ethyl, butyl, 2-ethyl Hexyl acrylates	Styrene	Butadiene	Acrylonitrile
Homopolymers and copolymers from reactor . . .	Polyvinyl acetate — emulsions, solutions & dry resin (beads) Vinyl acetate/acrylic esters Vinyl acetate/crotonic acid Vinyl acetate/dibutyl fumarate Vinyl acetate/dibutyl maleate Vinyl acetate/vinyl chloride Grafted polymers	Polyvinyl chloride — emulsions, solutions & dry resin Vinyl chloride/vinyl acetate Vinyl chloride/acrylic esters Vinyl chloride/fumarates Vinyl chloride/maleates	Polyacrylate-emulsions, solutions& dry resin Polyacrylic acid copolymers Acrylic esters/vinyl acetate	Polystyrene-emulsions, solutions & dry resin Styrenated phenols, etc.	Styrene-butadiene copolymers emulsions, solutions, resins & dry elastomers Carboxylated polymers	Styrene/butadiene/acrylonitrile copolymers, terpolymers & modifications Butadiene/acrylonitrile copolymers, emulsions, solutions & dry elastomers Carboxylated polymers
Other derivatives from reactor	Polyvinyl alcohol Polyvinyl butyral Polyvinyl formal Polyvinyl alcohol Ethoxylations		Sodium, potassium and ammonium polyacrylates			Sodium, potassium & ammonium polyacrylates
Trade use. . .	PAINTS: Interior Exterior PAPER: Coatings Shoe innersoles ADHESIVES: TEXTILES: Stiffeners Sizes Backcoating Body enhancing finishes Hosiery finishing Nonwonen fabrics LEATHER FINISHES Safety glass interlayer Electrical insulation Fibre & asbestos board coating	PAPER: Functional coatings Impregnators ADHESIVES TEXTILES: Stiffeners Flame retardant Component Coatings PLASTICS: Moulded Calendered Extruded Floor tile Phonograph records LEATHER: Artificial Finishes Electrical insulation Pipe and hose	PAINTS: Interior Exterior Industrial Paint thickeners PAPER: Coatings Saturants ADHESIVES TEXTILES: Coatings Abrasion resistants Impregnated finishing Sizes Nonwoven fabrics PLASTICS: Moulded Extruded LEATHER FINISHES Thickeners Latex stabilizers Oil additives Pigment binders	TEXTILES: Sizes Stiffeners Dullers Antislip finishes PLASTICS: Moulded Extruded Floor polishes Electrical insulation ADHESIVES	PAINTS: Interior PAPER: Saturants Coatings Wet end additives ADHESIVES TEXTILES: Printing binders Nonwoven fabrics Laminates Water repellents Anti-Crock PLASTICS: High impact Rug & upholstery backing Pigment binders Foam rubber adhesives	PAPER: Coatings Saturants ADHESIVES: TEXTILES: Finishes Sizes Printing pastes Nonwoven fabrics PLASTIC FIBRES LEATHER FINISHES Solvent resistant specialties Rug & upholstery backing Thickeners

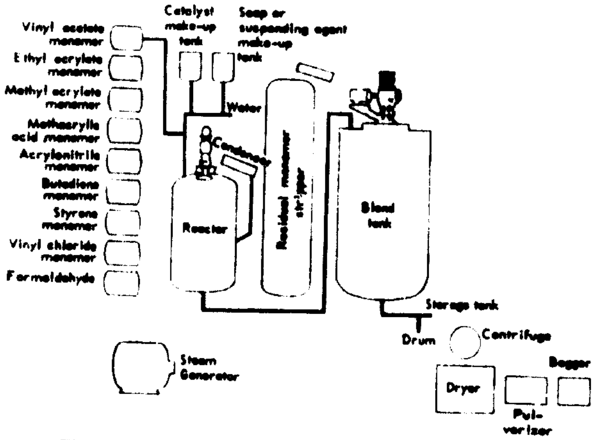


Figure I. *Flowsheet for polyvinyl acetate emulsion*

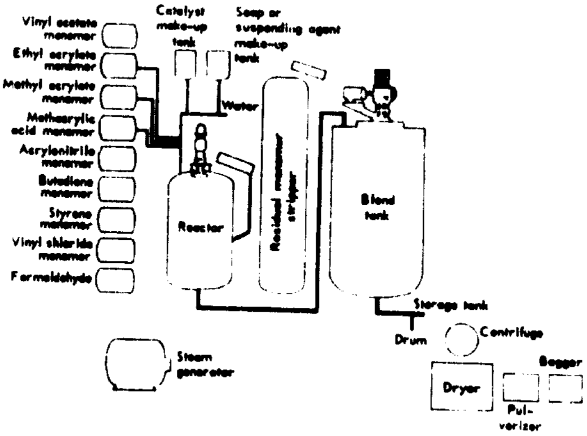


Figure III. *Flowsheet for acrylic emulsion*

stripping column are readily observed, although three reactors are actually installed in this particular complex.

The time required to produce each type of polymer varies greatly. Butadiene-styrenes are processed in as little as eight hours and as many as thirty hours. Generally, polyvinyl acetate can be produced in eight hours or less. Polyvinyl chloride production requires ten to sixteen hours. The polyacrylates average nine to twelve hours. Within each polymer group, the production time varies for specific end products. Certainly a minimum production rate per day would correspond at least to rated reactor capacity (4,000 gallons or 15,000 litres).

Cost of the installed equipment for a complete 4,000-gallon (15,000-litre) multipurpose reactor chemical complex is about $250,000 in the United States. Equipment costs are usually less in Europe and Asia. A sizeable portion of the equipment cost is in the dryer for dry resin production. Should the multipurpose complex be used for emulsions and polymer solutions, a substantial saving can be made. Plant facilities and supporting equipment vary so much that individual plant estimates in the country of establishment are required. The capital cost of a complete operation including operating capital would seldom exceed $500,000 unless large inventories of raw material might be required or a policy of extending credit to users exceeded an average of 45 days.

In initial plant layout, space should be provided for additional reactor installation. Since the products of the reactor are useful in many industries, the volume of production will assuredly increase. The cost of adding the first and subsequent reactors to an established plant is less than $75,000 per unit. The cost of these additions is quickly returned in increased sales, once the initial business is firmly established.

III. PRODUCTS

The more common homopolymers and copolymers made in the reactor are shown in the Multipurpose Chemical Manufacturing chart (see above). Some of the more important other derivatives from the reactor are given. Certainly polyvinyl acetate, polyvinyl chloride, and polystyrene were thrilling developments forming the base for the expanding plastic industry. The modern development of copolymers and terpolymers using butadiene, acrylics, and acrylonitrile has further expanded

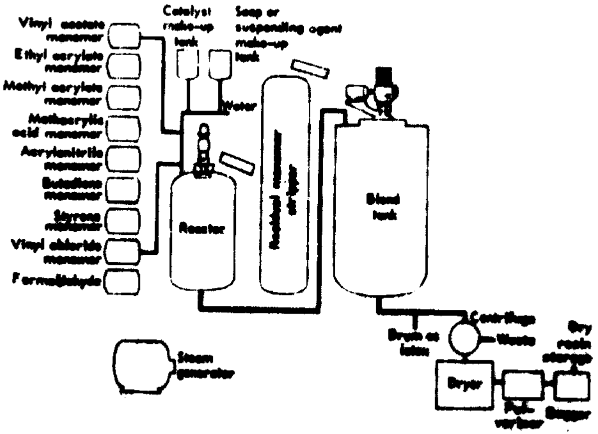


Figure II. *Flowsheet for polyvinyl chloride emulsion and resin*

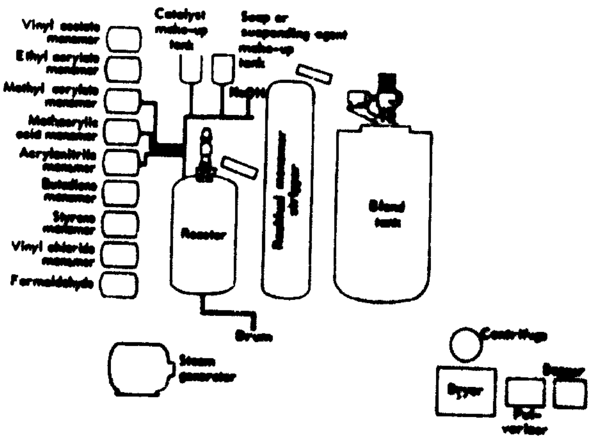


Figure IV. *Flowsheet for polyacrylic thickener*

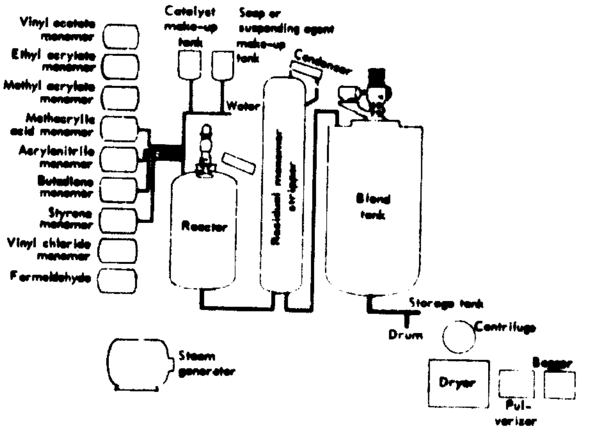


Figure V. *Combined flowsheets for butadiene-styrene latex, carboxylated butadiene-styrene latex and butadiene-acrylonitrile latex*

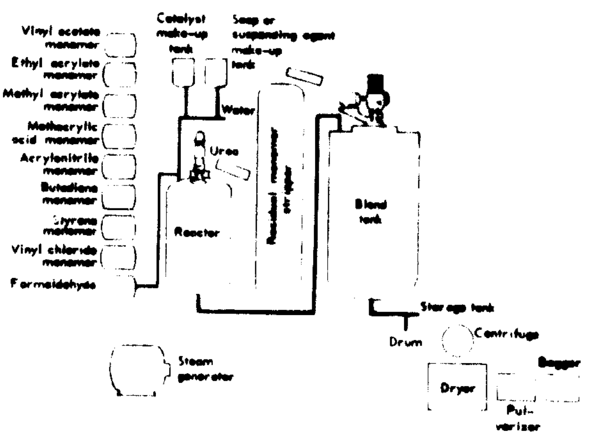


Figure VII. *Flowsheet for urea-formaldehyde resin solution*

use of petrochemical derivatives. Multiple combinations provide such diverse properties that the modern chemist can tailor products to his needs.

Urea formaldehyde has already been mentioned as a product of the reactor complex. Using the reactor, or in some cases portions of the multipurpose equipment, a vast number of other chemicals can be made. Additions of 1 per cent to 3 per cent of certain carboxylic acids to St/Bd terpolymers increase adhesion to cellulose. Detergents, penetrants, and wetting agents are readily manufactured tailored to the chemist's specifications. Sulfonation, ethoxylation, condensation, methylation, and esterification reactions add to diversity of chemicals. Natural oils, gums, and other indigenous products compounded with reactor output further add to the storehouse of chemical products. There are literally hundreds of useful combinations that can be made to meet modern industry's needs.

It would not be possible, even by cataloguing, to describe all the industrial products and their uses in a summary review of the multipurpose reactor concept. A few of the more important uses by industry are shown on the Multipurpose Chemical Manufacturing chart. By industry group, a few summary comments can be made:

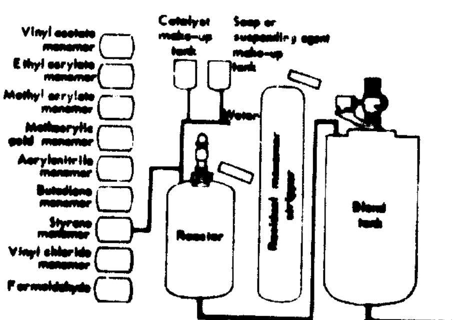


Figure VI. *Flowsheet for polystyrene resin*

Plastics. Polymers are almost immediately associated with the plastics industry. The dry resins are used in moulding, extrusion, and calendering machines for everything from phonograph records to costume jewellery. No single day goes by without the beginning of a new plastic production process or plant somewhere in the world. One important development has been the use of plastic pipe in modern irrigation practice. Many regions are critically short of water, and the water saved through use of pipe will provide for increased food supply. There has been no decrease in demand for plastic resins in this the " Plastics Age".

Textiles. Modern textile production has become synonymous with modern chemical technology. Wash-and-wear, synthetic fabrics, reinforced rugs and upholstery, laminated cloth, water repellent clothes, and many other innovations were once the specialities of a few nations. Today these terms have become common throughout the world. Sizing, stiffeners and body enhancing finishes from polyvinyl acetate homopolymers are widely used. St/Bd use in upholstery and rug backing not only increases the strength of the finished product but also requires less material use as fabric. Reactor output provides a comprehensive list of auxiliary products used in scouring, dyeing, and finishing operations.

Adhesives. Wood and paper adhesives still dominate the volume adhesives field. New adhesives for aluminium foil, cellophane, and waxed paper represent some of the recent developments in polyvinyl acetate adhesives. Phenolics are widely used in plywood and wood products. Foam rubber adhesives are increasing in demand. All of the multipurpose reactor primary products are used directly or compounded in adhesive formulations.

Paint. Paints made from linseed oil, tung oil, and varnish vehicles have been largely replaced by vinyl acetate copolymers, acrylics, and latex paints. Vinyl acetate/dibutyl/fumarate copolymers lead vinyl acetate/acrylate copolymers at present, although the acrylate is gaining a wider market due to ease of polymerization and high quality. St/Bd paints are still used in large quantity for interior finishes. Acrylic emulsions are also used in industrial finishes where high quality and special features are required. Cement and asbestos board paint have been developed from polyvinyl acetate copolymers. The polymer revolution in paint has contributed to superior products at substantially reduced cost.

Leather and leather finishes. Artificial leathers have grown in usage. High-fashion styles are promoting greater use of plastic leathers for handbags and shoes. Innersoles impregnated with polyvinyl acetate emulsions are increasingly used. Paper and artificial leather uses overlap – some artificial leathers are impregnated paper rather than plastics. Natural leather finishes provide another product field for polymer use.

Paper. One of the most rapidly growing, high-usage fields for polymers is in the paper industry for both decorative and functional applications. St/Bd additives to pulping and the wet end of paper production are increasing in use. Polyvinyl acetate, acrylics, and St/Bd are used in board and paper coatings as well as in impregnations. Paper lamination falls both in the adhesives and paper fields and shows promise of high demand for chemical products. The growing paper container market requires special finishes tailored to use conditions. Grease resistant coatings, moisture resistant coatings, and special uses of starch for coatings in connexion with polymers from the reactor are new fields in which the technology is rapidly improving.

The economics of product sales will vary from country to country and even internally as to product mix. There are some general conclusions applicable to product profitability that can be stated:

(1) The United States starting with a single reactor has been able to compete profitably in the chemical market with the largest chemical producers. Sales volume growth has averaged 20 per cent per year with additional reactors put on stream to satisfy demand. Sufficient return has been realized each year of operation to finance research, provide expanding facilities, and return a profit.

(2) The solutions and emulsions manufactured consist of up to 60 per cent water or solvent. An importer of monomers obviously has a distinct advantage in saving freight. Further, he retains the profit on the production of finished chemicals.

(3) Flexibility in product mix enables management to produce profitable chemicals. If competition or world market conditions impair economic operations on one or two products, the management has a diversified chemical storehouse of profitable items for which there is a growing demand. Conversely, alert management can quickly produce chemical products which may be temporarily in short supply or overpriced.

(4) Volume sales in paint, textiles, and plastics assure continuous operation of the reactor complex. Speciality products to meet specific user needs build growing business relationships for long-range assured demand.

IV. TECHNOLOGICAL REQUIREMENTS

The "know-how" required to establish and continue a multipurpose reactor chemical complex is divided into four phases, none of which can be neglected if the business is to grow and prosper:

Establishment

Perhaps of least concern in technology is the start of a reactor operation. All of the equipment and supporting facilities are virtually standard. Adaptation to locally available materials is certainly in order, using local currency to the maximum extent. The key planning step is establishment of economic size from which to build future growth. The reactor should certainly be built to manufacture all products, even if only one or two are made in the beginning. This provides flexibility in production and sales service for a wide market and does not restrict the company's market of the future. The size of the reactor is established by initial demand, but invariably the wide market for output will soon outgrow production facilities. A 2,000- to 4,000-gallon (7,000- to 15,000-litre) unit is highly desirable as an economic unit at the start of operations.

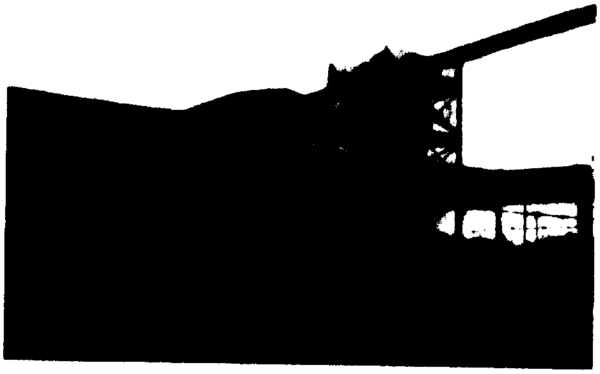


Figure VIII. *Multipurpose chemical manufacturing complex*

Manufacturing

None of the reactions or any of the formulations used in the manufacture of reactor production is patented. Specific formulations and processes are proprietary information. There might be a temptation to start a plant using general information and "match" trade products. Such a procedure would be extremely costly

Figure IX. *Pilot plant*

when a company can readily avail themselves of the many years of manufacturing experiences gained by the United States producer. This experience is transferred by having the overseas technician run first pilot operations (see pilot plant illustration) and later make production runs on every product he will make later in his own plant. Subsequent technology on product variances or new product additions are then readily transferred. There is no substitute for experience in polymer manufacturing. Quality control techniques and product specifications are vital to continued operation.

Sales service

The multiproduct chemical producer can first supply the needs of local industry, saving foreign exchange used for imports. While this alone can justify plant establishment in many cases, there are two further extensions of sales activity that promote a growing business. First, technical representatives from the plant can actively assist in establishing new business, further reducing finished product imports. Secondly, and a vital part of a successful future, technicians both in the plant and in the customer's plant can improve product usefulness, solve customer's difficulties or production problems, and constantly improve the products of manufacture. The "Technical Sales Service" concept is the most valuable tool an overseas producer can acquire from the American manufacturer. It is only in this manner that modern technology can spread outward to the larger business community, promoting benefits for both manufacturer and consumer.

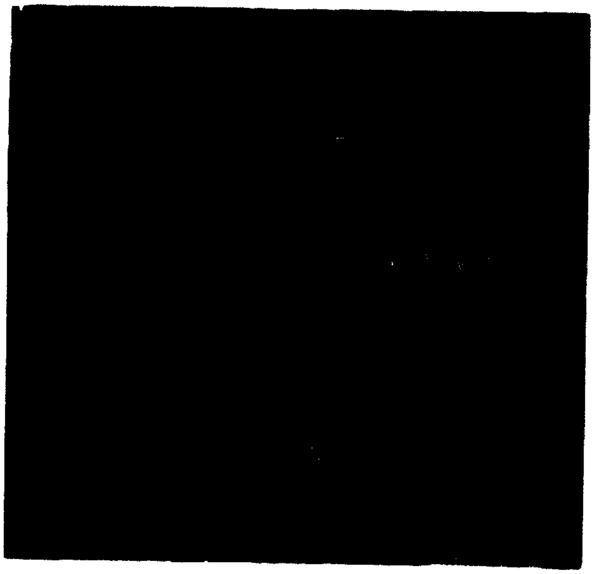


Figure X. *Laboratory*

Research

Close contact with the American producer will maintain the technological lead in all the various multiproduct fields. Polymer producers and formulators revise their products almost daily to meet continual changes in industrial advancement. For example, textile wet processing is changing significantly in the United States. Nonwoven fabrics are growing rapidly in many product areas. Upholstery and rug manufacture have undergone revolutionary changes. Paint today is entirely changed from common practice even ten years ago and continues in this change pattern.

No producer can remain static and expect to grow. His greatest long-range benefit will come from close association with a firm engaged in practical research for the developing market. The multipurpose concept enables him to move quickly into new products, improved adaptations, and entirely new industries with a minimum of cost or equipment changes. A single-product producer simply cannot keep up with accelerated growth of modern technology.

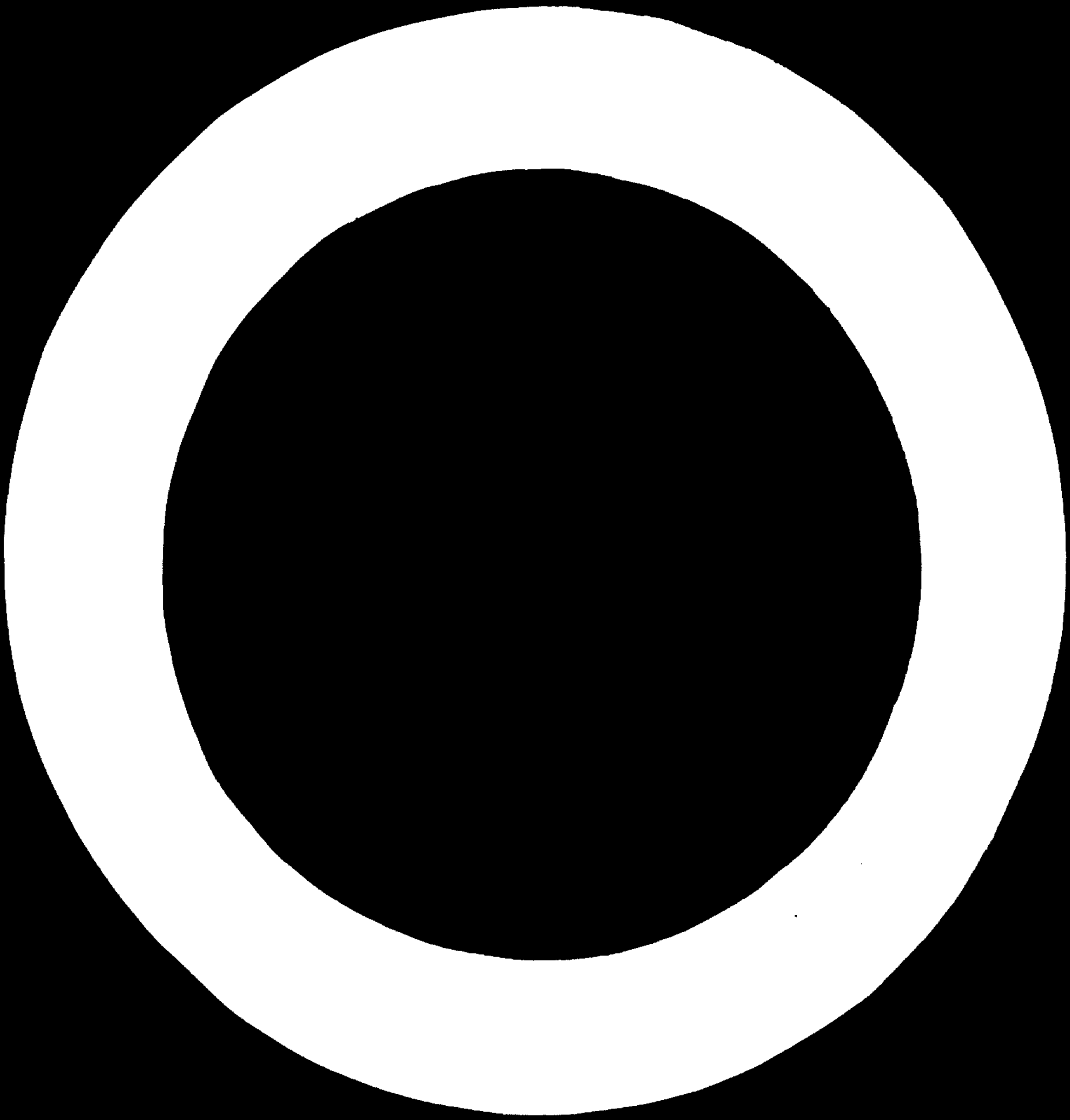
V. CONCLUSION

The multipurpose chemical manufacturing programme has been successfully used in the United States by a comparatively small-sized producer. A licensed operation in Mexico is proceeding successfully. Other operations are to be established in several countries of various populations and in varying stages of technological development. Where a local supply of petrochemical monomers is available, the entire complex is the internal business of the using country. In countries where some monomers must be imported, substantial savings are realized by processing for the final local market. There are few possibilities in manufacturing today that offer as wide a product field for as small an investment. Growth is built into the operation and assured by expanding polymer usage. Few manufacturing operations are as flexible — so readily adaptable to changing products and markets.

The establishment of dynamic multipurpose chemical manufacturing units will provide more things for more people of the world.

Chapter V

COUNTRY STUDIES



INTRODUCTORY SUMMARY

This chapter of country studies, the title of the Conference session at which they were delivered, is concerned with the current situation and the future prospects of the petrochemicals industry complex in a wide regional spread of countries, namely, Latin America, Eastern Europe, North Africa and Asia and the Far East.

Among all the countries in the ECAFE region, Japan is the only one which has developed the petrochemical industry to an international level, and both consumption and production of petrochemical products within the region are largely concentrated in Japan. Some countries of the region have already started to make nitrogenous fertilizers from natural gas or naphtha. Most of the countries have plans to establish naphtha cracker complexes for the production of basic petrochemicals.

The potential for petrochemical development in some countries of North Africa and the Middle East is based on the existence of proved and abundant sources of hydrocarbon raw materials which at present are not being utilized to any great extent.

In the discussions that followed the presentation of the country papers and statements, there were indications that it would be more beneficial to plan petrochemical development on a regional basis rather than for each country individually. Furthermore, it was evident that in the case of countries with abundant natural gas resources, the question of export markets outside the area looms large in the planning efforts. It was mentioned that regional planning is being seriously studied by some of the countries in this area with a view to developing a common market.

The discussions emphasized the need for more trained personnel and for training institutions, particularly in the field of petroleum and petrochemicals.

Apparent consumption of chemicals in Latin America was estimated by ECLA to be of the order of $3,000 million in 1959 with imports accounting for about 30 per cent of this total. For 1970, demand was projected to be of the order of $8,000 million.

The share of petrochemicals in the total was rather limited in 1959 but it is expected to increase substantially by 1970. Since the proportion of imports of petrochemicals was much higher than the average 30 per cent for the whole chemical industry, the need for a considerable effort in import substitution is foreseen in petrochemical raw materials and intermediates.

The Latin American countries represented in the Latin American Free Trade Association (LAFTA) have realized that:

While petrochemical industries are capital intensive industries, there is a scarcity of domestic capital in the area; also a high foreign exchange component of investment is required;

Economies of scale prevail in the development of petrochemical industries;

Full utilization of the locally available technology and skills is necessary;

A better allocation of resources and markets is desirable.

They therefore consider that a possible solution lies in integrating the petrochemical industries in Latin America and making them complementary. Sectoral meetings already recommended this to the Executive Committee of LAFTA in 1963 and 1964.

Positive factors to help in achieving this objective are: the clear understanding prevailing among the countries in the area that there is need to avoid costly duplication; the pioneering studies in the field of chemical industries done by ECLA; and the existence of a State oil industry in these countries having the strength to achieve the desired integration, by itself or with the co-operation of private industry.

State oil companies have already taken the initiative in reaching agreements to study how to make their industries complementary especially in the field of petrochemicals, starting immediately by exchange of technicians and technical information, utilization of idle capacities and exchange of products.

This trend towards integration has had recent expression in the meeting held in Buenos Aires under the auspices of Yacimientos Petrolíferos Fiscales (YPF), where all Latin American State oil agencies were represented, and the basis for joint action was discussed. The establishment of a permanent organization is expected in the beginning of 1965.

1. THE PETROCHEMICAL INDUSTRY IN ARGENTINA

Oscar Gatti, Group Chief of Chemical Works, de la Dirección General de Fabricaciones Militares, Eduardo A. Pasquinelli Yacimientos Petrolíferos Fiscales and Roberto F. Beltramino, Secretaría de Industria, Argentina

1. DEVELOPMENT OF THE PETROCHEMICAL INDUSTRY IN ARGENTINA

The petrochemical industry, one of the pillars of modern heavy chemistry, has made great strides in the most industrially advanced countries, including some which are not petroleum producers. In Argentina, in spite of a steady and adequate supply of hydrocarbons in the form of liquid fractions and natural and refinery gases, this industry, until a few years ago, had not gone beyond the initial stages because demand for petrochemical products was below the minimum required to justify the construction of industrial plants.

In spite of this adverse factor, this industry may be considered fairly well established in Argentina in relation to the development of the chemical industry in general, even though it was still in an incipient form until recently.

The petrochemical industry began in Argentina with the manufacture of products for which the demand was certain. Its origin dates from 1943, when an industrial plant was established for the production of iso-propyl alcohol and a pilot plant for the production of synthetic aromatic hydrocarbons (toluene, benzene, xylene). These plants constituted the first steps towards this type of industry, and their establishment took place long before the real development of an activity which today has taken on extraordinary dimensions all over the world.

The iso-propyl alcohol plant was erected by Yacimientos Petrolíferos Fiscales (YPF), and was expanded in 1949; the "synthetic toluene" plant, installed by the Dirección General de Fabricaciones Militares, was replaced by a modern catalytic hydroforming plant in 1952.

In 1953, a closed-furnace fuel oil plant began operation and produced lampblack, but in very small quantities; it was therefore abandoned.

Later, several studies were made of the possibility of further development in the petrochemical field. However, the industry in Argentina was paralysed by the absence of the production of basic hydrocarbons, particularly olefins.

Among the petrochemical products produced, although in small quantity, may be included naphthenic acid obtained from residue from the acid treatment of cuts of lubricating oils derived from crude petroleum with a naphthenic base imported from Peru; this is produced at the YPF refinery at Dock Sur and at the "Cóndor" refinery at Lomas de Zamora.

The continually growing domestic need for petrochemical products has stimulated new and more ambitious plans for industrial expansion, and initiatives have come from domestic and foreign private concerns wishing to co-operate in the development of this basic industry.

In 1956 and 1957, a period of industrial promotion began and petroleum undertakings like YPF received offers for making use of the residual gas of their refineries.

Under Act 14,780 concerning investment of foreign capital, numerous applications were made for investment in petrochemicals, and it was the firm of Koppers International which ushered in the second stage in the development of the petrochemical industry in Argentina.

This undertaking invested capital in the Sociedad Industrias Petroquímicas Argentinas Koppers S.A. (IPAKO), which commenced operations by setting up in Florencio Varela (Province of Buenos Aires) a plant for producing polystyrene from imported monomer. Later, the need arose to build other manufacturing plants in the Ensenada area (Province of Buenos Aires) and a contract was signed with YPF for the supply of residual gases from the La Plata refinery. Further investment was authorized for the establishment of ethylene, polyethylene and polystyrene plants. The first two plants began operation in March 1963, but the third project has not yet been implemented. In 1959, Industrias Químicas Argentinas Duperial was authorized to receive capital investment for the erection of a chemical complex consisting of four plants including one for the production of carbon sulphide by petrochemical methods. This project was carried out, and operations on an industrial scale began in 1962 in the Province of Santa Fé.

The same undertaking, pursuing its plans for expansion, decided to make a new proposal for capital investment, which was approved in 1961. An industrial plant for the production of ethylene and polyethylene was established and it will go into operation shortly.

Early in 1960, the Fish International Corporation (of Panama) proposed to set up a petrochemical plant near the YPF refinery at San Lorenzo (Province of Santa Fé). After various discussions and negotiations "Petroquímica Argentina S.A.", known as PASA, was formed, and this company is constructing a vast petrochemical complex comprising nine plants for the production of aromatic hydrocarbons (benzene-toluene, etc.). olefin hydrocarbons (ethylene, butadiene), styrene, synthetic rubbers (SBR and cis-polybutadiene) and other essential products for the subsidiary industries. It is anticipated that by the end of this year or early next year the naphtha reforming plants and the plant for the production of olefins (ethylene and butadiene) will begin operation, to be followed next by the styrene plant and finally by the synthetic rubber plants.

In the middle of 1960, **Cabot Argentina S.A.** (**CABASA**), a company established with the help of foreign capital, began production of lampblack. This, and the start of operation during July of this year at **Atanor S.A.M.**'s methanol plant, constitute real achievements in the field of petrochemicals.

Another project shortly to become a reality is the methanol plant which **Casco S.A.** is setting up at Pilar (Province of Buenos Aires). This plant will use natural gas. As a foot-note to the foregoing, we may add that the future of our petrochemical industry can be regarded as promising, for there are other production projects which already have government approval. Some of these, such as the Petrosur and Impagro projects for the production of simple and compound fertilizers and intermediate products for the chemical and plastics industries, are already at the financing stage.

Carboclor S.A. is another firm which has obtained approval of plans for the production of a number of organic products and solvents, including acetic anhydride, iso-propyl alcohol, secondary butanol, iso-propyl-butyl acetate and methyl-ethyl ketone. The company is at present making efforts to secure Argentine endorsement of financing from abroad. Early in 1964, **Parafina Del Plata** obtained approval by a Government decree for a plan to produce "dodecylbenzene" (a basic raw material in the manufacture of detergents).

There are other projects directed towards the plastic materials industry, such as the production of vinyl chloride, and also projects for the production of intermediate materials used in the manufacture of nylon 66 (adipic acid and hexamethylenediamine). As for intermediate chemical products, an application has recently been received which is thought worthy of consideration for the production of ethylene derivatives such as ethylene oxide, glycols, paraffin wax and chlorinated olefins. Also in the field of detergents, another proposal has been received for the production of dodecylbenzene sulphonate of sodium; this is under study.

The foregoing is a summary of the many proposals made for development in the petrochemical industry; many of them have not yet been implemented since financial problems have almost always been encountered. In spite of the difficulties which have arisen, there are real hopes for a bright future for this heavy industry. Its development will make it possible to meet existing requirements, to replace imports and to enter the foreign market with local products, particularly in the Latin American countries belonging to the Latin American Free Trade Association (LAFTA). It will also help to lay firm foundations for the development of our chemical industry in general.

2. ECONOMIC REASONS FOR FIXING PRIORITIES FOR THE PETROCHEMICAL INDUSTRY

The industrial development of a country comprises a series of activities directed towards producing goods needed by the economy, a task which should be carried out in the most comprehensive and economical manner possible.

It is a well-known fact that the value of raw materials is multiplied several times when they are converted into finished or semi-processed products. This is a general principle and it is basic for our economy, as there is an almost constant deficit in the balance of trade which is most serious for the country. When considering the possibility of exporting new products such as those derived from petroleum and petroleum gas, these factors must be taken fully into account.

While certain petrochemical industries can be developed with limited or medium-sized capital investment, those which are most important to our country require large-scale immediate investment. These include the manufacture of synthetic rubber, lampblack, weed-killers, pesticides, fertilizers, plastics, detergents, etc.: in these cases the plants must have a production capacity which is technically economic so that the goods produced can compete in quality and price in the domestic market and the export market and face the competition of countries outside the Free Trade Area whose markets enable them to sell at low prices owing to their large volume of sales.

Furthermore, the need to make the best possible use of available capital, in view of its scarcity, can be met effectively in the case of the petrochemical industry, at the present stage of its development, by avoiding duplication of investment through conclusion of complementary agreements, thus raising the productive level of the equipment installed.

This calls for a centralization of capital, whether it be share capital, from semi-public companies or from any other source. Without doubt, the financial aspect is one of the factors which must vitally affect the evolution of the petrochemical industry and contribute to the slow rate of implementation of projects.

The direct cause of this tendency is to be found in the position occupied by the chemical industry as a supplier of intermediate products for other industries, making it dependent, to a great extent, on the evolution of the consumer sectors.

A positive feature is the progressive improvement in the availability of raw materials as a result of the development of petroleum and gas production and the expansion of refineries.

Studies preceding the construction of a petrochemical plant begin with a study of the consumer market, and it is this that will indicate whether, irrespective of the abundance of hydrocarbons, this particular method of manufacture is the right one, in view of the usually high minimum economic level of operation and the need to market the by-products obtained in order to reduce the capital costs.

The absence of a significant domestic petrochemical industry merely delayed and did not prevent an increasing consumption of products obtainable by petrochemical methods. The required supplies needed were obtained through imports or production by other chemical processes (as in the cases of alcohol and acetone), even at the risk of greater costs. Many products are in fact produced in sufficient quantities to meet present needs by various non-petrochemical methods.

In the case of many products a fairly high level of demand has been achieved, and consumption could be increased substantially if the articles could be obtained at lower cost. Consequently, one of the prerequisites for establishment of petrochemical plants is a minimum of unsatisfied demand, or at least the incentive of substantial foreign currency savings through import substitution.

Potentially, Argentina has the raw materials for development of the petrochemical industry, but a factor to be taken into account is the position of such plants in relation to the country's total consumption, which up to the present time is considered small. All these considerations point to the need which has existed and still exists to plan investment in the petroleum and petrochemical industries with the maximum co-ordination compatible with their different productive goals, since, in the case of petroleum production, the marketing of residues and by-products is a means of increasing economy of operation, and, in the case of petrochemical production, the availability of an adequate supply of raw materials is vital to its existence. It is considered essential to encourage planning as the rational method for the development of our country. Plans must be based on technological budgets in keeping with the needs of the country, in order to achieve harmonious economic and social progress, and they must take into account what are judged to be the priorities. In this regard, one field which deserves priority attention is the petrochemical industry.

It should be understood, of course, that planning does not mean nationalization or limitations on private enterprise. The State must promote and stimulate the development of this industry through legislation and decrees designed to encourage and promote it and through co-operation with undertakings in order that they may bring projects to completion.

The establishment and development of the national petrochemical industry has thus far been based on a careful selection of products to be manufactured, in view of the existence of substitute industries which could be vitally affected by the competition which would arise if due caution was not observed.

This selection must take into account both economic and social factors, and the fact that some of the industries are regional or help to reduce the costs of food products must be borne in mind.

3. INSTITUTIONAL MEASURES FOR PROMOTING THE DEVELOPMENT OF THE PETROCHEMICAL INDUSTRY

The highly important place in the modern industrial structure assumed by the utilization of petroleum and natural gas in the manufacture of chemical products has led the government authorities to give attention to the need to foster the Argentina petrochemical industry by adopting measures to encourage and protect it. During the last twenty years, various methods have been employed to protect the industry, including foreign exchange permits, import quotas and automatic authorizations for certain materials.

In January 1959, Decree No. 5,439 established the present lists of imports liable to duties ranging from 0 per cent to 300 per cent depending on the products concerned. Later, the maximum level of duty was reduced to 200 per cent of the cost-and-freight value.

There is no doubt that if the national industry is to be as efficient as it should be, it must be able to face competition. The stimulus of competition would disappear, however, if solely because the domestic demand can be met, customs duties or charges are imposed which are much higher than is necessary.

In introducing protective measures, account has been taken in each case of the nature of the industry concerned and its importance to the country, and also of the desirability of encouraging competition in all sectors of industrial activity. In the application of this principle, the objective is to ensure firm external protection against the marking down of chemical products as a result of production surpluses or "dumping", subsidized export prices, etc., at the same time permitting or encouraging intensive domestic competition, something that cannot always be achieved.

The structural deficiencies in the growing industry generally, including the chemical industry, have made industrial protection imperative. The development of industries producing consumer goods and light goods at a rate out of proportion with the manufacture of intermediate chemical products has given the latter a certain vulnerability and instability, so that, for some time, until this danger disappears, a series of suitable measures will need to be taken in accordance with a plan drawn up to that end.

A series of measures were adopted from 1954 onwards, and mention may also be made of Act No. 14,722, published at the end of 1953, concerning foreign capital investment in industrial development. In 1957 it was repealed and replaced by other decrees designed to promote the industry, and, in February 1959, Act No. 14,780 concerning the investment of foreign capital and Act No. 14,781 concerning the promotion of industry were promulgated. These two laws, which are still in force, gave an impetus to the development of the chemical industry in general, and they affected the petrochemical industry in particular; numerous applications for the establishment of chemical industries based on derivatives of petroleum or natural gas were granted, some of them, as mentioned earlier, leading to successful results.

Basically, the law authorizing the investment of foreign capital in Argentina extends to capital invested in the promotion of new productive activities required for the country's economic development all the rights which the Constitution and laws grant to national investments.

Under this law, the investment may take the form of foreign currency, machinery, equipment or installations which will ensure normal development of the activities concerned. The entry of such capital requires government authorization, the grant of which is subject to a number of conditions.

The productive activities to be established, expanded or completed must offer adequate technical and economic guarantees, contribute directly or indirectly to import substitution, increase exports or promote such development as is conducive to the rational and harmonious growth of the national economy.

Particular consideration is given to foreign investment in the processing of raw materials for industry, making use of national resources and/or producing capital and intermediate goods.

Preference is also given to concerns undertaking to reinvest their profits in Argentina. The privileges which may be granted to foreign investors include the following:

Registration at the free market exchange rate;

Transfer, at the free market rate, to the country of origin of annual net profits from such investments;

Repatriation of the capital, subject only to such limitations as were laid down when the investment was authorized;

Privileges in connexion with customs duties, exchange tax regulations, credit terms and the inclusion of the investments under the most favourable régime for the promotion and protection of industry.

Act No. 14,781 concerning the promotion of industry establishes a system designed to create and maintain conditions which will ensure full and harmonious development of the country's industrial production. It is directed towards the following basic goals:

Achievement of balance-of-payments equilibrium;

Development of the country's existing and potential resources;

Decentralization of industry;

Improvement, expansion and diversification of industrial production;

Advances in manufacturing technology;

Meeting the needs of national defence, public health and public safety.

For the attainment of these objectives, the Executive is empowered under the Act to:

Grant, for the purpose of facilitating import, exemption from customs duties and other charges, subject to proof of destination, in respect of machinery and equipment which national industry is not in a position to provide;

Impose customs duties, increase existing duties or impose foreign exchange taxes on products, the import of which could affect the development of domestic production;

Suspend or limit imports of manufactured products and raw materials which are produced locally;

Grant preferential foreign exchange treatment for export of industrial products;

Grant credits on a preferential basis and take other measures to facilitate the financing of industrial projects;

Ensure preferential access to raw materials, energy, fuel and transport;

Give preferential treatment in purchases by State organs;

Grant tax exemptions and reductions for stated periods.

Other significant measures were those provided for in Decree No. 13,277/59 concerning the possibility of "industrial re-equipment" by means of the so-called "production line". The principal concession grated by this Decree was authorization to import, without payment of customs duties, "any set of machines and equipment which, although consisting of independent elements, make up an integral whole", even though some of these elements fall under Decree No. 5,439/59, which established import duties.

Concessions for "production lines" are granted in each case by executive decree relating to the whole or part of an industrial process, on condition that the production line is made up substantially of elements which national industry is not in a position to supply and that its establishment is justified by its importance to the economy. In June 1961, under the powers conferred by Act No. 14,781, the Executive promulgated Decree No. 5,039 providing for measures specifically intended to promote the petrochemical industry; this decree became essential as a result of the technological advances in the processing of raw materials required both for the production of synthetic chemical products and for the manufacture of final chemical products, and also because the country was importing numerous products which could be manufactured by petrochemical methods and their import represented a not insignificant drain of foreign exchange.

The Decree specified the industries which could enjoy the benefits granted, petrochemical plants being defined as those which initiate the productive cycle using petroleum or natural gas, or fractions or distillates thereof, and which produce mainly saturated olefin, diolefin, acetylenic, naphthenic or aromatic hydrocarbons and/or sulphur and/or hydrogen, and also those manufacturing one or more of the following products: synthetic rubbers, lampblack, fertilizers, pesticides, weed-killers, plastics and phenol resins, polyethylene, vinyl polychloride, polypropylene and polystyrene, provided that they are integrated, within a single enterprise or economic system of enterprises, with the basic plants described above.

Decree No. 5,039/61 may be said to have been the first decree concerning the promotion of the petrochemical industry as such; the relevant measures for which it provided included the following:

Exemption from customs duties and import charges on machinery, accessories and spare parts imported for the purpose of the establishment or expansion of industrial plants;

Income tax rebates;

Exemption from stamp tax on contracts for the supply of raw materials;

A declaration that the industries covered by the decree were of "national interest";

Authorization for the technical and professional personnel required for the execution of production plans to enter the country, and personal exemptions;

The supply by State agencies, at special prices, of the raw materials to be processed by benefiting undertakings.

This decree was rescinded, and replaced by Decree No. 5,338/63, which determined the various industrial activities to be the object of industrial promotion throughout the national territory, the petrochemical industry being included among those to be promoted. The new decree covered some additional industries such as those involving production of polyamides, polyesters, polyurethane and their monomers; it also provided for various forms of preferential treatment differing slightly from those provided for under Decree No. 5,039/59.

Decree No. 5,338/63 ceased to be in force on 1 December 1963, when it was rescinded by Decree No. 1,081/63. The latter fixed 30 November 1963 as the termination date of the validity of the declarations of national interest made by the Executive in favour of undertakings, the benefits granted under such declarations remaining only in respect of share issues offered for subscription on or before that date.

Decree Nc 5,339/63 established orders of priority with regard to equipment, subject to certain requirements and conditions which it laid down. Finally, on 30 April 1964, after new studies had been carried out, the present Government thought it desirable to introduce a new rational and equitable promotion system bringing together under one enactment all the provisions concerning benefits and preferences which, in the existing economic situation, can be granted in order to promote genuine industrial development, and establishing an order of priority among the activities and regions which it is thought necessary to develop, so that investment may be channelled accordingly. This new arrangement was instituted by Decree No. 3,113/64 which established the preferences to be granted to the industries covered, among which is included the petrochemical industry.

The advantages provided for in the Decree will be granted to undertakings applying for them before 1 January 1969. They include:

A ten-year rebate in accordance with a pre-established scale on income tax, excess profits tax and taxes replacing the assessment on the gratuitous transfer of property;

Exemption for up to ten years from the stamp tax on deeds of partnership;

Authorisation for the entry and temporary residence of foreign technicians and personnel necessary for the execution of projects;

Priority with regard to equipment, in accordance with the provisions of Decree No. 5,939/63 and as stipulated therein;

Preferential prices for gas, for power and fuels and preferential rates on the various transport systems.

It is clear from the foregoing that, in Argentina, the petrochemical industry is among those enjoying the greatest advantages and receiving the greatest encouragement for its establishment and development, because of the large potential markets at home and abroad for petrochemical products and the vast resources of raw materials available for this purpose.

4. MEASURES TO ASSIST THE PETROCHEMICAL INDUSTRY

A number of bodies in Argentina are studying the national problems in this field in considerable depth and on a considerable scale, and are engaging in scientific research. A large part of the population is now conscious of the fact that research bodies and research work are factors contributing to the national well-being, both present and future.

There are in the country certain large institutions, each of which is carrying out specified research tasks in science and technology. The National Council for Scientific and Technical Research (CNICT) is a relatively new and a dynamic institution which has done considerable creative work within a few years, doing much to promote the idea that research is essential in contemporary society. The Council, which is the axis around which a large part of the country's scientific activities revolve, was established on 5 February 1958 to promote, co-ordinate and guide research in pure and applied sciences. It was designed to work in three basic directions:

To promote the development of science and technology, to stimulate their expansion, to assist research and research workers and provide the latter with the equipment they require and with the necessary financial resources to enable them to live with dignity;

To co-ordinate scientific activities in order to prevent waste and duplication of effort, to channel individual initiatives and to encourage co-operation among research workers and institutions;

To guide scientific research in harmony with the basic activities and interests of the nation, national development plans and the requirements of a science policy that establishes appropriate priorities among the different branches of science.

The National Council for Scientific and Technical research was made directly responsible to the Presidency, being established as an autonomous body having legal personality and power to dispose of its own resources and administer those received from the State.

The Governing Board (*Directorio*) consists of fifteen members. Thirteen of these are appointed by the Government from among persons who have distinguished themselves in scientific and technical research. They include representatives of as many different branches of science as possible. Another member represents the Research and Evaluation Board of the Armed Forces and the remaining member is the Director-General of Culture in the Ministry of Education and Justice.

The function of the Governing Board is to define the general policy of CNICT, to discuss and approve its plans of action and the more important projects and decisions, such as those relating to the granting of scholarships and subsidies, admissions into the profession of scientific research worker, etc. In addition, to assist the governing organs of the Council, there are committees of honorary advisers made up of distinguished scientists. The latter are appointed: (*a*) by sciences or groups of related sciences, and (*b*) by regions.

In the first category are the advisory committees proper, whose task is to advise the Board on the awarding of scholarships, the granting of subsidies and other forms of promotion and stimulation of and assistance to scientific and technical research in different fields.

Then there are the regional committees, which are concerned with the same areas as the national universities and provide liaison between scientific circles in the provinces and the Council, their specific task being to help guide the activities of the Council in such a manner that the needs characteristic of each region are adequately taken into account.

The remaining advisory bodies which assist the Board are the Scholarships and Subsidies Committees and the board concerned with the qualifications and career prospects of scientific researchers. The Council is presided over by Dr. Bernardo Houssay, 1947 Nobel Prize winner in medicine and physiology.

Since the establishment in 1960 of the profession of scientific researcher, 238 researchers have entered the profession. In this profession, researchers can devote themselves wholly to science in stimulating surroundings, with adequate remuneration, security and opportunities for advancement. One fundamental requirement is that the researcher must devote himself exclusively to research, the only compatible function being teaching in institutes of higher education.

Researchers are given contracts varying in length from two to five years and, if their work is satisfactory, the contract is renewed until the cycle is completed; top-rank researchers may remain in the profession until they retire, and persons having a true vocation and scientific ability can thus devote their entire working life to research.

Through provision of subsidies, CNICT helped to establish the Mathematics Institute of the Faculty of Exact and Natural Sciences of the University of Buenos Aires, and the Faculty's rock analysis laboratory. It is now establishing a radioactive dating laboratory at the University of La Plata, which will be of great importance for geological and archæological studies. It is also organizing, with United Nations Special Fund assistance, a National Petroleum Institute to carry out all kinds of research connected with petroleum.

The scope of the activities undertaken by this fine institution on behalf of scientific research is therefore very broad. Since its establishment on 31 March 1963, it has granted 1,164 subsidies, with an approximate value of 260 million pesos.

The National Council for Scientific and Technical Research is above all an undertaking conceived and carried out by researchers for all the researchers in the country.

The National Institute of Industrial Technology (INTI) is an autonomous body established by the Government to promote and assist technical research that will contribute to the development of Argentina's industry.

The Executive Board (*Consejo Directivo*) consists of a chairman and eight members appointed by the Government, four of whom are nominated by associations of industrialists and one by the Banco Industrial de la República Argentina. The Board directs the work of the Institute, administers its funds, represents it, awards scholarships for technical and scientific research having industrial applications and encourages entrepreneurs to establish research centres.

Research centres are established on the initiative of industrial concerns, companies, university institutes, State agencies and societies or groups formed by such bodies or organizations with a view to carrying out specific programmes of study or research.

The INTI provides all the assistance required to keep each centre in operation until it is fully established as a private organization with its own funds, without the original founders losing the right to participate in its management. The assistance provided by the Institute takes many forms: financing, provision of services, provision of premises, laboratories, equipment, technical personnel, bibliographical service, etc. The INTI also provides, to ensure proper orientation of research, preliminary and periodic reports by its Advisory Committee. This consultative body consists of nine members nominated by the academies of pure and applied sciences, the professional staff of the National Universities of Buenos Aires and La Plata, professional organizations and private scientific and technical bodies of recognized standing.

Since the beginning of its activities in 1958, it has contributed to the establishment of the following research centres:

The Research Centre for Oils and Fats (CIGA), established for the purpose of investigating new sources of fat supply and improving the techniques at present used in Argentina;

The Automotive Research Centre (CIA), established in mid-1960 on the initiative of automobile manufacturers to facilitate the task of adjusting and controlling the production of the subsidiary industry. It acts as a technical, advisory and quality control centre for manufacturers and suppliers in the automotive industry.

The Research Centre for Efficient Use of Fuels (CIPUEC). This centre, with the advice of a United Nations expert, is studying the use of fuel in industry and advises the heads of industrial concerns on methods of achieving more efficient utilization of fuels. It provides its clients with a research and maintenance service for the thermal plant in their factories and a series of related services.

This research centre has given advice to major establishments in all branches of industry: textiles, leather, metallurgy, pottery, chemical industries, timber, refrigerators, distilleries, etc.

The Research Centre for Building Technology (CITAC). This centre was established in April 1959 to study problems related to structural concrete in Buenos Aires. It serves as an advisory and quality control centre. In particular, it carries out mechanical tests of different types of welded mesh and special steels for reinforced concrete and is organizing a service for controlling the manufacture of steels for which certificates of use are specified.

The Sheet Metal Research Centre (CIME) studies the organizational problems of small industries in order to find ways of ensuring economical production methods.

The Marine Biology Research Centre (CIBM) was established to carry out an exhaustive study of the algae of the Patagonian region, with a view to their possible industrial use.

The Documentary Research Centre (CID) was established in 1960 by an agreement between the INTI and twelve industrial groupings, including the Cámara Gremial de la Industria Química, the Cámara Argentina de la Industria Plástica, the Asociación Fabricantes de Papel, etc., with the object of facilitating technical research connected with industrial development. This centre was organized on the basis of studies of ten similar institutions in Europe.

The CID provides two main services: bibliographical research and photoreproduction of documents. The first of these services is very broad in scope and ranges from simple library checking of publications to tracking down documentary material in other countries in order to provide technical and commercial information required by industry.

The centre also issues a bibliographical bulletin arranged by subjects and groups of industries and provides information on different aspects of technological progress in Argentina and elsewhere.

The Argentine Productivity Centre (CTA).[1] This centre obtained INTI support in 1961 to carry out a plan of operations to promote the use of the techniques and principles of productivity by the country's professional and managerial cadres.

The Argentine Institute for the Standardization of Materials (IRAM). In June 1961, the INTI took over from the Government the responsibility for supporting this Institute. The latter has been doing intensive and important work for the last twenty-five years, particularly in the field of national industry. In addition to establishing technical standards in Argentina, it acts as secretariat for the Pan-American Committee on Technical Standards, whose function is to establish pan-American standards that will be useful for the Latin American market. The institute also carries out studies for international standards.

Other equally important research centres have recently been established. These include: the Research Centre for Leather Technology (CITE); the Research Centre for Industrial Microbiology (CIMI); the Research Centre for Mineral Industries (CIIM) and the Research Centre for Industrial Design (CIDI). The object of CIDI is to disseminate the principles and practices of industrial design in Argentina. These, together with other centres, complete the list of research establishments in Argentina.

The National Institute of Industrial Technology also has four laboratory departments, which serve the research centres and provide direct assistance to industries carrying out their own research programmes. The four departments are concerned, respectively, with physics, chemistry, materials testing and metallurgy, and special tests.

The industrial analysis section of the chemistry laboratory carries out general analyses of inorganic raw materials and semi-manufactured and/or finished goods, and also of organic products, chemical products, petroleum derivatives, soaps, protein products, paints, varnishes, etc.

There are other technological research establishments in Argentina, such as the "LEMIT" Laboratory (laboratory for materials testing and technological research) which, since 1942, has been doing most effective work in the fields of quality control and suitability of materials, structures, machinery, instruments, etc., and is also carrying out systematic experimental studies of the characteristics and properties of raw and other materials, structures, etc., and furthering, in collaboration with the standardization institutes, the technological and economic development of the country.

It undertakes applied research concerned with technological operations and processes for furthering balanced industrial development, with a view to raising the quality of production. It promotes the training of scientific, technical and skilled workers. It advises the Government on such matters as rational utilization of raw materials and by-products. It is developing a whole new range of activities of great industrial importance. Thus, it is currently engaged in research on asphalt from both the physical and chemical standpoints.

The Argentine Petroleum Institute. This institute was established on 30 July 1957 and its work is of an exclusively technical and scientific nature. Its members include the national universities, where courses are given on petroleum, all the petroleum and natural gas undertakings, the major consumers of petroleum derivatives, and national factories and representatives of foreign factories manufacturing equipment for the petroleum and related industries.

Its fundamental objectives are: to promote and coordinate scientific, technical, economic and statistical studies in the field of petroleum, natural gas and their derivatives, to further the training of suitable personnel for the petroleum industry and to collaborate in that connexion with scientific and teaching institutions in Argentina and abroad.

The Petroleum Institute collaborates with the Argentine Institute for the Standardization of Materials (IRAM) in drawing up materials standards for materials for the petroleum industry, and with the Research Centre for Efficient Use of Fuels (CIPUEC). It also co-operates with the Argentine Scientific Society and other technical and scientific institutions in Argentina in organizing conferences and research which is in the national interest.

The Institute has also collaborated in the preliminary studies for establishing in Argentina a technological training centre for specialists in the various technical fields and for carrying out technical and scientific studies.

The YPF Laboratories (at Florencio Varela) is another study and research centre oriented towards the petroleum and petroleum derivatives industry. It does work in the following fields: geophysics; secondary recovery of petroleum; extraction of isopropyl alcohol; fuels and lubricants; metals, etc.

The Research Council of the province of Buenos Aires carries out specialized scientific research, including studies in the petrochemical field.

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[1] A United Nations technical assistance project, with the ILO as executing agency.

The National University of Buenos Aires. In the Faculty of Exact Sciences and the Faculty of Engineering, the Industries Department, which is common to both, is doing research work on the chemistry of propane and biosynthesis of petroleum. The School of Petroleum, which forms part of the Faculty of Engineering, is engaged in research in various fields including the ionization of gases. It is a post-graduate school providing one-year courses in specialized subjects which include geology, geophysics, production, industrialization and gas.

The National University of La Plata. The Faculty of Chemistry of this University is carrying out a scientific research project on the oxidation of hydrocarbons by microbe action.

Universidad Nacional del Litoral (Province of Santa Fé). In the Faculty of Chemical Engineering, a working group has been set up to engage exclusively in petrochemical research.

The National University of Cuyo. This university has a "School of Fuels," which graduates petroleum engineers. Research work is being carried out there on the utilization of gases.

The National University of Tucumán. This University operates in the district of Salta a School of Petroleum Engineering, which carries out scientific and petrochemical research.

The Provincial University of Chubut. Courses are given primarily on petroleum and, in the neighbourhood of Dean Funes, there is a training school for skilled petroleum and petrochemical workers.

Seminars on subjects related to petroleum are held in the province of Neuquen.

In the field of private education, the work done in Argentina by Petroqulmica Argentina S.A. (PASA) deserves to be singled out as a great step forward in the training of experts and technicians for the petrochemical industry. This company is building a vast network of petrochemical plants for each of which it is training a group of young technicians by giving them theoretical and practical courses. The first of these courses, which was attended by 100 students, was for operators of the catalytic reforming plant and for machinists. Then a new group of forty selected students were given grants, and instructed in the operation of the SBR synthetic rubber plant, the next unit of the petrochemical complex to be started. The selection was made from among matriculating students and graduates of industrial schools. This course is designed to train the future operators of the different plants which the company is setting up; the second course is being given in accordance with the training programme being developed by PASA. It is concerned at present with the starting up of the catalytic reforming plant, which is the first to be put into operation.

This training centre for petrochemical plant operators was started by PASA in Rosario in November 1963. However, as the work of plant construction progressed, the centre was transferred to the plant site. Thus, in addition to the theoretical classes, practical classes were conducted in the plants themselves.

This is the first centre of its kind in Argentina. The students attending it, who are between twenty-five and thirty years of age, have been awarded grants by PASA and receive a monthly allowance. Classes, at the rate of seven hours a day, five days a week, last for six months. In the theoretical stage, audio-visual systems and modern teaching methods are used. Among the subjects taught to all the students is industrial safety, as it applies in industrial plants such as those of PASA. The instruction is given by foreign safety experts and will be extended to the entire staff of the PASA plants, including the workmen.

In the first course given for technical personnel, the students, in the judgement of the instructors (who were from the United States), reached a higher level than that achieved in similar courses by students from other countries which are more advanced than Argentina in the petrochemical industrial field.

Engineering organizations

At the University of Buenos Aires, it was decided to set up a single Industries Department for the Faculty of Engineering and the Faculty of Exact and Natural Sciences. This department participates in the teaching of specialized subjects covering: industrial engineering, chemical engineering and the doctorate course in chemistry (industrial orientation).

The doctor of chemistry studies the raw materials, suggests lines of manufacture and determines all the physical and chemical reactions and constants so that the most efficient production can be achieved. The actual processing in pilot plants is where the chemical engineer comes in. The latter verifies in those plants all the scientific information provided and uses it in the design of equipment and production lines. In short, in large-scale industry, everything which has to do with application, design and calculation is fundamentally the responsibility of the chemical engineer, whereas everything which has to do with basic and technological research is the responsibility of the doctor of chemistry. Instruction is given in the Industries Department on the following topics:

Techniques which do not alter the internal structure of substances, referred to as "unitary operations";

Techniques which alter the internal structure of substances and those known as "chemical processes";

Industrial chemistry, or the combining of one or more operations with one or more chemical processes for specific purposes (e.g., for the petrochemical industry, the iron and steel industry, etc.).

Industry being regarded as a technical-economic process with ramifications affecting society and the individual, industrial engineer's training covers the following areas: market study, organization of industrial concerns, production, scientific cost study, etc. The candidate must therefore have a basic scientific training and a knowledge of industrial application and economics to enable him to co-ordinate the various activities of a large industry. The industrial engineers' field of work is primarily oriented towards the extractive and manufacturing industries, although he might possibly operate within the chemical industry.

Wherever possible, the courses are supplemented by a period of three to six months of paid practical training in private or State firms collaborating with the universities.

In the other universities of Argentina, professional training for the chemical industries is given either in the chemical engineering branch or in the doctorate course in chemistry.

5. PRESENT TRENDS AND DEVELOPMENT PROSPECTS UP TO 1970

The unsatisfactory development of the chemical industry is reflected in the *per capita* production figures and the low figures for the production of basic industrial chemical products and modern organic synthetics, particularly petrochemical synthetics.

In general terms, the level of import substitution rose slowly until 1959 in the case of basic chemical products and petrochemicals, whereas it was high in the case of para-chemical products, products of natural origin and traditional consumer goods.

The absolute value of imports has been increasing steadily but the value in relation to consumption has decreased. Pharmaceutical products show the greatest total value, followed by chemical products for agricultural use and basic inorganic products, and synthetic and natural rubber have been imported in substantial quantities.

An annual cumulative growth rate of 7.9 per cent for the consumption of chemical products is forecast for the period 1960-1970. Certain development trends have been observed which point to a profound transformation of the structure of chemical product consumption. In this connexion, it is noted that the market for traditional goods is decreasing in importance in favour of that for more modern consumer goods, such as fibres, plastics and detergents, that, among the heavy chemical products in the organic sector, petrochemical and synthetic products are becoming increasingly important and that there is a progressive trend for intermediate goods, including fertilizers, to become predominant in the over-all value of demand.

In countries of moderate industrial development such as ours, a few large projects can give rise to fairly substantial increases in production.

By 1965 a marked increase will have been achieved in the production of modern synthetic products such as resins, fibres, rubbers, detergents, fertilizers, pesticides and goods intended for the chemical industry itself.

Among the encouraging developments forecast for 1961-1965 are the establishment of a petrochemical industry which will produce primarily basic materials used in the manufacture of plastics such as ethylene and polyethylene, and the development of the industry producing standard and high-impact polystyrene. This period will see the opening of a plant for the production of lampblack, which is highly important to the rubber and paint industries, and of plants for the production of carbon sulphide, synthetic phenol, methanol, synthetic fibres, etc. It is expected that a start will be made during this period on the production of fertilizers (organic and inorganic) and of synthetic rubber, preparations for the latter being well under way.

Nevertheless, it is expected that the most important increases in imports will be in respect of the principal intermediate products for the chemical industry itself: fertilizers, plastics, fibres, detergents, pesticides, synthetic and natural rubber, pigments, etc. On the basis of current development projects in various countries, it is forecast that by 1965 the balance of inter-Latin American trade in chemical products will probably be positive for four countries - Argentina, Brazil, Mexico and Colombia — and negative for the remainder. This reflects the unequal geographic distribution of the chemical industry in the region, and an attempt should be made to solve this problem by distributing investment in new projects more evenby, without losing sight of the principle of reciprocal advantages and the general interest of the region.

In order to prevent the steady increase in imports of chemical products from continuing in the years after 1965, it will be necessary to maintain in those years an annual production growth similar to that of the previous period; if that is done, the value of imports for 1970 will be reduced by 85 per cent, as occurred previously in Argentina and Brazil in 1959.

Considerable modifications are likely in the distribution of consumption among different groups of products, as can be seen in the relative positions of the major consumption groups for 1959, 1965 and 1970.

1959:

1. Surface-active agents, principally soaps;
2. Pharmaceutical products;
3. Materials for dyeing, painting, tanning and colouring;
4. Synthetic fibres;
5. Chemical products for agriculture.

1965:

1. Surface-active agents (soaps) and bleaches;
2. Pharmaceutical products;
3. Synthetic fibres;
4. Materials for dyeing, painting, tanning and colouring;
5. Principal organic products.

1970:

1. Synthetic fibres;
2. Surface-active agents;
3. Pharmaceutical products;
4. Plastic materials and synthetic resins;
5. Principal organic products.

(a) *Synthetic fibres*

The growing importance of synthetic fibres, reflecting the rapidly increasing preference for those products, is apparent. Consumption of synthetic fibres is increasing to the detriment of the expansion of the market for natural fibres particularly for cotton and wool. In recent years, the increase in consumption of viscose and cellulose acetate artificial fibres has tended to slow down, whereas the consumption of synthetic fibres — particularly the polyamide fibres (nylon, perlon, and rilsan) — has gained great momentum and the market in polyester, acrylic and vinyl fibres is growing very rapidly. Among the newer fibres, polypropylene appears to offer the greatest prospects.

The principal market for the acrylic fibres is in the traditional uses of wool, particularly knitted fabric. It is difficult to forecast the distribution of consumption of different types of fibres for five-, ten- or fifteen-year periods, since the market for those fibres is in the formative stage and the great variety of types of synthetic fibres causes intense competition between them and the cellulose fibres. However, it is felt that the most rapid growth will be in polyamide fibres, which should account for 5 per cent of the market in 1965 and 8 per cent in 1970, in contrast with 1 per cent in 1959. The 1965 consumption of polyamide fibres is estimated at 9,500 tons and that for 1970 at 20,000 tons.

These projections presuppose the development of an industry capable of providing the necessary raw materials at suitable prices, at least for the principal synthetic fibres: viscose, cellulose acetate, polyamides and polystyrene. Should this not occur, the projections will be only partially fulfilled.

(b) *Surface-active agents* (soaps and detergents)

Under this heading, the surface-active agents are considered with particular reference to the development of the detergent industry, since the active substance which is the basis of those agents is of petrochemical derivation.

In countries like Argentina which have a ready source of suitable fats and a highly developed soap industry, interest in the use of detergents has grown only in recent years, since the production of detergents frequently requires the introduction of foreign capital and foreign techniques.

In Argentina, the use of detergents is still in the first stages and it is likely that the replacement of soap by detergents will be a slow process. It is estimated that the present European *per capita* consumption will be reached by 1980.

The estimated growth of demand for detergents in Argentina is as follows:

1959, 4 per cent (of the total consumption of soaps and detergents), or 8,200 tons;

1965, 16 per cent (of the total consumption of soaps and detergents), or 37,000 tons;

1970, 25 per cent (of the total consumption of soaps and detergents), or 63,000 tons.

The process of replacement of soaps by detergents appears very slow in comparison with what occurred in the United States and in Europe, but it requires a great deal of capital investment and technological adaptation, which precludes any very rapid development. It is difficult to forecast which type of active substance will predominate in detergents, because of the wide range of products available and the relative difference in extraction costs, which will determine the advantages of certain recently developed types of detergents for certain applications.

(c) *Pharmaceutical products*

No report on these products is included, since they fall outside the scope of petrochemical production.

(d) *Plastic materials and synthetic resins*

The plastics market has become established in recent years through a rapid process of replacement of traditional materials, such as paper, wood, metals, and leather. The replacement of those materials is already partly achieved and the use of synthetic materials for an infinite number of purposes is fully accepted. Constant technological improvements ensure a wide field for this process and also make it possible to produce synthetic materials more cheaply.

The development of plastics consumption is dependent on three main variables:

(*a*) New uses of plastics as a substitute for traditional materials;

(*b*) Population growth;

(*c*) Increase in *per capita* income.

To date, the first of these three variables has been the most important. It is recognized, however, that it is in the more developed regions, where income levels are generally higher, that new uses of plastics to replace traditional materials have been developed most rapidly.

Among the factors preventing the plastics market from developing in Argentina to the extent achieved in other parts of the world are the following:

- The wide range of income distribution, which restricts the number of consumers;
- Restrictions and a high level of duties on imports of processing equipment and pure resins;
- The shortage of imported or locally produced processing equipment and resins;
- The fact that the principal resins are not available locally;
- The inadequate growth of advertising and marketing of plastic goods; and
- The low technological level in various fields of production.

Notwithstanding the negative factors listed above, the annual rate of growth of plastics consumption was more than 20 per cent between 1955 and 1959.

Forecasts of future growth are given below (in thousands of tons):

Year	*PVC*	*Polyvinyl acetate*	*Polyethylene*	*Polypropylene*	*Polystyrene*	*Alkyd and maleic resins*
1959. .	4.0	0.29	3.00	—	4.00	0.90
1965. .	12.0	1.00	11.5	2.0	6.00	1.50
1970. .	20.0	3.00	25.6	6.4	14.00	2.00

Year	*Urea-formaldehyde resins*	*Melamine-formaldehyde resins*	*Phenol formaldehyde*	*Cellulosics*
1959 . . .	1.04	0.40	1.54	0.50
1965 . . .	2.50	0.50	2.06	0.50
1970 . . .	3.00	0.50	3.50	0.50

Year	*Polyesters*	*Others*
1959 . . .	0.15	0.01
1965 . . .	1.50	1.50
1970 . . .	4.00	4.00

These forecasts are, on the whole, cautious, and the figures given therefore constitute only a minimum projection of the market. It is possible that in some cases the market potential of certain products has been overestimated while that of others has been underestimated. Nevertheless, to the extent that the negative factors mentioned above, which have hitherto prevented a greater expansion of the plastics market, are progressively eliminated, the growth forecast could be considerably exceeded.

(e) *Principal intermediate organic products for the chemical industry*

This group includes a certain number of products such as freons, for refrigeration and aerosols, tetraethyl lead, an additive for naphthas; ethylene dibromide, which in smaller quantities is used with tetraethyl lead in detonation inhibiting fluids, solvents (acetone, trichlorethylene and perchlorethylene) and also a group composed of ethyl, butyl and amyl acetates, known collectively as ester solvents.

CONSUMPTION PROJECTION (1965-1970)

(Tons)

Product	*1965*	*1970*
Freons	700	1,250
Tetraethyl lead	3,000	4,000
Ethylene dibromide	900	1,200
Acetone	2,500	4,500
Trichlorethylene and perchlorethylene	3,500	6,000
Ester solvents	4,000	4,000

The growth of the demand for synthetic products destined for final consumption and for the textile and rubber products industries is creating a great demand for the principal intermediate organic products destined for for the chemical industry itself. By 1970, the market for the principal aromatic hydrocarbons, especially benzene and xylenes, will have increased, as will that for the olefins, particularly ethylene. The great development of the market for these hydrocarbons, mainstays of the petrochemical industry, together with the production of synthetic nitrogenous fertilizers, will increase the relative weight of synthetic products as compared with natural products (e.g. alcohol, glycerine, etc.).

It is interesting to note how heavy petrochemical products — such as ammonia, nitric acid, benzene, toluene and xylene, methanol, formol, isopropanol, ethylene, propylene dichlorethane, butadiene, tetramerum of propylene, phenol, ethylene glycol, propylene glycol and cyclohexane — influence the increase in general consumption of chemical products.

The importance of the synthetic products of the heavy petrochemical industry in terms of the "value" of the principal intermediate chemical products is shown in the following table

Year	*Percentage of total value*
1959	7
1965	29
1970	33

This projection of the "values" of petrochemical products shows the effects of the expected expansion of the chemical industry for the years indicated on the basis of projects which have already been implemented or are in preparation.

(f) *Chemical products for agriculture*

Fertilizers indisputably play an important role in the world's agricultural economy. In the more agriculturally developed countries, including most of Europe and North America, consumption and production of nutrients are increasing very rapidly, owing to the practical application of the results of the industrial evolution which has been taking place in the world during the last hundred years.

Argentina, whose basic wealth is derived from agriculture and livestock raising, to which the greater part of its suitable land is already devoted, is no exception to this world-wide trend. Climatic conditions and agricultural exploitation have exhausted large areas of cultivated land, which will have to be reclaimed by means of rational fertilization together with other basic techniques.

In Argentina, fertilizer consumption is very low in relation to the cultivated area, being estimated at 0.6 kilograms of nutrients per cultivated hectare annually; the low level of consumption is evident when it is compared with that of other countries such as:

	kg/ha
United States	33
Italy	43
Australia	23
United Kingdom	141
France	86
Canada	6

This under-consumption is explained by the fact that in Argentina only certain intensively cultivated crops are fertilized, and that irregularly, while extensively cultivated crops are not fertilized at all. This is due, in some measure, to the large amount of cultivable land available (over one hectare per inhabitant). Consumption of various types of fertilizer totals 100,000 tons *per annum* (mixtures and complexes 53 per cent, simples and doubles 47 per cent) which is applied to fruit trees (30 per cent), sugar cane (25 per cent), grape vines (25 per cent), vegetables and flowers (15 per cent) and rice and tobacco (5 per cent).

Recently, in 1961, production of synthetic sulphate of ammonia began in Argentina, at the *Fabrica Militar Rio III* (Cordoba). This fertilizer is also manufactured as a by-product at the San Nicolás coke plant (SOMISA). At the present time, however, annual production totals only 20,000 tons and satisfies only part of the demand for this fertilizer.

For various reasons it has not yet been possible to establish a real fertilizer industry, producing concentrated fertilizers of suitable quality in sufficient quantity to meet economically the potential requirements of the agricultural sector, in accordance with the specifications of modern techniques and the characteristics of the various agricultural areas.

It has been stated that present fertilizer consumption is approximately 100,000 tons *per annum*, which is equivalent to 20,000 tons *per annum* of essential nutrients (nitrogen, phosphorus and potassium): the country's minimum requirements in the near future may be conservatively estimated at 190,000 tons *per annum*.

Studies made by the Organization of American States give minimum recommended fertilizer requirements for various types of intensively and extensively cultivated crops; these recommendations, expressed in nutrients, are given below:

	Thousands of hectares	*Nutrients (thousands of tons)*			
		N	*P_2O_5*	*K_2O*	*Total*
Crops	13 100	600	900	600	2,100
Pastures . . .	113,100	4,500	5,600	3,400	13,500
TOTAL	126,200	5,100	6,500	4,000	15,600

These figures do not include fruit trees, tomatoes and other vegetables.

It should be pointed out that at the present time the cultivated area (intensive and extensive cultivation) totals 30,000,000 hectares, of which INTA (*Instituto Nacional de Tecnología Agropecuaria*) (National Agricultural technology Institute) estimates that only 1,423,000 ha. have been fertilized. The OAS study envisages, in regard to crops, a quantity of nutrients 113 times greater than actual total consumption of nutrients in the period 1958-1959; if pastures are taken into account, total consumption would be 866 times greater than that for the period mentioned. These estimates, although they can be considered reliable, are far removed from what the country could, in reality, consume.

The INTA has made estimates of potential fertilizer consumption which may be considered more closely adjusted to the country's evolution. The following table shows the quantities of fertilizers, expressed in nutrients, that could be absorbed by various crops grown in Argentina, which are at present fertilized only partially or not at all:

	Thousands of hectares	*Nutrients (thousands of tons)*			
		N	*P_2O_5*	*K_2O*	*Total*
Partially fertilized crops [a]	1,423	66	76	49	191
Unfertilized crops [b] . . .	792	30	30	23	83
Sub-total	2,215	96	106	72	274
Pastures	2,000	120	160	40	320
TOTAL	4,215	216	266	112	594

[a] Sugar cane, rice, tobacco, fruit trees, vegetables.
[b] Cotton, tea, *yerba mate*.

These estimates do not include the most important extensively cultivated crops, and a "pasture" area much smaller than that considered by the OAS was used; nevertheless, the quantity of nutrients needed for partially fertilized crops alone is fifteen times greater than actual consumption during the period 1958-1959, and if requirements for "pastures" are taken into account, the quantity is thirty-three times greater than the consumption in that period.

The INTA estimates for nitrogen alone total 216,000 tons, a figure twenty-four times greater than consumption of this nutrient in the 1958-1959 period. Development of this potential market would require the adoption of measures affecting both the private and public sectors, and this would tend to eliminate the negative factors which have impeded development.

Legislation and decrees designed to promote the petrochemical industry are affecting fertilizer production, with the result that the establishment of raw material and fertilizer plants, whose capacities and technological processes permit production of those products at economic prices, is now being encouraged. In the particular case of nitrogenous fertilizers, there is a need for ammonia-producing plants with a capacity permitting manufacture of the various fertilizers (ammonium sulphate and nitrate, urea, nitramoncal, ammonium nitrasulphate complexes) the future demand for which will be considerably greater than the present one.

It is preferable to produce these fertilizers by petrochemical methods and their production is becoming progressively more urgent if agricultural development is to become a reality. For all these reasons this problem occupies an important place among the many problems to be solved in Argentina.

Other chemical products destined for agriculture

Together with fertilizers, pesticides, which include a large number of insecticides, weed-killers, fungicides and other disinfectants, occupy an important place. Unfortunately, owing to the enormous variety and mutability of pesticide application methods and the large number of special factors influencing this market, projection by product is a very detailed and highly complex task. For that reason, only certain products will be mentioned here. Among the insecticides, for example, there seem at present to be good prospects for the chlorade group (such as aldrin and chlordane toxaphene) and phosphorates such as metilparathion, parathion and malathion. DDT, HCH and pyrethrum are still of some importance.

In the weed-killer group, derivatives of acid 2,4-D and 2,4,5-T share the market with new types of increasing importance (including parachlorophenoldimethylurea and isopropylcarbonylatum). Among fungicides, copper and sulphur salts retain a fairly important place in relation to new types with greater potential, such as pentachlorophenol, zinc and manganese derivatives.

Hexachlorobenzene, DDT, lindane (HCH), 2,4-D acid, 2,4, D-B acid, TCA, copper sulphate, lead arsenate, sulphur and pentachlorophenol, are being manufactured in Argentina, some of them from imported raw materials. Local production covers domestic consumption, although consumption is limited owing to high prices, and the plants operate considerably below capacity.

Synthetic rubber

The use of synthetic rubber increased slowly until 1959. Since then, consumption of this product has expanded greatly, for, in addition to the need to satisfy the growing demand for articles of synthetic rubber, technological progress has endowed it with characteristics comparable to those of natural rubber.

The evolution of the consumption of these two types of rubber in Argentina has been as follows:

Year	*Natural*	*Synthetic*
	Percentage	
1959	70.27	29.73
1960	64.27	35.73
1961	63.70	36.30
1962	56.53	43.47

It is estimated that within the next few years the percentage of synthetic rubber will approximate the trend in the rest of the world, since production in Argentina will enable users to avoid import difficulties, payment of large deposits, taxes and duties, Moreover, the price of synthetic rubber is more stable than that of natural rubber.

In general, rubber consumption in Argentina shows a tendency to increase at a rate of approximately 7 to 8 per cent *per annum*. A study of the country's automobile and tyre market has made it possible to draw up a minimum production plan for the period 1965-1970 and on this basis an estimate has been made of possible future consumption of tyres, and hence of rubber. Consumption for this purpose was chosen because it accounts for the largest proportion (approximately 77 per cent) of the total estimated consumption for 1970.

Under the present pattern of rubber consumption, the rate of increase should probably be greater, but a progressive substitution of plastics for rubber is foreseen for certain uses, such as rubber tubing and electric conduits, so that 8 per cent means a higher rate of increase of consumption of products now made of rubber.

It is difficult to forecast the distribution of consumption between synthetic and natural rubber. It is presumed that consumption of natural rubber will remain constant and that the increased consumption will consist entirely of synthetic rubber.

PROJECTION OF THE DEMAND FOR NEW RUBBER (1965-1970)
(Thousands of tons)

Types of rubber	*1959*	*1965*	*1970*
SBR	9.4	28	35
Synthetic rubbers for special uses	0.4	3	5
Sub-total, synthetic rubbers	9.8	31	40
Natural rubber and stereo-isomers	22.7	19	25
TOTAL CONSUMPTION	32.5	50	65

PROJECTION OF THE DEMAND FOR NEW RUBBER (1965-1970)
(continued)

	1959	*1965*	*1970*
Percentages			
Principal types			
SBR	29	56	54
Synthetic rubber for special uses	1	6	8
Sub-total, synthetic rubbers	30	62	62
Natural rubber and stereo-isomers	70	38	38
TOTAL	100	100	100

	1959	*1962*	*1965*	*1970*
Rubber consumption per capita *(kilogrammes)*				
Argentina	1.6	2.5	2.8	3.0

Lampblack

In addition to rubber, the rubber products industry consumes large quantities of lampblack, other uses of this product being negligible in comparison with the rubber market. Consumption of lampblack can therefore be projected jointly with that of rubber, and within this framework the projection should be based on tyre production, which accounts for 95 per cent of the total consumption of this material.

The use of lampblack has been increasing steadily in Argentina, especially since domestic production of tyres began about 1950. Subsequently fluctuations occurred, due to various internal circumstances, but in later years imports became more stable, with a tendency to increase. Since July 1962 a lampblack plant has been in operation, which supplies the local market, its surplus output being exported.

The following table shows the projection of lampblack demand in Argentina, taking into account the development of the domestic rubber industry:

Year	*Thousands of tons*
1959	9
1965	12
1970	18

Lampblack consumption *per capita* is:

Year	*Kilogrammes*
1959	0.4
1965	0.7
1970	0.8

Yacimientos Petrolíferos Fiscales (YPF) is Argentina's largest petroleum enterprise.

It produces some 16 million m^3/year of crude oil, some 6,000 million m^3/year of natural gas, and substantial quantities of liquid propane-butane. This is virtually sufficient to cover national consumption of the various petroleum products, which are fractionated and refined in six YPF refineries distributed among the various centres of the country. Apart from the six YPF refineries, there are three other large refineries belonging to private companies. Argentina's total refinery capacity is now about 18.7 million m^3/year, of which 11.2 million m^3/year are provided by YPF and 7.5 million m^3/year by the private companies. Moreover, YPF is planning to expand and embark on new projects, in order to increase the variety of the by-products required by the market in respect of intermediate fuels and lubricating oils.

The distribution of petroleum, by-products and gas is facilitated not only by water, road and rail transport services but also by an extensive network of oil and gas pipelines which link the fields with the centres of consumption. There are more than 6,000 kilometres of gas pipelines and over 2,000 kilometres of oil pipelines in operation. There are also plans to lay another 1,000 kilometres of oil pipelines.

In addition, the proved reserves of crude petroleum in Argentina amount to some 500 million m^3. Those of natural gas amount to 200 million m^3 (in equivalent tonnage of petroleum).

This whole system of petroleum and gas production and reserves, together with the existing large-scale network of gas and oil pipelines and the various refineries supplying the entire range of hydrocarbons in the various parts of the country, make the development of a vigorous petrochemical industry in Argentina an immediate practical possibility and will facilitate it still more in the future.

For twenty years (from 1944) YPF operated an isopropyl alcohol plant with an isopropanol capacity of 1,500 tons/year at the San Lorenzo refinery (Santa Fé). For many years this plant was the only one of its kind in Latin America. YPF is now planning to install a modern isopropanol plant at the La Plata refinery, with sufficient capacity to supply the Argentine market and, possibly, to export to the Latin American Free Trade Association (ALALC).

YPF is also supplying raw materials to various other petrochemical companies in Argentina. Thus, it provides *Fabricaciones Militares*, a public enterprise of the Argentine Army, with various paraffin and naphtha cuts (some 1,500 m^3/month) for the hydroforming plant, which produces synthetic benzene and toluene, at Campana (Province of Buenos Aires). YPF also supplies the Compañia Ipako (an affiliate of Koppers International) with approximately 100,000 m^3/day of residual gas from the La Plata refinery, for the Ipako factory at La Plata which produces polyethylene.

Furthermore, YPF supplies liquid gas and natural gas under contract (through another public enterprise — Gas del Estado) to the PASA Company, which will manufacture SBR synthetic rubber (40,000 tons/year), and "natural" synthetic rubber (cis/polybutadiene-type), among other products, at the factory which it is building at San Lorenzo (Santa Fé).

YPF is now selling to the Duperial Company approximately 3,000 m^3/month of gasolene for that firm's polyethylene plant at San Lorenzo (Santa Fé). Thus, through the sale of various hydrocarbon fractions, YPF has already made a significant contribution to the development of the petrochemical industry in Argentina.

With regard to its own petrochemical plants, apart from the isopropanol plant which operated at the San Lorenzo refinery and the one which is to be built at the La Plata refinery, YPF is planning developments in the synthetic fertilizer sector: ammonium sulphate, ammonium nitrate ammonium phosphate and complex binary (nitrogen-phosphorus) and ternary (nitrogen-phosphorus-potash) fertilizers. This is in response to the farming and cattle-rearing requirements of Argentina, a country which, though a large-scale exporter of grains and meat, nevertheless consumes less synthetic fertilizers than might be expected. It is interesting to note that Argentina, one of the world's major food suppliers, is able to improve the quantity and quality of the grains and meat which it exports to other countries and for which the demand is extremely heavy, by the intensive use of fertilizers on its cultivated land and pasturage. To this end, YPF plans to build its own large fertilizer plant, which will supply the whole country with low-cost synthetic fertilizers. The low cost, and hence the low selling price, will encourage the farmer to purchase them and promote their widespread use.

YPF is planning other petrochemical projects in the solvents sector (isopropanol, butylic alcohols, methylethylcetone, chlorinated solvents, etc.) and also in the synthetic detergents sector (aromatic hydrocarbons, acetylene, etc.). For these projects YPF not only has easy access to all kinds of raw materials but also has its own industrial organization with over fifty years of experience in Argentina. Similarly, YPF's sales network extends throughout the national territory, a fact which will greatly facilitate the distribution and sale of petrochemical products.

With regard to laboratory studies, pilot plants and the synthesis, analysis and testing of products, etc., YPF has a large experimental laboratory at Florencio Varela (Province of Buenos Aires) equipped with the most modern scientific equipment. All this puts YPF in a favourable position with respect to the development of the petrochemical industry in Argentina.

The United Nations has invited us to propose topics which could be considered at the Interregional Conference on the Development of Petrochemical Industries to be held at Teheran. Such topics are suggested by the very petrochemical industries which YPF proposes to establish in Argentina: synthetic fertilizers, isopropanol, other solvents, synthetic detergents, aromatic hydrocarbons, etc.

At the Teheran Conference, it might be useful to hold discussions, assemble information and perhaps make contacts, relating it to "know-how", processes, economic aspects, financing, engineering and construction companies, etc., in respect of the industries mentioned above, or of others which may arise when considering broader regional markets.

As regards the regional market aspect, YPF, an Argentine public enterprise, may be of interest as a more economic supplier of the ALALC area resulting in economies of scale, provided that certain petrochemical industries were established in Argentina which could prove profitable thanks to the availability of raw materials, the existence of a national market which is already sizable and a geographical position in the south of the continent which enables Argentina to charge the minimum freightage for exports to several neighbouring countries, such as Uruguay, Brazil, Paraguay, Bolivia and Chile.

Annex I

OIL AND GAS FIELDS, THEIR RESERVES, CHARACTERISTICS AND OUTPUT

TIERRA DEL FUEGO FIELD

RESERVES

Oil:	30 million m³
Natural gas:	20 million m³ petroleum equivalent

CHARACTERISTICS

Oil

Specific gravity at 15 °C	0.821
Equivalent in degrees A.P.I.	40.1
Sulphur content (percentage weight)	0.08
Paraffin content (percentage weight)	7.2
Freezing point (in °C)	1

DISTILLATION BY THE METHOD PRESCRIBED IN DECREE 97.545/37

Naphtha (percentage)	31
Kerosene (percentage)	16
Gas-oil (percentage)	12
Reduced crude (percentage)	41

PRODUCTION

Petroleum (m³)

Enterprise	*1959*	*1960*	*1961*	*1962*	*1963*
YPF					
Under the standing arrangement	1,000	Transferred its installations to Tennessee, Argentina			
Under contract	300	268,100	476,159	946,343	922,085
TOTAL	1,300	268,100	476,159	946,343	922,085

Natural gas (thousands of m³)

Enterprise	*1959*	*1960*	*1961*	*1962*	*1963*
YPF					
Under the standing arrangement	—	—	—	—	—
Under contract	—	45,672	72,696	126,169	124,080
TOTAL	—	45,672	72.696	126,169	124,080

COMODORO RIVADAVIA FIELD

RESERVES

Petroleum:	273.3 million m³
Natural gas:	86.3 million m³ petroleum equivalent

CHARACTERISTICS

Petroleum

Characteristic	*Santa Cruz*	*Chubut*		*Rio Negro*
		YPF	*Pan American*	
Specific gravity at 15°C	0.895	0.916	0.913	0.908
Equivalent in degrees A.P.I.	26.6	23	23.5	24.3
Sulphur content (percentage weight)	0.14	0.28	0.19	2.3
Paraffin content (percentage weight)	8.5	8.3	11.3	6.6
Freezing point (in °C)	—7	—2	—8	—27

DISTILLATION BY THE METHOD PRESCRIBED IN DECREE 97.545/37

Naphtha (percentage)	10	5	6	9
Kerosene (percentage)	12	8	8	10
Gas-oil (percentage)	9	7	10	13
Reduced crude (percentage)	69	80	76	68

PRODUCTION

Petroleum (m^3)

Enterprise	*1959*	*1960*	*1961*	*1962*	*1963*
YPF					
Under the standing arrangement	3,142,493	3,844,770	5,802,269	6,796,568	7,015,923
Under contract:					
Boo. Loeb	—	316	272	—	
Panamerican	107,037	1,125,577	2,070,371	2,201,807	2,356,211
Miscellaneous	609,157	549,115	509,879	522,304	420,585
TOTAL	3,858,687	5,519,778	8,382,791	9,520,679	9,792,719

Natural gas (thousands of m^3)

Enterprise	*1959*	*1960*	*1961*	*1962*	*1963*
YPF					
Under the standing arrangement	847,197	910,347	1,443,807	2,101,975	2,408,496
Under contract	—	56,953	102,951	248,982	173,717
Miscellaneous	160,882	87,971	112,310	108,743	113,968
TOTAL	1,008,079	1,055,271	1,659,068	2,459,700	2,696,181

OIL PIPELINES IN OPERATION

Colonia Sarmiento-Caleta Cordoba

Flow velocity: 8,000 m^3/day of crude petroleum
Length: 135 km.
Diameter: 30.5 cm (12")/35.6 cm (14")
Maximum impact pressure: 60 kg/cm^2

GAS PIPELINES IN OPERATION

Comodoro Rivadivia (cañadón seco) - Buenos Aires and Azul-Lavallol "Loop"

Flow velocity: 1.3 million m^3/day
Length: 1,679 km.
Diameter: 25.4 cm (10").
Gas pressure: 70 kg/cm^2

NEUQUEN FIELD

RESERVES

Petroleum: 15 million m^3
Natural gas: 33 million m^3 petroleum equivalent

CHARACTERISTICS

Petroleum

Specific gravity at 15°C	0.876
Equivalent in degrees A.P.I.	30
Sulphur content (percentage weight)	0.37
Paraffin content (percentage weight)	7.4
Freezing point (°C)	2

DISTILLATION BY THE METHOD PRESCRIBED IN DECREE 97.545/37

Naphtha (percentage)	15
Kerosene (percentage)	11
Gas-oil (percentage)	11
Reduced crude (percentage)	63

Natural gas

Calorific value at 15.6 °C (60 °F)	9,300 cal/m³
Specific gravity	0.62 (atmosphere = 1)
Methane	92.8 per cent
Ethane	3 per cent
Propane	1.2 per cent
Butane	0.4 per cent
Pentane	0.4 per cent
Inert gases	1.9 per cent
O_2	0.3 per cent

Production

Petroleum (m³)

Enterprise	*1959*	*1960*	*1961*	*1962*	*1963*
YPF					
Under the standing arrangement	994,766	1,001,573	1,046,743	950,397	815,228
Under contract	—	2,239	9,925	15,223	9,045
Miscellaneous	15,900	111,842	9,353	992	—
Total	1,010,666	1,115,654	1,066,021	996,612	824,273

Natural gas (thousands of m³)

Enterprise	*1959*	*1960*	*1961*	*1962*	*1963*
YPF					
Under standing arrangements	255,217	214,879	223,267	245,578	317,883
Under contract		821	2,803	15,767	4,718
Miscellaneous	64,723	63,240	45,598	33,170	25,016
Total	319,940	278,700	271,940	294,515	347,617

Oil pipelines in operation

Challaco (Neuquen) — Puerto Rosales (Province of Buenos Aires)

Flow velocity: 7,000 m³/day
Length: 625 km

Diameter of pipe: 35.6 cm (14")
Maximum impact pressure. 65 kg/cm²

Gas pipeline in operation

Plaza Huincul (Neuquen) — General Conesa (Rio Negro)

Flow velocity: 600,000 m³/day
Length: 462 km

Diameter of pipe: 20.3 cm (8")
Gas pressure: 65 kg/cm²

MENDOZA DEPOSIT

Reserves

Petroleum: 129,500,000 m³

Natural gas: 11,000,000 m³ petroleum equivalent

Characteristics

Petroleum

Specific gravity at 15 °C	0.865
Equivalent in °A.P.I.	32.1
Sulphur content (percentage by weight)	0.11
Paraffin content (percentage by weight)	21.5
Freezing point (°C)	23

Distillation by the method prescribed in Decree 97,546/37 (percentage)

Naphtha	11
Kerosene	9
Gas-oil	9
Reduced crude	71

PRODUCTION

Petroleum (m^3)

Enterprise	*1959*	*1960*	*1961*	*1962*	*1963*
YPF					
Under standing arrangement . . .	1,550,193	1,374,543	1,043,892	1,346,060	1,448,238
Under contract, Banco Loeb . . .	219,581	1,068,816	1,217,013	1,465,965	1,416,213
Miscellaneous	600	761	787	739	1,364
TOTAL	1,770,374	2,444.120	2,261,692	2,812,764	2,865,815

Natural gas (thousands of m^3)

Enterprise	*1959*	*1960*	*1961*	*1962*	*1963*
YPF					
Under standing arrangement . . .	53,917	41,486	34,002	35,741	33,010
Under contract	—	31,614	32,171	37,001	34,677
TOTAL	53,917	73,100	66,173	72,742	67,687

NORTHERN OR SALTA DEPOSIT

RESERVES

Petroleum:	52,700,000 m^3
Natural gas:	74,800,000 m^3 petroleum equivalent

CHARACTERISTICS

Petroleum

Specific gravity at 15 °C	0.770
Equivalent in °A.P.I.	52.3
Sulphur content (percentage by weight)	0.03
Paraffin content (percentage by weight)	3.7
Freezing point (°C)	−32

DISTILLATION BY THE METHOD PRESCRIBED IN DECREE 97,545/37 (PERCENTAGE)

Naphtha	44
Kerosene	28
Gas-oil	13
Reduced crude	15

Natural gas

Calorific value at 15.6 °C (60 °F)	9,600 cal/m^3
Density	0.64 (air = 1)
Methane.	92.8 per cent
Ethane	2.8 per cent
Propane	1.0 per cent
Butane	0.5 per cent
Pentane	0.6 per cent
Inert	2.1 per cent
O_2	0.2 per cent

PRODUCTION

Petroleum (m^3)

Enterprise	*1959*	*1960*	*1961*	*1962*	*1963*
YPF					
Under standing arrangement . . .	438,723	909,096	1,241,683	1,344,736	1,039,259
Under contract	—	—	—	—	—
Miscellaneous	7,600	—	—	—	—
TOTAL	446,323	909,096	1,214,683	1,344,736	1,039,259

Natural gas (thousands of m³)

Enterprise	*1959*	*1960*	*1961*	*1962*	*1963*
YPF					
Under standing arrangement	768,186	2,052,600	2,832,971	3,229,890	2,711,014
Under contract	—	—	—	—	—
Miscellaneous	2,325	—	—	—	—
TOTAL	770,511	2,052,600	2,832,971	3,229,890	2,711,014

OIL PIPELINE IN OPERATION

Campo Duran (Salta) — San Lorenzo (Santa Fe)

Flow velocity: 9,000 m³/day for light petroleum or light fuels
Length: 1,483 km
Diameter of pipe — A.P.I. grade X-42: 32.5 cm (12-3/4")
Impact pressure: 70 kg/cm²

GAS PIPELINE IN OPERATION

Campo Duran (Salta) - Buenos Aires

Flow velocity: 7,000,000 m³/day
Length: 1,767 km
Diameter of pipe — A.P.I. — 5 LX-52:
Campo Duran-San Nicolas: 60 cm (24")
San Nicolas-Buenos Aires: 55 cm (22")
Gas pressure: 65-68 kg/cm²

ANNEX II

PETROLEUM REFINERIES AND THEIR PROCESSING AND STORAGE CAPACITIES

PRIVATE REFINERIES

Esso S.A.P.A.:
- Campana
- Bahia Blanca (Puerto Galvan)
- Elordi
- Dadin

Shell Dock Sud
Petroquimica
Condor
Ragor
Isaura
Lottero-Pappini
Tennessee

YPF REFINERIES

La Plata
San Lorenzo
Lujan de Cuyo
Plaza Huincul
Dock Sud
Campo Duran

LA PLATA REFINERIES (YPF)

Processing capacity:

	m³/day
Topping	17,500
Thermal cracking	4,000
Catalytic cracking	2,700
Alkylation	940
Polymerization	560
Vacuum	2,300

Storage capacity: 700,000 m³

SAN LORENZO REFINERY (YPF)

Processing capacity:

	m³/day
Topping	4,200
Thermal cracking	2,100
Vacuum	800

Storage capacity: 100,000 m³

Lujan de Cuyo refinery (YPF)

Processing capacity:	m³/day
Topping	6,500
Thermal cracking	4,220
Catalytic cracking	1,700

Storage capacity: 25,000 m³

Plaza Huincul refinery (YPF)

Processing capacity:	m³/day
Topping	490
Thermal cracking	80

Storage capacity: 10,000 m³

Dock Sud refinery (YPF)

Processing capacity:	m³/day
Topping	800
Thermal cracking	380
Vacuum	240

Storage capacity: 110,000 m³

Campo Duran refinery (YPF)

Processing capacity:	m³/day
Topping	4,500

Storage capacity: 30,000 m³

Campana Refinery (Esso S.A.P.A.)

Processing capacity:	m³/day
Topping	11,920
Thermal cracking	3,180
Catalytic cracking	1,590
Vacuum	4,770

Storage capacity: 155,000 m³

Bahia Blanca (Puerto Galvan) Refinery (Esso S.A.P.A.)

Processing capacity:	m³/day
Topping	1,590
Thermal cracking	795

Storage capacity: 41,400 m³

"Manuel Elordi" refinery (Esso S.A.P.A.)

Processing capacity:	m³/day
Topping	240

Storage capacity: 8,000 m³

Shell Dock Sud refinery

Processing capacity:	m³/day
Topping	9,900
Thermal cracking	3,800
Vacuum	1,000

Storage capacity:	m³
Crude	297,997
Heavy distillates	187,428
Light distillates	239,081

Destileria Petroquímica E.N.

Processing capacity:	m³/day
Topping	750
Vacuum	500

Kellogg	370
Coking	75
Cross	250
Redistillation	65

Storage capacity:	m³
Crude	12,380
Heavy distillates	29,157
Light distillates	11,013

Destileria Condor S.A.

Processing capacity:	m³/day
Topping	120

Storage capacity:	m³
Crude	2,500
Heavy distillates	1,000
Light distillates	2,800

Destileria Ragor S.A.

Processing capacity:	m³/day
Topping	40

Storage capacity:	m³
Crude	528
Heavy distillates	250
Light distillates	482

Destileria La Isaura S.A.

Processing capacity:	m³/day
Topping	750
Thermal cracking	180

Storage capacity:	m³
Crude	20,400
Heavy distillates	10,573
Light distillates	12,711

Destileria Lottero-Pappini S.A.

Processing capacity:	m³/day
Topping and vacuum	130

Storage capacity:	m³
Crude	600
Heavy distillates	700
Light distillates	1,400

"Dadin" refinery (Esso S.A.P.A.)

Processing capacity:	m³/day
Topping	80

Storage capacity: 5,510 m³

[illegible] refinery

Processing capacity:	m³/day
Topping	50

Storage capacity:	m³
Crude	59,812

Annex IIA

DESCRIPTION AND CHARACTERISTICS OF PETROCHEMICAL PLANTS AND THEIR PRODUCTION

Petrochemical Industry	*Company*	*Location of the Plant*	*Staff*				*Ownership*			*Origin of technology*	*Capital invested or to be invested*	*Financial structure*
			Engineers	*Employees*	*Technicians*	*Communications and transport*	*Private*	*Semi-public*	*Public*			
Basic intermediary	DGFM	Campana, Province of Buenos Aires (benzene-toluene-xylene)	109	8	42	6	—	—	X	Kellogg Patent (USA) Hydroforming process	321,200,000 pesos	State-owned
	YPF (see also separate sheet at the end of the tables)	San Lorenzo, Province of Santa Fé (isopropyl alcohol)	1	1	—	1	—	—	X	Argentine patent No. 55,341. Process patented by YPF research workers. Esterification and hydrolysis	1,500,000 pesos	State-owned
	Atanor S.A.M.	Río Tercero, Province of Córdoba (methanol)	45	3	1	1	—	X	—	Reforming of gas (French origin). Reconversion of carbonic anhydride. Italian synthesis (Italian)	450,000,000 pesos	Semi-public
	Duperial S.A.	San Lorenzo, Province of Santa Fé (carbon sulphur)	2	1	1	1	X	—	—	Patent Food Machinery (USA) and Chemical Corporation (Canada). The plant was manufactured in the United Kingdom	$US 1,680,000 or £600,000	Investment of foreign capital, Imperial Chemical Industries. Investment of Argentine capital, Duperial Ind. Quim. Argentinas. Reinvestment of profits
	Petroquímica Argentina S.A. (PASA)	San Lorenzo, Province of Santa Fé (benzene-ethylene-styrene-butadiene-synthetic rubber)	700 persons. At the beginning, 45 United States instructors				X	—	—	Catalytic reforming, model Continental Oil (USA) Aromatics and alkylation plant, Houdry (USA). Synthetic rubber Texas and US Rubber (USA). Styrene, Shell (Netherlands)	$US 6,366,998	Investment of foreign capital (private firms, banks). Foreign credit
	Casco S.A.	Pilar, Province of Buenos Aires (methanol)					X	—	—	United States patent-Borden Company Chemicals	$US 5,000,000	
	Duranor	Río Tercero, Province of Córdoba (phenol)	38	3	2	2	X	—	—	Raschig Patent (Germany) modified by Walter Prahl. When Hooker Chemical Corporation acquired the rights to the process, the first US phenol plant was established	$US 1,821,176 $US 2,000,000 $US 1,821,176 $US 5,642,352	Investment of foreign capital. Hooker Chemical Co. Credit from Export-Import Bank. Investment of Argentine capital

Annex IIA (*continued*)

Petrochemical industry	Company	Location of the Plant	Staff: Engineers	Staff: Employees	Staff: Technicians	Staff: Communications and transport	Ownership: Private	Ownership: Semi-public	Ownership: Public	Origin of technology	Capital invested or to be invested	Financial structure
Basic intermediary	Carboclor	Campana, Province of Buenos Aires (various organic solvents)	(At the project stage)				X	—	—		$US 7,000,000	
	Dow Chemical	San Lorenzo, Province of Santa Fé	(Under study)				X	—	—	Dow Chemical Company (USA)	$US 28,500,000	Foreign investment of up to $US 25,000,000
	Ducilo S.A.	To be determined	240		120	90	X	—	—	Dupont (USA)	$US 35-40,000,000	Under study
Nitrogenous fertilizers	Impagro	Bahía Blanca, Province of Buenos Aires (ammonia-ammonium sulphate-nitrate of ammonium-urea)	(At the project stage)				X	—	—		$US 26,000,000	Foreign investment: (Credits from foreign banks)
	Petrosur S.A.	Campana, Province of Buenos Aires (ammonia-ammonium sulphate-urea-compound fertilizers)					X	—	—	Catalytic reforming (USA)	$US 22,700,000	$US 10,000,000 (loan from Inter-American Development Bank). $US 10,000,000 from national and foreign shareholders
Plastic materials	Koppers S.A. (Ipako)	Florencio Varela, Province of Buenos Aires (polystyrene)	69	13	10	3	X	—	—	Polystyrene (polymer styrene) — Koppers International (USA)	$US 1,035,000	Investment of foreign capital 50 per cent US capital 49 per cent Argentine capital Loan from Export-Import Bank, Washington, USA
		Ensenada, Province of Buenos Aires (ethylene-polyethylene) (1)	52	24	28	11	X	—	—	Ethylene-polyethylene — Koppers International (USA)	$US 13,400,000	
	Monsanto Arg.	Zárate, Province of Buenos Aires (polystyrene)	43	6	9	9	X	—	—	Monsanto Company (USA)	$US 1,039 000	100 per cent foreign investment
Thermoplastics	Plastico Bonaabo	Villa Lugano, Federal Capital (polystyrene)	18	3	2	2	X	—	—	Own method	40,000,000 pesos	National investment (domestic resources)
With the exception of those whose plants are marked (1), all plants polymerize monomers	Duperial S.A.	San Lorenzo, Province of Buenos Aires (ethylene-polyethylene) (1)	(Staffing in progress)				X	—	—	Ethylene: Lurgi process (Germany) Cracking purific: Linde (Germany) Polyethylene: polymerization (Process Imperial Chemical Industries, United Kingdom)	£ 5,760,000 $US 16,130,000 *Ethylene and polyethylene*	Investment of foreign capital Imperial Chemical Industries Ltd

Annex IIA (*continued*)

Petrochemical industry	*Company*	*Location of the Plant*	*Staff*				*Ownership*			*Origin of technology*	*Capital invested or to be invested*	*Financial structure*
			Engineers	*Employees*	*Technicians*	*Communications and transport*	*Private*	*Semi-public*	*Public*			
Thermoplastics	Nassau-Plast	Ramos Mejía, Province of Buenos Aires (methyl polymethacrylate). A new production and recuperation plant being built at km 35 on route 3 is to be opened in April	9	2	2	1	X	—	—	Own techniques and patent, originally with advice from Mitsubishi Rayon (Japan) based on German technology	13,829,600 pesos	Argentine capital only
	Plastotal S.A.	Matanza, Province of Buenos Aires	22	1	—	2	X	—	—	Own patent (Argentina)	10,000,000 pesos	Argentine company (domestic capital)
	Industrias Químicas, Antares	Pasaje Don Cristobal 4046, Federal Capital	1	1	1	1	X	—	—	Argentine patent	800,000 pesos	Argentine company (domestic capital)
	Industrias Plásticas Argentinas Escobar	Escobar, Province of Buenos Aires	6	2	1	2	X	—	—	Argentine patent	2,445,000 pesos	Argentine company (own capital)
Synthetic rubber	Petroquímica Arg. Pasa	San Lorenzo, Province of Santa Fé	Total 700				X	—	—	Texas and US Rubber patent (USA)	$US 76,366,998	Foreign investment. Private companies. Banks. Capital investment and loan
Lampblack	Cabot Arg. S.A. Cabon	Campana, Province of Buenos Aires	42	12	32	10	X	—	—	Design by Cabot Engineering (USA). Supervision and installation: Techint Compania Tecnica Int. SAC and I	$US 4,200,000	Foreign investment by Cabot Corporation (USA)
	Pasa	San Lorenzo, Province of Santa Fé	(In planning stage)				X	—	—			
Detergents	Parafina del Plata	J. M. Gutiérrez, Province of Buenos Aires	6	(In planning stage) 14	5	1	X	—	—	Italian patent	582,300,000 Italian lire	Foreign capital invested by Societa Italiana Resine S.A. Transfer of foreign currency
	Compania de Industrias Arg. de Buenos Aires S.A.	Dock Sud, Province of Buenos Aires	3	3	2	1	X	—	—	Model Sulphonator 1000. Patented by Mario Ballestra of Milan (Italy)	1,500,000 pesos	Own capital
Insecticides, pesticides, weed-killers	Atanor (2,4-D and DDT)	Río Tercero, Province of Córdoba	30	3	5	1	—	X	—	2,4-D Argentine Patent D.D.T. Ge Patent	160,000,000 pesos	Domestic capital. Semi-public company

Annex IIA (continued)

[illegible]	Company	Location of the Plant	Staff				Ownership			Origin of technology	Capital invested or to be invested	Financial structure
			Engineers	Employees	Technicians	[illegible]	Private	Semi-public	Public			
	[illegible]	Cinco Saltos, Province of Rio Negro	100	8	6	4	X	—	—	Pechiney and Saint Gobain licence. Other parts, national technology	$US 9,000,000	Argentine Company with French capital investment, counterpart shares issued
Insecticides, pesticides, weed-killers	Cia. Química [illegible]	Llavallol, Province of Buenos Aires	40	3	3	1	X	—	—		44,000,000 pesos	Argentine company — own investment
	[illegible]		7	2	3	1	X	—	—			
	[illegible]	Cap. Bermudez, Province of Santa Fé	5	26	7	1	X	—	—	Imperial Chemical Industries patent (United Kingdom)	113,865,000 pesos	Domestic company with domestic capital
	Ducilo S.A.	Berazategui, Province of Buenos Aires	40	35	17	2	X	—	—	Dupont (USA)	$US 11,000,000	Available resources of the company
Synthetic fibres The companies mentioned [illegible]	[illegible]	La Plata, Province of Buenos Aires										
	[illegible]	Azul, Province of Buenos Aires								Polyester fibre plant. Polyethylene terephthalate plant. Glycol plant	$US 500,000 $US 425,200	Foreign investment and placement of capital Foreign investment and placement of capital
	[illegible]	Mercedes, Province of Buenos Aires								Italian technology	650,000,000 pesos	Argentine company (domestic capital)
	[illegible]	Hernández, Province of Buenos Aires										
	[illegible]	Rawson, Province of Chubut										

Annex III

Petrochemical industry	Product	1963							Installed capacity	Raw material	Local price in pesos 1963
		Capacity			Petrochemical products (tons)	Domestic consumption (total) (tons)	Export (tons)	Destination of export			
		Installed	Being installed	Planned					1970		
1	Benzene	16,700	45,000 Aromatics	—	3,296	3,296		—	45,000	Naphta cuts	26/litre
	Toluene	3,400		—	651	1,500	—			C_6-C_7-C_8 (Naphtha reforming)	53/litre
	Xylene	3,350		—	1,657	2,000	—	—			52/litre
	Isopropanol	1,300	—	—	Shut down since Nov. 62	1,300	—		12 000	Propylene-propane	57/litre
	Methanol		12,000 16,500		6,210	8,617	—		55 000	Natural gas	36.70/kg
	Carbon sulphide	15,000	—	—	3,820	7,400	—	—	15 000	Natural gas	35.70/kg
	Styrene	—	15,000	15,000	—				30 000	Benzene-ethylene	50.30/kg
	Butadiene	—	32,000	—	—					Light and intermediate petroleum fractions. Butane (refinery gas)	
Basic agents	Phenol	8,000	—	—	2,500	3,000	—	—	8,000	Benzene	98/kg
	Acetic anhydride	—	—	9,000	—	950	—	—	9,000		
	Secondary butanol	—	—	4,000	—		—	—	4,000		
	Isopropyl acetate	—	—	2,600					2,600		
	Secondary butyl acetate	—	—		—		—	—		Refinery gases C_3-C_6 cuts	
	Methylethylketone	—	—		—					Propane-propylene-	
	Methylisobutylketone	—	—	2,000		320	—	—	2,000	Butane-Butadiene	
	Methylisobutylcarbinol	—	—			40					
	Ethylene oxide	—	—	Under study	—						
	Glycol	—	—		—	1,250	—	—	12,000	Propane hydrocarbon mixtures	$270/t
	Chlorinated paraffins	—	—			1,100	—	—	7,000		
	Chlorinated olefins	—	—		—	—	—	—	3,000	Methane (natural gas)	$270/t
	Diethylene glycol					500	—	—	1,500	CyF	
	Triethylene glycol					—	—	—	59		
2	Ammonia	—	—	133,000	—	—	—	—	133,000	Natural gas	
	Ammonium sulphate	—	—	108,000	—	35,920	—	—	108,000	Ammonia and ammonium sulphate	10/12/kg
Nitrogenous fertilizers	Ammonium nitrate	—	—	35,000	—	350	—	—	35,000	Ammonia and ammonium nitrate	30/kg
	Urea	—	—	60,700	—	6,000	—	—	60,700	Ammonia	12/kg
	Compound manures	—	—	30,000	—	12,000	—	—	30,000		
3	Ethylene	10,000	15,000	—	3,500	3,500	—	—	25,000	Light distillates C_3-C_4	170/kg
	Polyethylene	7,000	12-14,000	—	3,200	5,500	—	—			
	Polystyrene	12,000	—	5,000	5,400	5,100			27,000	Styrene (imported)	137-159 pesos/kg
Plastic and thermoplastic materials	Polypropylene	—	—		—						
	P.V.C.	—	—	43,000	—	8,500			45,000		
	Methyl polymetacrylate (sheets)	650	440	200	500					Methyl metacrylate (imported)	400 pesos/kg

Annex IIIB (*continued*)

Petrochemical industry	Product	1963							Installed capacity	Raw material	Local price in pesos 1963
		Capacity									
		Installed	Being installed	Planned	Petrochemical products (tons)	Domestic consumption (total) (tons)	Export (tons)	Destination of export	1970		
4 Synthetic fibres	Adipic acid	—	—	20,000	—	—					Benzene or ammonia cyclohexane
	Hexamethylenediamine	—	—	7,000	—	—					
	Dimethyl terephthalate	—	—	4,000	—	—					
	Polyethylene glycol terephthalate . . .	4,000	739								
	Polyamides	5,520	—	10,000	3,310	3,700					Monomer (imported)
	Polyacrylics	3,000	750		281						
	Polypropylenics . . .	30	—	—	42						Polypropylene (imported)
5 Synthetic rubber	S.B.R. (Styrene butadiene)	—	35,000	—	—	15,500	—	—	45,000	Benzomethylene Butadiene Butadiene	
	Cispolybutadiene. . .	—	10,000		—						
6 Lampblack	Lampblack	13,000	17,000	13,000	13,000	13,243	3,000	Uruguay	30,000	Heavy petroleum fraction with high C and H ratio (aromatic concentrates)	55-60/kg
7 Detergents	Dodecylbenzol	—	—	10,000	—					Propane mixture	$30.20/kg
	Dodecylbenzol sodium sulphonate	—	—	Under study (7,000 t)	—	5,720	—	—	—	Propylene (Dodecyl benzene sulphur-caustic soda)	
8 Insecticides, weed-killers, pesticides	Hexachlorocyclohexane	5,500	—	—	2,300	2,300	—	—	9,000	Benzene	80/kg
	Acid-esters 2, 4, D. . .	2,500	—	600	247		—	—	2,400	Phenol	
	D.D.T.	1,500	—		1,330	600	—	—	1,500	Benzene	145/kg

A

PROCESSED CRUDE AND PROCESSING OF PETROLEUM DERIVATIVES BY YPF REFINERIES, 1963

(Cubic metres except as otherwise specified)

Derivatives (m³)	*La Plata*	*San Lorenzo*	*Luján de Cuyo*	*Plaza Huincul*	*Dock Sud*	*Campo Durán*
Aviation spirit	50,200	—	—	—	—	—
Motor spirit						
Regular	612,504	192,757	446,723	34,823	63,539	656,797ᵃ
Special	172,245	—	53,056	—	14,220	—
Solvents	3,006	2,899	819	164	2,911	—
Oil of turpentine	—	—	—	—	2,956	—
Kerosene	230,250	67,735	109,186	8,839	23,161	148,463
Agricol	25,155	7,458	12,197	476	—	12,431
Gas-oil	421,993	177,926	281,521	28,521	23,585	145,260
Diesel oil	351,103	80,215	349,877	14,923	18,298	69,331
Fuel oil	2,646,473	861,486	512,082	4,213	107,799	81,320
Lubricating oils	17,219	—	—	—	16,358	—
Paraffin	—	—	552	—	—	—
Greases	—	—	—	—	5,605	—
Asphalts	118,080	—	—	—	—	—
Coke (tons)	—	—	—	—	—	—
Propane gas	30,593	43	40,923	—	—	154,690
Butane gas	1,022	6	67,458	—	—	173,100
Dry gas (thousands of m³)	57,875	7,729	61,910	1,143	9,987	—
Processed crude	4,855,241	1,402,339	1,999,000	200,067	302,765	1,093,770
Jet fuel	20,533	—	179	500	—	—
Metallurgical coke (tons)	206,573	—	135,807	—	—	—

ᵃ Gasolene transferred to naphtha 7375.

B

PROCESSED CRUDE AND PROCESSING OF PETROLEUM DERIVATIVES BY PRIVATE REFINERIES, 1963

(Cubic metres except as otherwise specified)

By-product (m³)	*Esso S.A.P.A.*				*Shell Dock Sud*	*Petro-química*	*Condor*	*Ragor*	*Isaura*	*Lottero-Pappini*	*Tennessee*	*Sol*
	Campana	*Ba. Blanca Pto. Galván*	*Campana Y.P.F.*	*Dodin*								
Motor spirit												
Regular	309,284	68,186	69,952	—	456,432	43,605	—	—	47,408	76	1,703	—
Special	114,179	—	25,399	—	118,750	—	—	—	1,870	—	—	—
Solvents	15,209	144	2,605	—	28,655	—	5,186	956	102	4,845	—	493
Oil of turpentine	7,154		1,549	—	140,208	180	3,113	1,349	—	2,341	—	577
Kerosene	169,926	4,779	30,138	—	258,543	7,865	1,233	60	18,590	157	—	—
Agricol	36,276	16,878	6,909	—	14,227	78	—	—	4,277	—	—	—
Gas-oil	201,112	1,698	41,965	—	319,000	18,566	172	—	22,149	52	—	—
Diesel oil	190,538	54,562	27,562	—	190,250	21,366	165	—	7,713	65	1,955	—
Fuel oil	698,604	119,191	152,923	—	1,540,700	95,226	2,306	1,239	36,964	300	—	—
Lubricating oils	41,426	—	—	—	38,683	187	3,850	1,756	—	3,410	—	—
Paraffin	—	—	—	—	—	—	—	—	—	—	—	—
Greases	2,276	—	—	—	—	—	—	—	—	—	—	—
Asphalts	67,089	—	2,120	—	100,196	6,633	—	—	—	3,366	—	—
Coke (tons)	21,867	38	5,677	—	22,021	1,103	—	—	—	—	—	—
Propane	29,226	5,724	6,226	—	—	—	—	—	—	—	—	—
Butane	42,148	—	8,958	—	—	960	—	—	—	—	—	—
Dry gas (thousands of m³)	22,310	3,344	4,036	—	73,447	7,117	—	—	—	—	—	—
Processed crude	1,977,485	272,238	397,000	—	3,343,065	220,332	35,727	12,300	157,130	34,187	4,017	—
Jet fuel	33,875	—	8,590	—	36,405	—	—	—	—	—	—	—
Metallurgical coke (tons)	—	—	—	—	—	—	—	—	—	—	—	—

Annex IV

MAP OF ARGENTINA, WITH PARTICULARS OF PETROLEUM AND GAS DEPOSITS

2. THE PETROCHEMICAL INDUSTRY IN BRAZIL

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1. DESCRIPTION

This paper is aimed at presenting the general aspects governing the establishment of the petrochemical industry in Brazil. Practically speaking, the Brazilian petrochemical industry had its beginning only seven years ago. However, even though somewhat recent in origin, this industry has already made fairly appreciable progress. This can be noted from the industrial units already in existence, under construction or scheduled for the future. These data reflect the concrete and promising manner in which the industry is being developed.

This rapid progress and the quite spontaneous growth of the industry are somewhat unusual but highly significant in a country where there has been sound development right from the start, spurred by a population avid for work and progress.

The diversified processes and goals of the petrochemical industry are of fundamental importance to Brazil because of the prospects of their becoming a stepping stone to further growth. In other words, the industry will stimulate small chemical processing industries which are in turn a significant "multiplier" of industrial activities. Such industries create a new labour market and thus make it possible for many living far away from the large centres to achieve a better standard of living.

For a country such as Brazil, which is spread over a wide area and where the industrial nuclei are not always well distributed, it is of interest to know that the petrochemical industry, together with the general and diverse chemical industry, manages to promote industrial progress so promising that it is even hard to predict in precise terms. Brazil has, in fact, sometimes exceeded consumption forecasts. Hence it is not even possible to make a sound appraisal of the probable projection of the market once a basic industry is established.

The other encouraging aspect of the petrochemical industry in Brazil is the possibility of designing petrochemical units of a size larger than that needed for purely domestic consumption, so as to supply also the Latin American market through LAFTA. (Latin American Free Trade Area). This aspect is noteworthy because it may readily justify the immediate establishment of units which would otherwise only be built at a much later date.

In appraising the existing situation, it appears to us that it would be exceedingly opportune if an agreement were to be reached between the Latin American countries belonging to LAFTA to define what priorities exist and what locations should be chosen for petrochemical projects. The locations should be selected in such a manner as o bring the greatest possible benefit, not only to the country constructing the plants, but also to the entire Latin American community. This procedure, if adopted, would assist in the formation of a Latin American petrochemical industry within the shortest possible period of time.

A scheme of this type would avoid the risk of two countries simultaneously building the same type of petrochemical unit, something which would, of course, be detrimental to both. Such duplication of facilities would be far from advisable since it would certainly lead to commercial competition in a field where everything, or nearly everything, still remains to be done. It would have yet another negative aspect when one considers that the investment tied up in such duplication of units might be better used constructing a different type of unit which could cover another specific area of consumption.

We would call to mind the fact that to achieve this objective it would not be enough merely to stipulate the rules to be adopted, which might remain purely theoretical but also to display a great deal of determination and will-power in strengthening Latin American industrial-mindedness which is, as yet, incipient. This attitude is of the utmost importance since, on the one hand, there is the present and fully understood need for fast industrial progress in Latin America but, on the other, there are abundant difficulties not the least of which are the burden of tradition hand in hand with the ease of importing from those countries accustomed to doing business with Latin America.

To overcome these difficulties, which may appear trivial but in reality are of greater influence than can be grasped at the outset, it seems to us that advantage could be taken of a single factor of fundamental significance, namely, the price of the product.

Undoubtedly, the product price ought to be one of the most important aspects of the question. This is true because of the special facilities that the Latin American affiliates of LAFTA have that make it possible for them alone to set prices at a level well below the international market level; due, of course, to the existence of a guaranteed market and to the corresponding tariff protection.

Furthermore, the absence until the present time of a trading system of the LAFTA type has not permitted the emergence of a true Latin American commercial mentality. By that same token, it did not justify or encourage the existence of certain facilities, now considered basic, such as adequate maritime transportation, which is only now being stimulated. Even considering this recent encouragement, it is quite likely that it remains easier to transport goods from Latin America to other parts of the world than to haul these same goods within Latin American itself.

In the specific case of Brazil, the petrochemical industry had not yet been able to utilize the normal basic raw material, natural gas. The reason for this is the shortage in Brazil of natural gas, owing to, among other things, the present stage of development of petroleum production in Brazil and also to the fact that PETROBRAS has dedicated its efforts principally to the production of crude petroleum. Crude petroleum production has been given a high priority in view of the needs for developing the country and for balancing its trade. Added to this is the fact that the natural gas fields are a long way from the regions which have so far been traditionally strong in industry. Although distance is a factor or lesser importance for the use of petroleum because of the facilities for solving transportation problems, the same cannot be said for the transportation of natural gas. Therefore, although Brazil had not yet been able to use natural gas as a raw material for the petrochemical industry, the progress of this industry has not been hindered. The reason for this is that Brazil has used, and will continue to use even more in the future, both refinery gas and liquid petroleum fractions. So much is this the case that, at present, a naphtha pyrolysis unit is being constructed to produce ethylene.

Another point to be considered is that Brazil has not yet been able to evaluate with accuracy its natural gas reserves.

In the design of refineries to be constructed by PETROBRAS in the future, the process scheme will be planned with particular attention to obtaining raw materials for the petrochemical industry. This is true with regard to both residual gases and liquid petroleum fractions.

Although not included in the State monopoly governing the petroleum industry in Brazil, the petrochemical industry is strongly affected by this monopoly. This is because the petrochemical industry is closely linked with petroleum refining, not only on account of its very nature but also because it has so far been based exclusively on refinery gases and liquid petroleum fractions, which are directly controlled by petroleum refining policies.

To obtain a better understanding of the structure of the Brazilian petrochemical industry, it is necessary to present a brief description of the legal aspect of the petroleum refining industry, intimately connected with the petrochemical industry in the supply of raw materials.

2. THE LEGAL ASPECT OF THE PETROCHEMICAL INDUSTRY IN BRAZIL

To understand the mechanism underlying the establishment and subsequent development of the petrochemical industry in Brazil, it is necessary to grasp at least the main aspects of the legal structure through which it was made possible to set up this type of undertaking.

The monopolistic policy of the petroleum industry commenced with Law No. 2,004, of 3 October 1953, vesting monopoly in the Union and providing that exploration, production, refining and transportation of petroleum would all be handled by the National Petroleum Council and by Petroleo Brasileiro S.A. — PETROBRAS, a mixed economy corporation created by the said law, as the executive agency.

After the creation of the State monopoly, Government policy with regard to procedures to be established in this area of activity was handed down by the National Petroleum Council through its resolutions. Hence on 13 April 1954, through its resolution No. 3/54, issued by the 767th Ordinary Session, the National Petroleum Council recognized, thereby showing a broad grasp of the industrial problem in Brazil, the advisability of establishing a petrochemical industry to use petroleum products and by-products as raw materials, in view of the great interest such an industry would have for the Brazilian economy as a whole.

In its above-mentioned resolution, the National Petroleum Council recommended that, because of the diversification which is a feature of the petrochemical industry, this industry should as far as possible be set up by private enterprise. The Resolution further recommended that prior agreements be established between the Special Committee for the Petrochemical Industry (now the Petrochemical Division of the Industrial Department of PETROBRAS) and interested parties, whereby petrochemical raw materials from the industrial units of PETROBRAS might be used by private petrochemical industry as soon as these raw materials came into production. In other words, this previous agreement would obviate any failure to take advantage of these new raw materials as soon as they were available to the industry. This was one of the first decisions taken by the Brazilian Government aimed at setting up and stimulating the petrochemical industry in the country.

Another decision in the petrochemical field was made on 30 January, 1957, by resolution No. 1/57, issued at the 895th Ordinary Session. In that resolution the National Petroleum Council:

Considering the outstanding economic importance of this type of industry,

Considering that there were market conditions, and production conditions, existing in Brazil at that time for the manufacture of basic raw materials derived from by-products of petroleum refining and thus making it possible for the petrochemical industry to be established,

Considering that the petrochemical industry was not a government monopoly,

Considering that the establishment of this industry in Brazil should as far as possible be done by private enterprise,

Considering that the special conditions in the petrochemical industry lend themselves to the formation of monopolies, which ought to be avoided,

Considering that the Union could engage in industry and commerce in the petrochemical field through PETROBRAS,

Considering, finally, that it was in the interests of Brazil to discipline the establishment and development of the petrochemical industry in Brazil,

Decided to rule that liquefied petroleum gas (LPG), gasoline, kerosene, fuel oil for internal combustion engines (diesel oil), gas-oil, signal oil, fuel oil, lubricating oil and asphalt shall be considered products and by-products of petroleum refining and hence subject to the production monopoly vested in the Union, in line with Law No. 2,004, of 3 October, 1953.

In the same resolution, the National Petroleum Council stated that the following are considered basic raw materials for the petrochemical industry:

(*a*) Aliphatic hydrocarbons:
Saturated: methane, ethane, propane and butanes.
Unsaturated: ethylene, propylene, butenes and acetylene.

(*b*) Aromatic hydrocarbons: benzene toluene, xylenes.

(*c*) Mixtures of hydrogen and carbon monoxide: "synthesis gas".

It was also laid down in the resolution that the following be considered as the essential products of the petrochemical industry:

(*a*) Methanol;
(*b*) Ammonia;
(*c*) Nitric acid;
(*d*) Tetra-ethyl lead;
(*e*) Butadiene;
(*f*) Styrene;
(*g*) Synthetic rubber.

Resolution No. 1/57 furthermore stipulated that it was incumbent on the National Petroleum Council to issue authorization for installation in Brazil of industries for producing the basic raw materials and the essential products of the petrochemical industry.

It was stated in the same resolution that PETROBRAS could engage in industrial and commercial activity in the petrochemical field provided that this was in the economic interests of the corporation. It could also so operate when there was a need for guaranteeing production of basic raw materials and essential products of the petrochemical industry when private industry was not interested in manufacturing such products or for avoiding any kind of monopoly in the hands of private enterprise in the supply of basic raw materials and essential products of the petrochemical industry. It was also decided that PETROBRAS should operate in this field to stimulate adequate development of the industry in Brazil and that this should be one of the corporation's primary goals. This is why PETROBRAS is actually a factor of utmost importance in the success of the development of the petrochemical industry in Brazil.

The petrochemical units, built by PETROBRAS to date and producing essential products in line with resolution 1/57, are those for ammonia, nitric acid and synthetic rubber. A butadiene unit is under construction and units for making anti-knock fluid (based on tetra-ethyl lead) and styrene are in the planning phases.

It is worthwhile to note that some of the basic raw materials for the petrochemical industry can be produced only by PETROBRAS since they involve petroleum refining operations.

Although the petrochemical industry is not a government monopoly, this does not mean that the State is barred from operating in this area if the economic incentive exists or if this is in the national interest and not only a question of national security but also when it is of fundamental importance to economic development. Hence in two undertakings, the Fertilizer Plant at Cubatão, and the Presidente Vargas Petrochemical Complex at Rio de Janeiro, PETROBRAS did not limit itself to the production of raw materials but continued to the final product. However, although this is a correct policy in particular cases, it seems more advisable to us from the point of view of industrial development and in line with the speed of development and diversification of the industry that PETROBRAS concern itself on a priority basis with the production of basic raw materials. It would thus permit the establishment and development of a chemical industry, which is undoubtedly very promising, entirely by private initiative.

In Brazil, natural gas as a raw material for the petrochemical industry is not as yet assured. In addition, since the gas fields are located far from the present large industrial centres, natural gas will not be a starting material in the immediate future.

Furthermore, off gases from the refining of petroleum are not yet produced in sufficient quantities to meet the demands for petrochemical raw materials.

Since the present Brazilian fuel market does not need the more severe refining operations which would produce more refinery gas, we see no solution other than to base the Brazilian petrochemical industry on liquid petroleum fractions until such time as it is possible to take advantage of new natural gas fields and/or refining schemes which produce greater quantities of refinery gas.

Based on these facts, PETROBRAS is turning towards liquid petroleum fractions, as shown by the naphtha pyrolysis unit being constructed to increase the production of ethylene.

In the present situation, the progress of the petrochemical industry could be speeded up by adopting the following policies:

(*a*) Development of the existing natural gas fields;

(*b*) Facilities for the supply of liquid fractions of petroleum, mainly naphtha, for the production of basic raw materials provided this does not interfere with the State monopoly; in other words, provided the manufacture of these raw materials does not result in the obtaining of by-products whose output and commercialization are the exclusive right of PETROBRAS under its monopolistic set-up;

(*c*) Intensive and immediate promotion by PETROBRAS of the production of those raw materials which can only be produced by it in accordance with the government monopoly. This includes those raw materials whose production involves commercialization of products included under the government monopoly and which are necessarily obtained during the process scheme.

Generally speaking it may be said that the goal of PETROBRAS is to run its enterprises and develop them in such a manner that they may supply the basic raw materials and products essential to private industry. It is not in the interests of PETROBRAS to extend its monopoly to the petrochemical industry since this could side-track it from its principal objective, which is self-sufficiency for fuels in Brazil. Another reason is that a monopoly could also slow down the progress of the chemical industry owing to the natural diversification of this industry.

However, even though it is not in its interests to monopolize the petrochemical industry, PETROBRAS does not commit itself to limit its operations to the production of raw materials or essential products. It may, in fact, produce the final product when this is of economic or national interest. On the other hand, it might even be said that there is already a trend in PETROBRAS towards permitting private enterprise to produce the basic raw materials and essential products for the petrochemical industry whenever this does not conflict with its own interests or go against the law which fixes the State monopoly.

3. INDUSTRIAL ASPECT OF THE PETROLEUM CHEMICALS INDUSTRY IN BRAZIL

The 1950-1960 period is of special significance for Brazil, since it was in the last quarter of this decade that, with the nitrogeneous fertilizer plant at Cubatão, the petrochemical industry really got under way in Brazil. This plant was started by the National Petroleum Council and completed by PETROBRAS as soon as this latter entity was created.

PETROBRAS' petrochemical plants at present include the following units: the ethylene and propylene units located in the Presidente Bernardes Refinery at Cubatão (RPBC), producing basic raw materials; the synthetic rubber plant located in the Presidente Vargas Petrochemical Complex (COPEV), whose product is considered as essential (resolution No. 1/57 of the National Petroleum Council); and the Cubatão Fertilizer Plant with its ammonia and nitric acid units, which also produce essential items, and the ammonium nitrate fertilizer plants, which produce end products.

PETROBRAS plans the following expansion of these units already in full operation: ethylene unit to be expanded to 100 tons capacity a day; propylene to 60 tons a day; and ammonia to 140 tons a day. These units are located in the Presidente Bernardes Refinery in Cubatão. So that it may be possible to boost the production of ethylene as planned, a unit for the pyrolysis of naphtha or ethane is being built at the Presidente Bernardes Refinery.

At present, PETROBRAS is constructing the following petrochemicals plants: butadiene, located in the Presidente Vargas Petrochemical Complex (COPEV); ammonia and urea, located in the Bahia Petrochemical Complex (COPEB); and extraction of aromatics, located in the Presidente Bernardes Refinery (RPBC).

The raw material for the butadiene unit will be produced in a Butanes Feed Preparation Unit, to be located in the Presidente Vargas Petrochemical Complex (COPEV), at Duque de Caxias. Construction of this unit is scheduled to begin shortly.

Besides the above, a catalytic reforming unit is being constructed which will supply an aromatic-rich reformate stream to serve as raw material for the aromatics extraction unit in Cubatão.

The following petrochemical units are also scheduled to be built by PETROBRAS: styrene, ethylbenzene, dodecene, tetraethyl lead, and SBR latex. Studies are now being made for these plants.

It should be borne in mind that it is PETROBRAS' intention to transform the two petrochemical units already begun into vast petrochemical complexes. The units under reference are the Presidente Vargas Petrochemical Complex at Caxias in the State of Rio de Janeiro and the Bahian Petrochemical Complex at Camaçari in the State of Bahia.

At the Presidente Vargas Petrochemical Complex, there already exists an SBR-type copolymer rubber manufacturing unit and plans call for the addition of new units such as DDB, SBR latex and units for other types of synthetic rubber.

At the Bahian Petrochemical Complex construction has begun on the ammonia unit and plans call for commencement of the urea unit shortly.

The petrochemical units of PETROBRAS already in existence, under expansion, and scheduled for construction, are summarized in the following tables:

TABLE 1. UNITS OF THE PETROCHEMICAL CENTRES OF PETROBRAS

Existing PETROBRAS *units*

Units	*Raw materials*	*Products*	*Capacity of project*	*Location*
1. Nitrogeneous fertilizer plant	1. Refinery gas or GLP	Ammonia	90 t/day	Pres. Bernardes Refinery (RPBC) Cubatão, State of São Paulo
		Nitric acid	340 t/day	
	2. Atmospheric air	Calcium nitrate	340 t/day	
	3. Limestone	Ammonium nitrate	34 t/day	
2. Ethylene	Gases from thermal cracking unit	Ethylene	57 t/day	Pres. Bernardes Refinery, (RPBC) Cubatão, State of São Paulo
3. Propylene	Propylene-rich liquid stream from ethylene unit	Propylene	30 t/day	Pres. Bernardes Refinery (RPBC) Cubatão, State of São Paulo
4. Synthetic rubber plant	1. Butadiene 2. Styrene	Synthetic rubber, types: SBR-1500 SBR-1502 SBR-1710 SBR-1712	40,000 t/yr	Pres. Vargas Petrochemical Complex, Caxias, State of Rio de Janeiro

TABLE 2. UNITS IN COURSE OF EXPANSION

Units	*Capacity after expansion*	*Location*
1. Ethylene . .	100 tons per day	Presidente Bernardes Refinery Cubatão, State of São Paulo
2. Propylene	60 tons per day	Presidente Bernardes Refinery Cubatão, State of São Paulo
3. Ammonia	140 tons per day	Presidente Bernardes Refinery Cubatão, State of São Paulo

TABLE 3. UNITS UNDER CONSTRUCTION IN PETROBRAS

Units	*Raw materials*	*Products*	*Capacity of project*	*To be ready by*	*Location*
1. Butadiene .	1. C_4 fraction	Butadiene	33,000 t/year when processing n-butane	Mid 1966	Pres. Vargas Petrochemical Complex Caxias, State of Rio de Janeiro.
2. Ammonia .	1. Natural gas 2. Atmospheric Air	Ammonia	200 t/day	End 1966	Petrochemical Complex of Bahia, COPEB, Camaçari, State of Bahia
3. Extraction . of aromatics	Stream from catalytic reforming unit	Benzene	100 t/day	Mid 1965	Pres. Bernardes Refinery, Cubatão, São Paulo

TABLE 4. UNITS PROGRAMMED IN PETROBRAS

Units	*Raw materials*	*Products*	*Capacity of project*	*To be ready by*	*Location*
1. Ethylbenzene	1. Ethylene 2. Benzene or 3. Reformate stream containing ethylbenzene	Ethylbenzene	23,000 t/yr	End-1966	Not decided
2. Styrene	Ethylbenzene	Styrene	20,000 t/yr	End-1966	Not decided
3. Propylene and/or cumene tetramer	Stream of hydrocarbon of the propane	Dodecene	250 bbl/day	Mid-1966	Landulpho Alves Refinery (RLAM) Mataripe, St. of Bahia
4. Dodecylbenzene	1. Benzene 2. Dodecene	Dodecylbenzene	10,000 t/yr	Mid-1966	Pres. Vargas, Petrochemical Complex, COPEV, Caxias, St. of Rio
5. Urea plant	1. Ammonia 2. Carbonic gas	Urea	250 t/day	Early 1967	Bahia Petrochemical Complex, COPEB, Camaçari St. of Bahia
6. Anti-knocking fluid plant	1. Salt 2. Lead 3. Ethylene or 4. Ethyl alcohol	Tetra-ethyl lead	11,500 t/yr	End-1967	Not decided

To provide an over-all picture of the chemical industry in Brazil, we have listed in the following table the main chemical products which are almost entirely produced in private industrial plants. Part of these products are of petrochemical origin. We have also listed the expansions planned and the new units scheduled.

TABLE 5

Item No.	*Product*	*Present capacity (t/year)*	*Expansion (t/year)*	*Capacity new unit (t/year)*	*Future capacity (t/year)*
1.	Methanol	10,000	8,000	9,000	27,000
2.	Formaldehyde	31,000	11,500	15,000	57,500
3.	Phenolic resins	4,200	—	—	—
4.	Urea resins	8,500	—	—	—
5.	Vinyl resins	24,000	—	—	—
6.	Styrene	16,000	—	18,000	34,000
7.	Toluene	1,120	—	—	—
8.	Polyethylene	17,000	—	17,000	34,000
9.	Carbon black	32,000	—	15,000	47,000
10.	Polyvinyl chloride (PVC)	32,000	20,000	—	52,000
11.	Trichloroethylene	3,000	—	—	—
12.	Perchloroethylene	700	—	—	—
13.	Nylon	20,000	—	—	—
14.	Heptyl alcohol	400	—	—	—
15.	Cellulose acetate	7,500	—	—	—
16.	Vinyl acetate	8,700	—	—	—
17.	Vinyl emulsions	1,000	—	—	—
18.	Isopropyl alcohol and derivatives	9,900	—	—	—
19.	Polystyrene	15,000	2,200	—	17,200
20.	Phenol	5,400	3,600	—	9,000
21.	Superphosphate	204,000	60,000	—	264,000
22.	Maleic anhydride	500	—	1,000	1,500
23.	Polyester	500	—	—	—
24.	Acrylic sheeting	1,500	1,500	—	3,000
25.	Phthalic anhydride	6,000	—	—	—
26.	Dioctyl phthalate (DOP)	2,500	—	—	—
27.	Dibutyl phthalate (DBP)	1,200	—	—	—
28.	Polyurethane	600	—	—	—
29.	Acetone	2,000	—	—	—
30.	Sulphur	6,000	—	—	—
31.	Ammonium sulphate	8,202	—	—	—
32.	Benzene	6,400	—	—	—
33.	Xylene	276	—	—	—
34.	Crude naphthalene	2,100	—	—	—
35.	Sulphuric acid	164,200	—	—	—
36.	Carbon tetrachloride	1,800	—	—	—


PETRÓLEO BRASILEIRO S.A.
REFINERIES AND PETROCHEMICAL
INDUSTRY IN BRAZIL

3. PETROCHEMICAL COUNTRY STUDIES — BURMA

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HISTORICAL SURVEY

During exploratory drilling in 1960 the presence of natural gas was detected at Chauk oilfields in Central Burma. More work of this kind is in progress to determine the reserves and it is expected that firm figures as regards the size of the field will become available during 1965. Depending on this, plans will be undertaken to start a petrochemical industry for the country.

As a start, one 69,000-tons per annum fertilizer plant will be installed using natural gas as starting material. The process here will be to produce urea, which tests indicate will be most suitable for our present need.

If the gas reserve so found is of considerable size the petrochemical industries to be undertaken later may include plastics and synthetic fibres. At present a few small plants import raw plastics for the manufacture of domestic articles.

Investigation into the possibility of making nylon yarns from imported raw material is being undertaken and this would obviously receive more impetus should the available resources within the country prove promising.

Thus the petrochemical industry in Burma is now in its initial stages of development and its future expansion depends on firm estimates of the country's resources in natural gas. Once this is available, plans will be made and implemented with speed.

ECONOMIC MOTIVES

Initial investigations show that, given good reserves in resources, petrochemical products could be produced at a reasonable operational cost. As an example, urea fertilizer when produced from locally available natural gas would cost around Ks 300/ton as against the imported value of around Ks 500/ton f.o.b.

The industry, when established will be State-owned and its products will be primarily intended to improve yields of the main agricultural crops. Profit considerations would therefore be of very little importance.

INSTITUTIONAL MEASURES IN FAVOUR OF DEVELOPMENT

At present the use of petrochemicals in Burma is increasing. Measures now undertaken by the State give good priority to improvement in crop yields, making use of fertilizers, mostly nitrogenous, more or less compulsory. Soil research centres carry out work required for various crops and the results so far obtained show the need for nitrogenous fertilizers in most cases.

Of importance also is the narrow boiling range of isohexane (62°C/82°C) — for use in rice bran oil extraction. This petroleum solvent is now being imported mostly. A similar solvent needs to be made from the locally available petroleum fractions. Currently existing facilities in crude oil refining produce a solvent of 50° to 130°C boiling range without any difficulty.

These two cases illustrate the need to start a petrochemical industry. Studies show that units of economically operable sizes could be built to achieve good initial results.

While imports still continue to meet the country's requirements, plans to meet these requirements from locally available materials will be made as necessary.

SUPPORTING ACTIVITIES FOR PETROCHEMICAL INDUSTRY

Burma's crude oil production currently is around half a million ton per annum. All this is processed to produce major petroleum products in the two refineries whose combined capacity is 1.2 million tons *per annum*. In addition, crude petroleum is imported to augment the local production as feedstock to the refineries.

The oil industry as a whole is completely staffed by nationals of Burma. It has been in existence for the past seventy years. The industry is State owned and could without much difficulty include petrochemical operations.

The country also has full-scale applied research facilities, where work in all fields could be undertaken, and an institute operates effectively to train the engineering personnel.

Facilities to produce major equipment do not fully exist yet. Plans for this would however come in due course.

EXPECTED LINES AND RATE OF DEVELOPMENT UNTIL 1970

As stated earlier, plans made so far are all subject to figures about to be obtained on reserves of natural gas.

Should these be favourable, the first unit in petrochemicals would be for *nitrogenous fertilizers*. Here, some 3 thousand million cu. ft. of gas will be used to produce 60,000 tons of urea *per annum*. The product with nitrogen content in excess of 45 per cent will be packed in 35 kg polythene bags and distributed widely for use in agriculture. As the approximate period required in construction, test runs, etc. would be around five years, it is likely that the unit will be on stream by 1970.

Gas requirements of 3 thousand million cu. ft. *per annum* would include 1.18 thousand million cu. ft. needed for power generation in the fertilizer factory.

Next in line for consideration will be *plastic materials*. It is likely that the use of these materials will increase rapidly in years to come and it would soon be possible to produce them locally. Here again, the availability of raw material will be the influencing factor. Unless other changes occur, the chances of the introduction of a plant for plastic materials before 1970 is rather remote.

Investigation work may also start for *synthetic fibres*. But it is unlikely that plans for implementation could be made before 1970.

Crude oil currently refined in the country includes imports. Should this change drastically in quality and become one of the sour varieties, plans may further be made to extend petrochemical industries — to sulphur and other products from refinery gas. This however is quite uncertain in the present circumstances.

Research work is in progress to investigate the possibility of manufacturing *detergents and pesticides*. This will initially start with imported base material but continuous work will be carried out to explore the possibilities for a local substitute.

GENERAL REMARKS

Effective development programmes are being set up for Burma's petroleum industry. During the implementation of such programmes, continuous efforts will be made to include petrochemicals wherever possible so that the petroleum industry would become one complete enterprise.

Indications so far obtained in exploration efforts include gas detection and it is hoped that this will soon show a very large-size reservoir.

Refining facilities are also expanding and may soon include processes to produce good quantities of Refinery Gas. This would then become another source to be considered especially for minor products.

4. PETROCHEMICAL INDUSTRIES IN CHILE

Juan Tampier, CORFO & ENAP (Chile)

A. HISTORICAL SURVEY

1. *Creation and functions of the Chilean Development Corporation*

The Chilean Development Corporation during the past twenty-five years has played a leading role in the development of agricultural, industrial and mining productions in Chile.

This government instrumentality was created by law in 1939 and its organic law was enacted in 1941 and updated in 1960.

The legal text[1] when determining the functions of the Board of the Corporation emphasized the following:

"Formulate a plant to foment national production with the purpose of raising the standard of living in the country by making use of natural resources, diminishing production costs and improving the balance of payments. The plan should contemplate an adequate distribution in the development of mining, agriculture, industry and commerce and attempt to satisfy the needs of the different regions in the country."

In accordance with these functions, the Coporation started prospecting actively for oil in 1943 in the Province of Magallanes, which presented favourable geological conditions and where some prospecting had been undertaken previously by other government entities. Drilling started two years later and the first oil field was discovered in December 1945 near Cerro Manantiales on the island of Tierra del Fuego.

The Corporation continued exploring and developing oil until 1950 when it was deemed that the time had come to create a commercial entity to develop the oil industry with enough flexibility to take charge of exploring for, producing, refining and selling petroleum. This in no way altered the law that reserved for the State the property of all oil fields and the right to refine petroleum.

2. *Creation and functions of Empresa Nacional del Petróleo*

In June 1950, a law was enacted creating the Empresa Nacional del Petróleo (ENAP). This autonomous entity is linked to the Chilean Development Corporation and must submit its annual report for approval to the Board of the Corporation.

In accordance with this law and the by-laws of ENAP "The rights and functions of the State with respect to petroleum exploration, production, refining and sale of its products and by-products shall be exercised by said entity".

Amongst its objectives shall be to "Erect, install, acquire, rent and operate plants for treating, transforming, refining and utilizing petroleum, its derivatives and by-products".

3. *Petro-carbochemical projects in Chile*

Both the Chilean Development Corporation and Empresa Nacional del Petróleo have been concerned for some years with the development of the petrochemical industry. In 1956 the Corporation made a preliminary study to utilize in petrochemical industries the by-products of ENAP's refinery, the steel-mill coke ovens and the beet-sugar plants in order to manufacture a wide range of petro-carbo-sucro-chemical products for internal consumption.

This study was enlarged in 1958 with the co-operation of the United Nations expert, Mr. Krijgsman, and another study made by Mr. Jean Delorme in 1959 in the field of plastics. These studies were all based on meeting the requirements of only the local market.

ENAP has also made preliminary studies since 1959, but so far none of these studies has yet been implemented.

ECLA has made for the whole of Latin America several studies, mostly related to markets, which appear in the recently published report entitled "Chemical Industry in Latin America". This report contains interesting considerations on the present and future demand for the main chemical and petrochemical products as well as on the relative suitability for their production in the different countries.

4. *Present situation of the chemical and related industries*

Chile, as well as most other Latin American countries, has only a budding chemical industry. The existing industry mainly manufactures consumer good or performs only the last stage of a series of processes that start from a basic raw material and go through intermediate products before arriving at a product consumed by parachemical or other industries.

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[1] Author's translation from original in Spanish.

During the last decade, some important industrial developments have taken place, one of the most outstanding being the development of the paper and cellulose industry (present production being 200,000 tons a year of newsprint paper and 100,000 tons a year of cellulose with expansion under way to reach 250,000 tons a year, other projects, some under way, will double these figures during the next five years).

Some basic products such as chlorine (6,000 tons), caustic soda (7,000 tons), sulphuric acid (160,000 tons) and carbon sulphide, are manufactured in connexion with other industries such as viscose rayon, cellophane and cellulose. Benzene, toluene and xylene are obtained from light oils available from coke ovens.

Synthetic nitrogenous fertilizers have not been developed. It should be noted that Chile is the main producer and exporter of natural nitrate.

Organic synthesis derived from fermentation alcohol is somewhat limited owing to the high cost of raw materials. Some products are available: ethyl acetate (600 tons), ethyl alcohol (6,000 tons), acetic acid, etc.

There are plants producing formaldehyde from imported methanol (3,000 tons with future expansion to 8,000 tons) and advanced projects to produce melamine formaldehyde, urea formaldehyde, phenol formaldehyde, etc.

The petrochemical industry is in its very first stages. It should be noted that polyester fibre is about to be produced from imported polyester chips in a plant with initial capacity of 1,000 tons and planned expansion to 8,000 tons. Other similar plants are in the project stage to operate some two years hence.

Presently, a polyamide fibre plant importing chips has a capacity of 1,800 tons a year and there are advanced projects to increase the installed capacity in the country for polyamide fibres.

Styrene monomer is being imported and polymerized locally to obtain different grades of polystyrene resin for moulding, including high-resistance polystyrene. Present production of 1,200 to 1,500 tons a year meets 60 per cent to 75 per cent consumption.

In similar fashion, starting from the imported monomer, polyvinyl acetate is produced for the manufacture of emulsions used for paints and adhesives (500-700 tons a year of monomer).

Some 200 to 300 tons a year of polyester resins and 1,500 tons a year of alkydresins are also produced.

Parachemical and allied industries that use chemical raw materials that can be mentioned are: plastics (10,000 t/year capacity); elastomers (tyres and similar use 6,000 to 8,000 t/year of natural and synthetic rubber and 2,500-3,000 tons of carbon black); textiles (30,000 tons of cotton, some 3,500 t/year of viscose rayon are produced with expansions under way and synthetic fibres are woven for all domestic consumption); soap and detergents (dodecylbenzene is imported and sulphonated locally): litographic industry, particle boards, etc. All of these are highly developed and Chile has one of the highest *per capita* consumption of these products in Latin America.

B. PRESENT SITUATION OF THE PETROCHEMICAL INDUSTRY IN CHILE

1. *Basic information*

(a) *Local market development*

In the mid-fifties, industries to transform and formulate products of petrochemical origin began to develop in Chile. These consisted of the manufacture of plastic and rubber products, paints, enamels and adhesives formulation of synthetic detergents and, more recently, manufacture of synthetic fibres and spun yarn, mostly nylon and polyester. In 1957, imports of raw materials and products of petrochemical origin reached a figure of about $US 4 million, in 1963 it climbed to $US 20 million and if an accelerated programme of substituting imports by locally produced products is not adopted, imports could reach a figure of $US 45 million by 1970.

It is interesting to point out that the equipment presently installed in the transforming and formulating industries allows for a wide range of diversification of final products of high quality, owing mainly to the important renovations and expansions made possible by the policy of encouraging imports of capital goods that existed up to two years ago.

(b) *Latin American Free Trade Association (LAFTA)*

The Treaty of Montevideo that created the Latin American Free Trade Association went into effect on 1 June 1961. LAFTA is presently composed of nine Latin American countries: Argentina, Brazil, Chile, Colombia, Ecuador, Mexico, Paraguay, Peru and Uruguay. At the time when this treaty was being written, Venezuela had shown its intention of joining LAFTA.

One of the fundamental aims of the Montevideo Treaty is to establish the base for an eventual Latin American Free Market with a potential of 200 million consumers.

The instruments and elements provided by the Montevideo Treaty, which are being perfected yearly by resolutions approved by the members, permit new possibilities of developing certain industrial sectors, with a regional approach to be visualized. This is particularly applicable to the most dynamic sections of Latin American industry, amongst which the petrochemical field is outstanding.

Studies undertaken by ECLA in the Latin American chemical field and published in the report entitled "Chemical Industry in Latin America" point out to this fact and evidence the enormous possibilities offered by Latin America for the integrated and co-ordinated development of the petrochemical industry.

(c) *Technological aspects*

The ever-dynamic technological changes in equipment, processes and products make it possible to apply new concepts in planning the development of the petrochemical industry.

New techniques and processes make possible the economic utilization of resources and raw materials that up to a few years ago were useless.

Also, the development of oil production and refining in Chile is making available raw materials for petrochemical synthesis that were not available ten years ago. Thus, for example, the development of large natural gas fields in Southern Chile, together with the expansion and modernization of refining facilities, offer large quantities of natural gas and liquid fractions to the petrochemical industry.

2. *Lines of action*

(a) *Feasibility studies*

Information gathered from the studies and reports mentioned before, complemented by preliminary contacts made at petrochemical meetings under the auspices of LAFTA and field trips to petrochemically developed countries, moved the Corporation and ENAP to contract the services of specialized firms to perform market survey and feasibility studies in the field of petrochemicals. The purpose of these studies is to determine the advisability of establishing in Chile petrochemical complexes that, with raw materials and resources available locally, will manufacture those products that look particularly attractive under Chilean conditions.

For this purpose the Corporation and ENAP have jointly contracted the services of The Fluor Corporation Ltd. of Los Angeles, California, to perform a general feasibility study of the petrochemical industry in Chile, including a market survey for selected products at a Latin American level. This survey was sub-contracted to Arthur D. Little Inc. The Fluor study is well under way and should be completed by the end of the year.

Also, on behalf of the Corporation, the firm Humphreys and Glasgow Ltd. of England is working on a preliminary project for the establishment of a polyvinyl chloride plant in Chile mainly for local consumption.

(b) *Formulation of development plans and policies*

The aforementioned studies, complemented by specific studies in promising petrochemical fields in Chile, will serve as a basis to formulate a short, medium and long-range plan for the development of the industry.

This plan is to be submitted soon to the new administration that will be assuming its functions jointly with the recently elected President of the Republic.

A technical commission composed of representatives of the Corporation and ENAP will be formed *ad hoc*, and will have as its main function the formulation of this plan as well as to make recommendations as to incentives, investments and co-ordinating policies. Since the petrochemical industry is one of the industrial activities that the Government wishes to develop rapidly, it is safe to assume that adequate means for its realization will be available.

In fact, the existing legislation is adequate to justify capital investments in fields considered to have national interest. In effect, authorizations to invest in Chile have the nature of a contract, between the investor and the Government, that guarantees the investor, particularly the foreign one, the free return of his capital, interest and profit. In addition, the law contemplates the granting of certain custom and tax exemptions for industries considered to have a national interest.

This is not the time to quantify the amounts of the possible exemptions in the petrochemical field, since the new Government's policy for industrial development is still in its last stages of completion. However, it seems plausible to assume that a logical way to obtain a rapid and harmonious development of this industry in Chile would be through joint ventures with participation of qualified foreign capital and technological know-how as well as marketing experience at different levels. The national counterpart in these joint ventures could be formed by both the Government, represented by the Corporation and ENAP, as well as private local individuals or firms.

C. PRELIMINARY PLAN FOR THE DEVELOPMENT OF THE PETROCHEMICAL INDUSTRY, 1965/1970

1. *Probable nature of complexes*

Although the feasibility studies previously mentioned have yet to be completed, it is possible to advance in a preliminary way and only for general orientation purposes the opinion that the following petrochemical complexes might become promising to establish in Chile between 1965 and 1970:

(*a*) Ethylene complex consisting of the following plants:

Ethylene ex light naphtha plant.
Chlorine-caustic soda electrolytic plant.
Ethylene dichloride plant.
Vinyl chloride plant.
Polyvinyl chloride and copolymers plant.
High pressure polyethylene plant.
Ethylene glycol plant.
PVC compounding plant.

(*b*) Aromatics complex, consisting of the following:

Aromatics extraction and separation from reformate.
Phthalic anhydride ex ortoxylene plant.
Phthalic plasticizers plant.
Terephthalic acid ex phthalic anhidryde plant.
Polyester chips plant.

(*c*) Ammonia complex:

Synthesis gas ex natural gas plant.
Synthetic ammonia plant.

2. *Investments and financing*

The definite composition of the complexes to be developed during 1965/1970, as well as the size of the component plants, will be determined when the feasibility studies are completed. Nevertheless, it is possible to give preliminary estimates as to the amounts to be invested during the six-year period. The total amount should not be under US$ 50 million, of which approximately one half could be provided by the public and private national sectors in local currency and the other half would be provided by external investments and credits.

3. *Probable location of complexes*

It is believed that both the ethylene and aromatics complexes should be located next to one of the two refineries that will be operating in 1965: that is, either next to the existing refinery at Concón, near Valparaíso, or the one under construction at San Vicente near Concepción.

The ammonia complex should be located near the large natural gas fields in Magallanes, on the extreme southern portion of Chile, where it could be associated with a methane liquefaction plant presently under study.

4. *Regional petrochemical integration*

The Chilean petrochemical industry is being planned bearing in mind the regional integration made possible by the Latin-American Free Trade Association. Thus, three types of petrochemical production appear likely:

(*a*) Production aimed mainly at the local market having costs similar to those of other LAFTA countries.

(*b*) Production devoted to regional markets that are presently supplied from outside the association and that owing to local conditions with respect to raw materials, utilities or otherwise may be produced more economically in Chile than in other LAFTA countries.

(*c*) Petrochemical production of a highly specialized nature where all of the LAFTA market may be supplied by one or two economical plants.

Other petrochemicals, not included in immediate plans for manufacture would be imported, preferably from LAFTA countries, with which agreements to complement the Chilean petrochemical production might be reached in accordance with the terms of the Montevideo Treaty.

5. INDUSTRY STUDIES — CHINA (TAIWAN)

Te-Lin Yu and Shu-Hsun Ting, Chinese Petroleum Corporation, China (Taiwan)

I. INTRODUCTION

1. *Short historical survey of the development of the petrochemical industry*

The development of the petrochemical industry in any country depends on two prerequisites; one is availability of raw material and the other is market. To assure adequate supply of raw materials, we need a well-developed petroleum industry, including a good reserve of oil or gas and a modern and good-sized refinery. On the other hand, to assure a dependable outlets for petrochemical products, it is essential to cultivate a market for them, substantially for local consumption

After almost twenty years of incessant development, the petroleum industry in this country has laid quite a solid foundation for the development of the petrochemical industry. During various stages of modernizing our Kaohsiung Refinery, we have taken into serious consideration in the choice of processes and facilities those which will also provide a reliable source of supply of basic materials for starting petrochemical industries. Processing units such as catalytic reforming facilities, one with 2,500 bbl/d and the other with 5,000 bbl/d, were installed in 1955 and 1961 respectively. They serve not only to step up the gasolene-octane production, but also to provide an ample supply of reformate, which is a base stock from which basic aromatic chemicals such as benzene, toluene and xylenes are extracted. A small aromatic extraction unit was also installed by which we have gained experience in producing high-quality basic aromatic chemicals and which paves the way for large-scale production. Catalytic cracking facilities were installed in 1957 from which substantial refinery gases are produced and are being fed to the Kaohsiung Ammonium Sulfate Corporation to make ammonia. Adequate topping capacities have been installed to turn out a sufficient quantity of naphtha, which will be a principal source of supply of another significant category of petrochemical basic material, namely the olefins such as ethylene, propylene and butylenes.

Despite the lack of crude oil in Taiwan, substantial reserves of natural gas have been discovered in this country in the wake of extensive geological survey and exploration work. Natural gas is another essential raw material for the petrochemical industry and it can be most economically utilized to make nitrogen fertilizers, such as ammonia and urea.

The availability of raw material alone does not justify setting up a petrochemical industry unless there is an adequate market to warrant the disposal of its products. Whereas the availability of petrochemical raw material is the natural outcome of the growth of petroleum industry, the development of a market is something more complicated and closely related to population and national economy. We are all aware that manufacturing petrochemical intermediates such as those for plastics and synthetic fibres cannot be done on a small scale. In other words, there is a minimum economic quantity below which they cannot be made economically to compete in the world market. Consequently, we need to build up a sizable market first before we can start establishing our petrochemical industry. The growth of market is usually very gradual, its achievement varying to a large extent with the size and growth of population, development of allied industries, and growth of national economy. The rate of growth can be used for reasonable projection of the market to determine the opportune time for starting petrochemical industries.

The need to have both raw material and market in order to set up petrochemical industry can be well illustrated in the development of the industry in Taiwan. The well-developed agriculture in this country has resulted in a requirement for a large quantity of chemical fertilizers. For more than fifteen years, the amount of nitrogen fertilizers being consumed more than justifies the building of big ammonia and urea plants. However, with the exception of fertilizers made from coal, for many years only a small amount of ammonia was made from refinery gases owing to the limited supply of gas, and it was not until the discovery of a substantial reserve of natural gas in this country that we were able to set up a large-scale petrochemical complex using natural gas as the raw material to make ammonia and urea. Once the raw material, i.e. natural gas, was found to be available in abundant quantity, coupled with long-existing and ever-increasing markets for fertilizers, the essential elements were then complete to enable immediate construction of that complex. The complex, which is a joint venture of the Chinese Petroleum Corporation, Mobil Chemical Company, and Allied Chemical Corporation, and having a capacity of 45,000 metric tons/year of ammonia and 100,000 metric tons/year of urea, was completed and successfully put into operation in only three years from the date of the first discovery of our new gas reserve. The combination of these two elements will also enable us to embark on new projects such as more ammonia and urea plants and other projects to make acetylene and methanol, both of which are also in great demand in this country.

The development of other petrochemical industries such as the manufacture of intermediates for plastics and synthetic fibres has not yet begun in this country. However, every indication points to an early start. On the raw material side, as stated before, we are well prepared to begin large-scale production of aromatic and olefinic basic materials. On the market side, the growth of population, the rise of the standard of living, and the development of allied industries and of the national economy have accelerated the rate of growth of requirements for petrochemical products such as polyethylene plastics and polyester and polyamide fibres. We would mention that in the case of synthetic fibres, the promotion of a market for them is largely attributable to the development of the textile industry in this country. With the present volume of consumption and at the projected rate of increase, we have reason to believe that the minimum economic sizes required for manufacturing such petrochemicals can be met in a couple of years. We can therefore start planning such complexes as a naphtha cracking-polyethylene plant, a polyester fibre intermediates plant (from mixed xylenes to polyester chips) a caprolactum plant (from benzene to caprolactum, to be used in polyamide fibre), etc. reasonably ahead so that they can be completed in time to meet the market requirements.

Aside from the prerequisite of raw material and market, we would like to mention two auxiliary elements, namely, manpower and satellite industries, which are also indispensable to the development of petrochemical industries. During the past ten to fifteen years, taking into account that managerial and technical manpower are the backbone of all industries, we have mapped out long-range programmes for the training and building-up of manpower which have been successfully carried out in leading private and public enterprises. We shall therefore face no difficulty in the recruitment of the experienced managerial and technical personnel required for such new industry. Satellite industries are important so that good use may be made of the petrochemical intermediates or products. A number of plastic moulding factories already exist in this country, however, they still need to be expanded and modernized to match the complexes for plants under discussion. As for the synthetic fibre industry, the existing textile industry in this country has done a good job in promoting the sales of the various fibres such as dacron and nylon. They have started building modern spinning facilities for such synthetic fibres which will utilize the intermediates to be produced from the petrochemical complex. Other facilities, such as for weaving, dyeing and finishing, need also to be strengthened to turn out quality products.

2. *The economic motives and considerations for assigning priority in the petrochemical industry*

The following factors are considered in assigning priority to petrochemical projects.

(1) *Improving the position of international trade.* For more than a decade before 1963, there were trade deficits every year which were supplemented by foreign aid. In order to maintain a balanced economy, acceleration of the establishment of industry that will produce locally to replace imports should be the major target. Consequently, projects that can save the largest amount of foreign exchange will usually receive highest priority. The following statistics show some major imported petrochemicals in recent years:

	1961		*1962*		*1963*	
	Quan. MT	*Value $US*	*Quan. MT*	*Value $US*	*Quan. MT*	*Value $US*
Polyethylene	1,480	808,207	3,166	1,349,269	5,293	1,893,975
Nylon	2,160	4,262,800	2,023	4,259,467	2,180	5,237,943
Polyester	173	516,000	400	1,106,124	510	1,346,841
Polyacrylonitrile	230	461,000	476	755,362	887	1,332,758
TOTAL	7,043	6,048,007	6,065	7,470,222	8,870	9,811,517

MT – Metric tons.

It can be seen from the above table that polyethylene, nylon, polyester and polyacrylonitrile are the biggest dollar consumers. Implementation of projects for these products will result in the saving of foreign exchange of more than ten million dollars a year. In addition to meeting the local requirements, some petrochemicals have a very promising potential for overseas markets. To encourage export will help change the picture.

(2) *Employment opportunity.* Projects that can hire more people or create more jobs will be given higher priorities.

(3) *Betterment of standard of living.* Through industrial development and mass production, costs of commodities can be lowered with consequent reductions in price. At the same time, increase of production enlarges the buying power of the public thereby affording a general improvement of the standard of living.

Hindrances which have been encountered in the past and at present are:

(1) *Size of market.* This is the biggest factor that has been retarding the build-up of petrochemical industry. Local requirements for many petrochemical items are still not big enough to justify plants of minimum economical size. However, consumption of certain products, such as polyethylene, polyester fibre and polyamide fibre, are now sufficient for it to be feasible to establish these industries.

(2) *Pattern of demand.* Pattern of demand determines the quantity and type of products to be manufactured and the processes to be employed. Fortunately, in Taiwan,

the pattern of demand is such that the requirement for certain products is not divided among many types but concentrated on a single one, thus the economical size of a plant is still ensured. For instance, the demand in Taiwan for polyethylene is 90 per cent for high-pressure, low-density type; and only 10 per cent for linear, high-density type. Therefore only the high pressure polymerization plant will be built.

3. *Institutional measures in favour of petrochemical development*

The Government has made every effort to encourage the development of industries, of which petrochemical is a major one. The important measures taken are:

(1) Promulgation of a statute for the encouragement of investment. In general, two main items had been emphasized in this statute, i.e., tax benefit and facilities for aquiring plant sites. Petrochemical industry is one of the catagories that enjoy income-tax relief for buyers of a specific type of securities.

(2) Exemption or reduction of income tax for profit-seeking-enterprises. Almost all the petrochemical products are listed in the categories of enterprises eligible for income-tax exemption or reduction.

(3) Tariff protection and import restriction. The tariff rate of petroleum crude oil is comparatively low while a higher custom duty has to be paid on imports of petroleum products. Besides, imports may be banned for three years if any specific item produced locally has the following qualifications: (*a*) it is a quality product, (*b*) the quantity meets local requirements, and (*c*) the selling price does not exceed 115 per cent of landed value of the same product imported.

(4) Amendment of the statute on investment by foreign nationals. Provision has been made that foreign nationals may apply for foreign exchange for the net profits or interest accruing from their investment and remit this to their own countries.

(5) Exemption of import customs duty on plant equipment. Amendment to the statute for encouragement of investment is being proposed to provide that import duty on equipment of certain categories of industry with equity capital exceeding NT$ 90 million will be exempted. Petrochemical industry is one of the categories.

4. *Supporting activities for petrochemical industry*

A. *Specialized research institutes*

Two organizations are doing specialized research work in petrochemicals.

(1) Union Industrial Research Institute. Allied with industries owned by the Government, research on petroleum and petrochemicals is one of its major undertakings. Efforts are being concentrated on topics such as the vapour phase oxidation of ortho-xylene and naphthalene, the polymerization of low olefins and some related themes.

(2) Chiayi Solvent Works of Chinese Petroleum Corporation. With a laboratory capable of undertaking research in petrochemicals, the work is developing the integration of operation on isomerization of the salt of dibasic acids, as well as oxidation of cyclohexanes from petroleum raw materials.

These research projects are aiming at the development of processes for making polyethylene, polypropylene, polyester and polyamide.

B. *Engineering organization and equipment fabrication facilities*

The progress of engineering, equipment fabrication and machinery industry in Taiwan has been great in recent years. Advanced technique for equipment design and manufacture is now available. Petroleum refining plants were designed and constructed by local manpower with only basic technical information supplied by co-operating foreign companies. Furthermore, many chemical plants, such as a sulphuric acid plant, a sugar refining mill, a drum making plant, a solvent extraction plant, and a plastic processing plant have been built entirely with locally designed and manufactured equipment and machinery. Two of the major machine shops on this island are:

(1) The Chinese Petroleum Corporation's Kaohsiung Refinery machine shop is capable of manufacturing high-pressure and vacuum vessels, fractionating towers and trays, reactors, heaters and heat-exchanging equipment.

(2) The Taiwan Machinery Co. specializes in manufacturing vessels and storage tanks, pumps and compressors, boilers and many other items used in the chemical industry.

5. *Expected lines and rate of development in the future until 1970*

A four-year Economic Development Plan is being drafted by government agencies. In this plan petrochemical industry will play an important role. Including the production of basic intermediates, two essential lines of development that constitute the petrochemical section are:

(a) *Synthetic fibre.* A number of spinning mills for polyester, polyamide and polyacrylonitrile fibres are under construction or contemplated based on the economics of importing chips and supplying fibres to local textile industry. The integration of synthetic fibres and petrochemicals calls for the establishment of a caprolactam plant and a polyester chips plant, capacities of which will be twenty tons per day and fifteen tons per day, respectively. The project will be carried out by joint ventures with foreign investors that produce intermediates with their own processes so as to ensure technical know-how and to safeguard the operation. It is anticipated that plant construction will be completed within the four-year period.

(b) *Plastics.* In addition to the PVC plastic that uses carbide as a source of hydrocarbon building blocks, polyethylene will be the first plastic to be produced from petroleum raw material within the period of the plan. A project of constructing a high pressure polyethylene plant of 40 million pounds capacity is being negotiated between the Government and a foreign investor. At the same time, expansion of PVC plastic production using both carbide and natural gas as a source of acetylene is under consideration, and the quantity plasticizer required will justify the construction of a plant. The estimated demand of synthetic fibre intermediates and plastic materials is as follows:

	1965 *(metric tons)*	*1968* *(metric tons)*	*1970* *(metric tons)*
Polyester chips	900	7,000	7,500
Caprolactam	1,600	8,000	9,000
Polyethylene	9,000	20,000	25,000
Plasticizer	15,000	30,000	35,000

To support the above projects, facilities for producing basic intermediates should be established simultaneously. A naphtha cracker of 100,000 tons per year feedstock and an aromatics extraction unit of 20,000 tons per year of benzene and xylenes are scheduled to be installed within the of the plan period. Production of basic intermediates is estimated as follows:

	1965	*1968*	*1970*
Benzene (kilo litres)	1,500	5,000	8,000
Xylenes (kilo litres)	450	6,000	8,500
Ethylene (tons)	—	18,000	18,000
Propylene (tons)	—	—	8,000

II. DESCRIPTION AND CHARACTERIZATION OF PETROCHEMICAL PLANTS

Basic intermediates

1 Number of Petrochemical plants:

Production of petrochemical intermediates is now a branch line of the refining industry. There is also one aromatic extraction unit in the solvent works.

2 Location:

Refinery: Kaohsiung.
Aromatic extraction: Chiayi.

3 Products produced:

Olefinic hydrocarbons, benzene, toluene and mixed xylenes.

4 Installed capacity and 1963 production:

Olefinic hydrocarbons are currently by-products of refining processing units.

Installed capacity of aromatic extraction is 750 BPSD. Production in 1963:

	Bbls.
Benzene	6,700
Toluene	7,700
Mixed xylenes	1,600

5 Domestic consumption: All the products are consumed domestically.

6 Exports: None.

7 Destination of exports.

8 Employment in the industry:

The major function of the refinery is petroleum refining and that of the solvent works is solvent manufacturing. Employment of the two plants do not represent petrochemical intermediates manufacturing. For example, employment in the solvent works, which produces aromatics, aliphatic petroleum solvents, fermented solvents, etc., are:

Unskilled labour	316
Skilled	403
Technician	71
Engineers and scientists	

9 Ownership: Government-owned.

10 Origin of technology:

That of aromatic production is self-developed glycol extraction process.

11 Origin of investment:

That of the aromatics production:

	$ US
Equipment	160,000
Construction and others (equivalent in local currency)	125,000

12 Raw materials: Oil fractions from Middle East crude oil.

13 Domestic price of feedstock and output:

The feedstock of the aromatic extraction is transferred to the plant at an average price equivalent to US¢ 13 per USG.

Products prices:

Benzene: $NT 6.00/litre equivalent to $US 56.5/USG
Toluene: $NT 6.00/litre equivalent to $US 56.5/USG
Mixed Xylenes: $NT 6.00/litre equivalent to $US 56.5/USG

14 Plans for developing petrochemical industries for 1965 and 1970.

Within the four-year period beginning 1965, it is intended to install a steam-cracker unit producing ethylene, propylene, etc. from 100,000 tons per year of petroleum naphtha, and another aromatic extraction unit of the capacity to produce 20,000 tons per year of benzene and xylenes in the Kaohsiung area to supply the raw materials for the forthcoming petrochemical plants.

The estimated annual production in 1970 will be as follows:

Ethylene (tons)	18,000
Propylene (tons)	8,000
Benzene (kilo litres)	8,000
Xylenes (kilo litres)	8,500

15 Total capital investment:

Total capital investment is estimated at the equivalent of $US 6,500,000 of which 50-60 per cent will be spent in foreign exchange. It will be financed by the Government fund.

16 International co-operation:

Except benzene and toluene which may be exported to the regional area as solvents or chemical raw materials, there is little prospect for international co-operation on other basic petrochemical intermediates.

$NT = National Taiwan dollar.

Nitrogenous fertilizers

1 Number of petrochemical plants:
One plant making ammonium sulfate.
One plant making ammonia and urea.

2 Location:
Ammonium sulfate plant: Kaohsiung.
Ammonia and Urea Plant: Miaoli.

3 Products produced:
Ammonium sulfate.
Ammonia.
Urea.

4 Installed capacity and 1963 production.
Installed capacity:

	tons per year
Ammonium sulfate	150,000
Ammonia	106,000
Urea	100,000

1963 production:

Ammonium sulfate	107,000 tons
Ammonia	Starting production early 1964.
Urea	Starting production early 1964.

5 Domestic consumption:

Total domestic consumption of nitrogenous fertilizer in 1963 is 128,500 tons of N_2, major portion of which is produced from coal or imported.

6 Exports: None.

7 Destination of exports.

8 Employment in the industry (total):

Unskilled labour	610
Skilled	580
Technical Engineers and scientists	160

9 Ownership:
Ammonia sulfate plant: Government-owned.
Ammonia-urea plant: 30 per cent Government, 70 per cent foreign investment.

10 Origin of the technology:
Ammonium sulfate plant: Chemical Construction, U.S.A.
Ammonia-urea plant: Allied Chemical, U.S.A.

11 Origin of the investment:
Ammonium sulfate plant: Not reported.
Ammonia-urea plant:
Equipment and know-how: $US 18 million.
Construction: $US 5.2 million equivalent in local currency.

12 Raw materials:
Ammonium sulfate: Refinery off-gas and fuel oil.
Ammonia-urea: Natural gas.

13 Domestic price of feedstocks and output:
Refinery off-gas: Fuel oil equivalent.
Fuel oil: $NT 1,260/ton equivalent to $US 31.50/ton.
Natural gas: $US 0.46 equivalent in local currency per million BTU.
Ammonium sulfate: $NT 2,800/ton equivalent to $US 70/ton.
Ammonia: $US 84 equivalent in local currency per ton.
Urea: $NT 5,200/ton equivalent to US$ 130/ton.

14 Plans for developing petrochemical industries for 1965 and 1970:

A new ammonia plant with a daily capacity of 400 tons will be built at Hsinchu using natural gas as feedstock. Ammonia produced will be subsequently converted into urea and ammonium sulfate. One existing ammonia plant using coal as raw material will switch to natural gas when the projected pipeline leads to plant site. One existing ammonia plant using electrolysis hydrogen for synthesis is going to be modified so that fuel oil will be used as feedstock.

15 Total investment of the new ammonia plant is estimated at $US 26 million, of which 60 per cent be spent in foreign exchange to procure equipment and materials and 40 per cent for local procurement and construction. Project will be financed by government fund.

Carbon black

1 Number of petrochemical plants: one.

2 Location: Chinshui gas field, Miaoli.

3 Products produced: Channel carbon black.

4 Installed capacity and 1963 production:
Installed capacity: 500 tons per year.
1963 production: 245 tons.

5 Domestic consumption: 230 tons.

6 Exports: 15 tons.

7 Destination of exports: Japan.

8 Employment in the industry:

This plant is a part of the natural gas-producing complex. It is operated and maintained by the employees of the gas field.

9 Ownership: Government.

10 Origin of technology: Self-developed channel process.

11 Origin of investment: No record because plant built twenty years ago.

12 Raw materials: Natural gas locally produced.

13 Domestic prices of feedstock and output:
Feedstock: \$NT 0.65/M^3 equivalent to \$US 46/MCF.
Product: $NT 12,000/ton equivalent to $US 0.136/1b.

14 Plans for developing petrochemical industries for 1965 and 1970:
None.

Sulphur

1 Number of petrochemical plants:
Sulphur is produced in the refinery as a by-product.

2 Location: Kaohsiung.

3 **Product produced**: Sulphur.

4 **Installed** capacity and 1963 **production**:

Installed capacity: 15 tons/day.
1963 production: 2,400 tons.

5 Domestic Consumption:

All the products are consumed domestically.

6 Exports: None.

7 Destination of exports.

8 Employment in the Industry:

This sulphur recovery unit is run and maintained by the refinery employees.

9 Ownership: Government.

10 Origin of technology: Pinch Bamag, Federal Republic of Germany.

11 Origin of investment:

Equipment: $US 220,000.
Construction and other $US 100,000 in local currency.

12 Raw materials:

Hydrogen sulfide extracted from the off-gas of the refinery by Girbitol process.

13 Domestic price of feedstock and outputs.

Feedstock not accounted for.
Sulphur $NT 2,450/ton equivalent to $US 61.25/ton.

14 Plans for developing petrochemical industries for 1965 and 1970:

None.

Detergents, pesticides, and others

1 Number of petrochemical plants:

Detergent alkyl benzene is produced in the refinery. One agricultural chemical plant producing DDT, BHC and other pesticides and four small plants producing BHC only.

Three small saccharin manufacturing plants.

2 Location:

The refinery and the agricultural plant are located at Kaohsiung. Most of these small plants are scattered in the southern part — Kaohsiung-Tainan area.

3 Products produced:

Alkyl benzene
DDT
BHC
Saccharin

4 Installed capacity and 1963 production:

Installed capacity:
Alkyl benzene: 2,500 tons per year.
DDT: 250 tons per year.
BHC: 1,500 tons per year.
Saccharin: 100,000 lbs per year.

1963 production:
Alkylbenzene: Start operation early 1964.
DDT: 120 tons.
BHC: 350 tons.
Saccharin: 35,000 lbs approximately.

5 Domestic consumption: All the products are consumed domestically.

6 Exports: None.

7 Destination of exports.

8 Employment in the industry:

Alkyl benzene plant: Operated and maintained by the refinery employees.
DDT:
BHC:
Saccharin: } Not reported.

9 Ownership:

Alkyl benzene unit: Government-owned.
Agricultural chemical plant: Government-owned.
Four small BHC plants: Private.
Saccharin plants: Private.

10 Origin of technology:

Alkyl benzene: Universal Oil Products Company, U.S.A.
Agricultural chemicals: Not reported.
BHC: Self-developed.
Saccharin: Self-developed

11 Origin of investment:

Alkyl benzene:
Equipment: $US 215,000
Construction and other: $US 45,000 in local currency
BHC and DDT plants: Not reported.
Saccharin: Not reported.

12 Raw materials:

Alkyl benzene: Benzene and tetramer.
BHC and DDT: Benzene.
Saccharin: Toluene.

13 Domestic prices of feedstock and output.

Feedstocks:
Benzene: $NT 6.00/litre or ¢US 56.5/US gallon.
Toluene: $NT 6.00/litre or ¢US 56.5/US gallon.

Products prices:
Alkyl benzene: $NT 9.00/kg equivalent to $US 0.225/kg.
DDT: $NT 44/kg equivalent to $US 1.10/kg.
BHC: $NT 10.60/kg equivalent to $US 0.265/kg.
Saccharin: $NT 80/1b. equivalent to $US 2.00/1b.

14 Plans for 1965 and 1970:

Expansion and modernization projects are contemplated.

15 Total capital investment: Not reported.

6. THE BEGINNING OF THE PETROCHEMICAL INDUSTRY IN COLOMBIA: THE RECOVERY OF ETHYLENE AND PROPYLENE AND THE PLANNING OF A POLYETHYLENE PLANT

Mario Galán-Gómez, President, Empresa Colombiana de Petróleos (Ecopetrol), Colombia

As a petroleum-producing country, Colombia has traditionally been self-sufficient. Its current daily output averages 160,000 barrels, of which one half is refined locally and the balance exported. There are two major refineries and three small topping plants, sufficient to cover the demand for fuels and lubricants, except for certain specialities.

Historically, Colombia's major source of foreign exchange has been the exportation of coffee. In the aftermath of the sharp decline in the price level of this commodity since 1954, the development of the country has been sharply curtailed, owing to dwindling foreign exchange availabilities for the importation of machinery and equipment needed for rapid industrialization.

Apart from coffee and petroleum, Colombia lacks virtually any exportable commodity, barring some minor items such as textiles, bananas and cement. In the light of continued low price levels for coffee, the authorities responsible for economic planning have resolved to seek exportable products derived from petroleum, in other words petrochemicals.

The initial steps for the development of a petrochemical industry in Colombia date back to 1952, when different government entities and private interests set up the Industria Colombiana de Fertilizantes, S.A., to manufacture ammonia, urea and mixed fertilizers. Hampered by various difficulties, above all under-capitalization and lack of financing, this plant did not reach the production stage until ten years later, in 1962. The company currently produces fifty tons of ammonia per day, converted into ammonium nitrate and urea.

In 1959 the International Petroleum Company (Intercol), an affiliate of the Standard Oil Co. of New Jersey, approached the Colombian Government for permission to build a 300-ton-a-day ammonia plant and an eighty-ton-a-day nitric acid plant at its Cartagena refinery. Upon receiving such permission, Intercol joined with foreign and Colombian investors to form the Abocol Company for the purpose of producing urea, ammonium nitrate and other mixed fertilizers requiring imported phosphorus and potassium.

In 1961, Ecopetrol (Empresa Colombiana de Petróleos) resolved to expand the capcity of its Barrancabermeja Refinery from 45.000 to 70.000 barrels a day, and at the same time took under consideration the possibility of adding petrochemical plants to the complex.

It was Ecopetrol's view that its initial production should be limited to so-called "building blocks" or raw materials for the petrochemical industry and that it should encourage the establishment of industries devoted to further processing of such raw materials.

Current expansion plans for the refinery contemplate an annual capacity of 35 million lbs of high-purity ethylene, including 14 million tons from the reforming of gases from the existing cracking plant and the one to be constructed as part of the expansion programme. The remaining 21 million lbs a year will be obtained by cracking ethane produced at the refinery. Plans also call for the production of 22 million lbs of propylene reformed from refinery gases.

For the utilization of these raw materials, a study was conducted to determine the marketing potential of different semi-finished products obtained therefrom. This led to the conclusion that there was sufficient potential in Colombia to warrant a 10,000-ton polyethylene plant by 1966 and that preparatory projects for the construction of such a plant should be initiated. To this end, different foreign companies of recognized capability in the field of polyethylene production were invited to submit proposals on a possible joint venture with Ecopetrol in the implementation of this project. Eleven foreign companies responded to the invitation, but only four presented proposals of sufficient interest to warrant further consideration. Ultimately, after considerable study and analysis, the proposal advanced by the Dow Chemical Company was found to be the most favourable both to Ecopetrol and to the Colombian economy in general. The agreement with Dow stipulated a fifty-fifty capital investment by Dow and Ecopetrol in a proposed plant for the production of low-density polyethylene by the Agfo process.

The main provisions of the Dow-Ecopetrol contract are as follows:

1. Ecopetrol and Dow will form a new company, each contributing 50 per cent of its capital. The Ecopetrol share will be contributed in cash, whereas the Dow investment will be partly cash and partly know-how.
2. The polymerization plant will utilize Agfo know-how and the finished plant will employ the Dow process. The new company will pay Dow a percentage royalty on the sales of both plants for the use of its know-how.
3. The plant will be operated by Ecopetrol with Dow personnel acting in a consulting capacity.

4. Dow will grant Ecopetrol a fifteen-year option to repurchase its share in the new company at a price equal to Dow's original investment in dollars plus the initial payment for the use of its know-how.
5. The new company will procure ethylene from Ecopetrol at a price to be determined in line with the price for polyethylene sold to the public. It is estimated that the price will be in the neighbourhood of $0.05 per lb.

The plant will have an initial annual capacity of 22 million lb of polyethylene, but its design will incorporate features permitting ready increase of capacity to 30 million lb to meet possible increased demand for domestic and/or export markets. As to the surplus ethylene which may be available initially, the possibilities are being explored to use it for the manufacture of other products, such as dichloroethane, styrene, ethylene oxide and glycols.

No definite industrial application has yet been envisaged for propylene; however studies have been initiated to explore possible manufacture of acrylonitrile, acetone, isopropyl alcohol and polypropylene.

Again, the underlying problem with regard to all these derivatives of propylene is the limited size of the existing markets. Nevertheless, we are confident that with the rapid development of the country throughout the remainder of this decade and with the possibilities afforded by the Latin American Free Trade Area, we shall shortly have the capacity to produce at least one of these propylene derivatives.

7. THE PETROCHEMICAL INDUSTRY IN ECUADOR

Galo H. Salvador G., National Committee on Planning and Economic Co-ordination, Ecuador

1 BRIEF SURVEY OF THE DEVELOPMENT AND PRESENT POSITION OF INDUSTRY IN ECUADOR

An examination of some of the features of the growth of industry in Ecuador will give an idea of the country's present industrial situation and help to explain why the development of its petrochemical industry has been slow. In 1961 the share of the manufacturing industries in the total gross domestic product was 15.4 per cent. This proportion declined throughout the period 1950-1961, a fact which is responsible for the lack of growth of the industrial sector of the Ecuadorian economy.

There is a remarkable contrast between the proportion of the country's imports and exports represented by manufactures. Whereas imports of manufactures accounted for 94.3 per cent of total imports in 1961, manufactures constituted only 6.2 per cent of all exports.

Manufacturing industry in Ecuador is divided into two major sectors: industrial manufacture,[1] which is particularly dynamic; and craftwork and home industry, which is the less dynamic sector. The latter accounts for a huge proportion (89.2 per cent) of persons employed in manufacture, but its share of the product (44.2 per cent) is less than that of industrial manufacture. There is a great difference in the productivity of the two sectors.

The structure of industrial production shows a market preponderance of industries producing consumer goods (especially non-durable consumer goods) and a correspondingly limited development of industries producing intermediate and capital goods. Ecuador is following the typical pattern which has occurred in all countries in the first stages of industrialization.

The average annual rate of growth of Ecuador's manufacturing industry during the period 1950-1961 was 5.1 per cent. The industrialization process, i.e. the relationship between the growth of industry and the economy as a whole gave a ratio of 0.9 for the period 1950-1961, which is fairly low when compared with the ratios achieved by other Latin American countries.

2. THE PRODUCTION OF PETROLEUM AND ITS DERIVATIVES

There are four companies in Ecuador engaged in petroleum production. They are, in order of size:

Anglo-Ecuadorian Oil Fields Ltd.
Tennessee del Ecuador S.A
Carolina Oil Co.
Petropolis Oil Co. S.A.

Of these companies, the first two also have petroleum refining plants with a current refining capacity adequate to supply the domestic market. The only producing area at present is at Puntilla de Santa Elena in the province of Guayas. In many parts of Ecuador's territory, both in the coastal and in the eastern areas, prospecting and exploitation concessions have been granted, the Putumayo area on the Colombian frontier being the one which offers the best prospects for the future. In fact, drilling operations carried out at Puerto Asis on the Colombian side have shown good results as regards both the size of the deposits and their quality.

As shown in table 1, prior to 1958 Ecuador exported substantial quantities of crude petroleum owing to the limited capacity of its refineries. Since 1959 the country has become an importer of crude petroleum because of the decline in production and the installation of a new refinery which enables all the petroleum required to be refined locally and provides a large proportion of the most common derivatives. Nevertheless, some special derivatives, such as lubricating oils and asphalts, have still had to be imported in increasing amounts as the figures in table 1 indicate.

Ecuadorian petroleum is of the naphthenic type and does not therefore yield the derivatives which are associated with petroleums of the paraffinic type.

As can be seen from the table 2, natural gas from petroleum wells is used in Ecuador for the production of

TABLE 1. IMPORTS OF SPECIAL DERIVATIVES
(in kilogrammes)

Year	*Lubricating oils*	*Asphalts and tars*
1954	4,993,246	5,986,457
1955	4,053,713	5,519,007
1956	4,184,502	10,894,802
1957	4,384,127	584,136
1958	4,631,537	2,990,315
1959	5,104,438	8,713,160
1960	5,383,837	2,337,427
1961	5,558,223	395,964
1962	5,301,748	1,993,817
1963	6,536,972	9,043,554

SOURCE : *Anuario de Comercio Exterior.*

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[1] Industrial manufacture is considered to include industries employing seven or more persons and having an annual production valued at more than 180,000 sucres.

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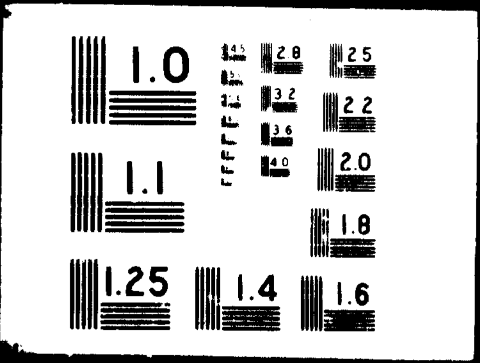

TABLE 2. PRODUCTION OF CRUDE PETROLEUM AND ITS DERIVATIVES

(In thousands of US gallons)

Year	Crude petroleum extracted	Gasoline produced from natural gas	Crude petroleum refined	Commercial gasoline	Special gasoline	Kerosene	Diesel oil	Residual fuel oils	Gas oil	Spray oil	Stripped crude	Derv	Lubricants	Others	Total production of derivatives	Fats (thousands of lb)
1950	110,552	4,341	67,907	22,921	—	5,120	2,413	29,016	7,792	—	—	—	—	165	67,427	—
1951	113,749	5,136	71,540	23,998	—	5,532	273	31,210	9,822	—	—	—	—	286	71,121	—
1952	119,296	5,578	74,409	24,511	—	5,975	257	30,917	12,136	—	—	—	—	152	73,948	—
1953	124,001	5,877	71,397	24,708	—	6,948	408	25,062	13,677	—	—	—	—	180	70,983	—
1954	132,150	6,696	80,627	27,412	—	7,750	437	30,132	14,136	—	—	—	—	372	80,239	—
1955	148,284	7,197	84,300	27,880	—	8,250	11,110	32,526	3,186	—	—	—	—	958	83,910	—
1956	143,652	7,110	85,569	28,676	—	9,029	15,006	31,561	—	—	—	—	—	770	85,042	—
1957	134,011	6,984	87,000	27,022	—	9,200	14,811	33,822	167	—	—	—	—	1,438	86,460	—
1958	130,558	6,673	102,222	30,966	—	10,088	18,679	39,042	59	—	—	—	—	2,445	101,279	—
1959	115,869	5,570	118,708	36,975	642	10,669	26,912	28,797	—	2,625	9,414	1,817	224	38	118,113	14
1960	115,762	5,334	178,203	63,117	8,594	12,622	29,028	52,031	—	3,635	3,210	1,377	218	237	174 069	6
1961	122,904	5,303	177,067	51,234	7,673	13,357	31,432	64,836	—	4,811	—	1,871	235	293	175,742	10
1962	108,070	4,613	165,219	40,350	21,237	13,482	29,322	51,174	—	4,993	1,064	2,272	208	340	164,442	8
1963	101,353	4,551	183,879	50,242	26,607	15,107	34,156	48,960	—	3,966	—	3,252	225	664	183,179	8

Source : Mining and Petroleum Department.

gasolene, but a certain amount of the gas is pumped back into the wells and some of the gas which is not used is burnt. It has not been possible to obtain from the companies engaged in petroleum operations even an approximate estimate of the quantity of gas available for possible applications in the petrochemical industry.

The figures for derivatives of nationally produced petroleum in table 2 show an over-all steady increase, consistent with the general growth of the Ecuadorian economy.

One point to which attention should be drawn is that, from 1959 onwards, gasolene has been divided into two types of different octane-rating: 63-octane commercial gasolene and 80-octane special gasolene.

The new refinery opened by Anglo-Ecuadorian in 1959 has made available, in addition to the higher-octane special gasolene, a further range of derivatives which are listed in table 2.

Although there are four firms producing crude petroleum and two of them have refineries, it can be said that Anglo-Ecuadorian Oil Fields, because of its large production capacity and economic strength, exercises monopoly control over the interests producing petroleum and its derivatives in Ecuador.

3. THE MARKET FOR PETROCHEMICAL PRODUCTS IN ECUADOR

With the exception of the petroleum derivatives industry, the country has no real petrochemical industry, in the sense of an industry producing intermediate goods for the manufacture of a large range of final products, or of a producer of materials absorbed by other sectors. It is only in recent years that the industry, including the production and consumption of intermediate goods, has developed rapidly and some of the products used are still of imported origin.

Ecuador must be considered, now and for some years to come, as a market consuming intermediate petrochemical products. Tables 3 and 4 below give details of its consumption, which during the years listed consisted exclusively of imported petrochemical products.

The main demand for intermediate petrochemical products is for paraffin waxes, phenolic plastic materials and artificial resins. The most important of the products consumed by other sectors are nitrogenous and compound fertilizers.

Two items listed in the table which have shown a marked increase in the last year are carbon black and synthetic rubber, both raw materials for the tire industry; in fact, the first tire factory in Ecuador started operations in that year (1963).

A consumption sector which deserves special mention is that of plastic materials used in the manufacture of polyethylene bags for packaging. Since Ecuador is the largest exporter of bananas in the world and needs polyethylene bags to pack the products for export, it requires exceptionally large amounts of polyethylene in powder, flake and granulated form. In 1962 the demand for this raw material was 1,516 tons, which was not

TABLE 3. ECUADOR'S IMPORTS OF THE MAIN PETROCHEMICAL PRODUCTS

(In kilogrammes)

Year	*Benzol, toluol, xylol etc.*	*Petrolatum*	*Paraffin wax*	*Ammonia*	*Propane, butane, etc.*	*Aliphatic ketones*	*Urea*	*Halogenated hydrocarbons*	*Phenolic plastic materials*	*Plastic moulding powder*	*Synthetic resins*
1956 . . .	60,886	57,764	2,728,609	14,174	2,944	9,066	—	1,243	462,804	111, 396	59,302
1957 . . .	102,951	48,994	3,074,457	37,396	2,130	11,728	—	492	613,918	190 '959	127,841
1958 . . .	130,171	111,037	2,884,203	15,700	19,117	9,129	356	851	244,082	113 707	233,287
1959 . . .	93,320	54,037	2,855,743	17,631	1,589	23,264	2,031,965	7,178	170,086	20'050	269,436
1960 . . .	122,090	87,464	3,180,146	20,460	69,776	15,521	1,353,416	15,344	281,184	17 010	374 431
1961 . . .	64,671	77,392	2,993,346	18,732	62,519	15,985	1,674,583	522	390,901	33,461	406,122
1962 . . .	87,655	90,942	3,562,174	24,856	125,569	20,397	539	15,299	517,025	17,210	469,002
1963 . . .	64,233	107,877	3,971,885	39,751	17,696	25,612	50	129,432	1,572,744	7,129	569,490

TABLE 3 *(continued)*

Year	*Carbon black*	*Detergents*	*Sulphoricinates, sulpholeates*	*Lubricants*	*Nitrogenous fertilizers*	*Compound fertilizers*	*Synthetic rubbers*	*Synthetic yarns*	*Synthetic fibres*	*Synthetic fibre waste*
1956	9,038	221,715	68,990	372,241	2,148,727	5,556,407	—	*	*	*
1957	3,363	175,220	116,639	354,189	3,624,042	8,602,135	—	*	*	*
1958	12,651	253,835	177,044	439,219	3,396,336	8,104,112	—	*	*	*
1959	11,364	245,930	143,920	393,924	5,907,241	7,190,580	—	*	*	*
1960	14,318	170,770	234,849	394,995	4,856,614	10,480,128	—	*	*	*
1961	17,784	148,779	247,741	398,291	4,391,665	8,340,931	—	*	*	*
1962	26,855	114,126	297,875	410,707	3,714,899	6,405,111	—	285,727	322,338	468
1963	459,926	96,919	399,446	524,480	5,967,587	10,441,115	361,457	239,622	98,905	9

Source : Anuarios de Comercio Exterior.

* Not determined, since they are included under the heading of cellulose products.

TABLE 4. IMPORTS OF PETROCHEMICAL PRODUCTS IN 1962

Tariff item	*Product*	*Quantity (kilogrammes)*	*FOB value (sucres)*	*CIF value (sucres)*
205 a	Benzol, toluol, xylol, etc.	87,655	204,069	306,735
206 b	Aviation spirit, hexane, etc.	1,313,885	1,423,404	1,596,640
206 e	Lubricating oils	5,301,748	19,490,388	24,053,019
207	Petrolatum	90,942	359,736	442,643
208	Paraffin wax	3.562,174	7,601,051	9.182,099
211	Asphalt mixtures and emulsions	69,908	285,738	360,441
217 e	Ammonia	24,856	198,365	289,333
217 h	Propane, butane and similar products	125,569	258,655	341,927
271	Aliphatic ketones (acetone)	20,397	88,126	132,211
272 b	Urea	539	23,519	26,293
274 a	Halogenated hydrocarbons	15,299	106,102	143,179
279	Phenolic plastic materials	517,025	4,506,187	5,176,247
280	Plastic materials in powder form	17,210	237.942	269,444
285 b	Synthetic resins	469,002	4,674,734	5.401,612
303	Carbon black	26,855	112,111	153,101
321	Detergents	114,126	1,032,318	1,293,552
322	Sulphoricinates, sulpholeates, etc.	297,875	2.487,637	3,106,019
323	Lubricants containing oils	410,707	1,972,227	2,400,354
343	Nitrogenous fertilizers	3,714,899	5,015,050	6,089,800
346	Compound fertilizers	6,405,111	10,616,460	12,429,221
369 b	Synthetic rubber	—	—	—
462 b	Synthetic yarns	285,727	16,391,354	17,634,663
465 b	Synthetic staple fibres	322,338	2,985,219	3,379,816
466 b	Artificial silk waste	468	5,224	7,585

SOURCE : *Anuario de Comercio Exterior.*

included in the country's imports because it was subject to the "draw-back" system. Plastic bag manufacturing plants are already operating in Ecuador and are meeting the demand for the product.

4. MAIN OBSTACLES TO THE DEVELOPMENT OF THE PETROCHEMICAL INDUSTRY IN ECUADOR

(a) *The small size of the market for petrochemical products in Ecuador, as compared with the relatively large plant capacity required for economic production*

The market has been described in the previous section; it is still, for almost all the products, a small one. Only the demand for polyethylene reaches a significant level, owing to the demand for polyethylene bags used for banana exports and to the production of other everyday plastic articles. Although this market might justify the establishment of a plant to produce this raw material locally, there are other obstacles to its establishment; these are described below.

(b) *Uncertainty as regards natural resources and raw materials for the industry*

Economic associations such as the Latin American Free Trade Association (LAFTA) might provide the answer to the market problem but uncertainty as to the extent of the available resources of petroleum and natural gas and poor future prospects in this field make it most inadvisable to plan petrochemical projects for the country. This problem is closely related to the one next described.

(c) *The private monopoly in the Ecuadorian petroleum industry and defects in the legislation governing its operations*

Petroleum in Ecuador is in the hands of a virtual private monopoly which handles the production, refining and marketing of the product in accordance with its commercial interests and fluctuations in world production and on the world market. Major difficulties in petroleum exploitation in the only area in the country in which prospecting and extraction are carried on are reflected in higher production costs, with the result that the company operating in Ecuador, which is a subsidiary of an international company, is showing less interest in operations in Ecuador than in other areas where they are less difficult. Since 1959, Ecuador has been importing petroleum for its refinery in ever-increasing quantities and these imports now constitute a fairly substantial item in the country's balance of trade.

Moreover, there are certain omissions and defects in the legislation governing mining operations in the country as regards the system of petroleum concessions, prospecting and extraction, and the ownership of the by-products of petroleum production (natural gas).

(d) *The newness of the industry and its new, difficult and changing technology*

The petrochemical industry and its technology are relatively new everywhere, and particularly in the less developed countries, whose low level of industrialization is a further serious obstacle to the development of this industry.

Moreover, owing to the intensive scientific research being carried out in the field of petroleum chemistry, which is continually expanding, new products and processes are constantly replacing the old, all of which constitutes a severe threat to the equipment of countries which have no facilities for keeping in step with research.

(e) *The major capital needs of the petrochemical industry*

In addition to necessitating large-scale operation and involving new, difficult technology, this industry requires a heavy outlay of capital, which it is very difficult for the less developed countries to provide, unless the State participates in the execution of projects and arranges for regular international loans.

5. PROSPECTS AND OPPORTUNITIES FOR DEVELOPMENT

Owing to the lack of a mineral survey which would show whether there was sufficient raw material available to justify the planning and operation of petrochemical plants, the prospects for development in this field in Ecuador are somewhat uncertain and of a short-term nature.

Moreover, the present market for most petrochemical products in Ecuador is rather small, and it would therefore be necessary to grant compensatory market concessions in respect of certain products in order to enable each country within a region to plan petrochemical projects of a sufficiently high technical and economic level to satisfy the wider market of a group of countries in the region.

The market for petrochemical products in Ecuador has nevertheless grown considerably in recent years as a result of the establishment of several plants which produce articles using these products as raw materials. The following is a partial listing of existing plants which use petrochemical products:

Type of product	*Number of firms*
Synthetic woven fabrics	6
Synthetic knitted fabrics	3
Rubber tyres and tubes	1
Detergents	1
(Paraffin) wax candles	9
Paints and varnishes	4
Plastic sheathing for wire	1
Gramophone records	2
Polyethylene bags, sheet and pipes	7
Plastic footwear	3
Plastic tableware and toys	2
Plastic bottles and containers	2

The most important of the projects now being planned under the General Development Plan are concerned with fishing nets (nylon), detergents, nitrogenous and compound fertilizers, production of insecticides, plastic sheathing for wire, plastic radio cabinets, buckets, etc., plastic fasteners and buttons, and vinyl tiles. The existing plants and the new projects to be implemented within the next few years will bring about a rapid growth in the consumption of intermediate petrochemical products.

The very wide range of plastic products which are now used as excellent substitutes for traditional products made of wood, rubber, glass, paper, leather and even iron make this a sector with good prospects for future development involving increased use of plastic raw materials for various applications which will depend on the nature of the final product.

As a result of the rapid rate of growth of the intermediate petrochemical product industry — due in turn to the equally rapid growth of the industries producing the final products — these industries represent a truly dynamic sector of over-all industrial development. Because of this fact, it is absolutely essential for a country like Ecuador to plan these activities in such a way as to avoid wasting resources and to determine the most suitable policy to be followed in this very new industrial field.

A number of projects have been planned which take into account all these points and the country's development prospects; details of these projects are given below.

6. DEVELOPMENT PROJECTS INVOLVING PETROCHEMICALS

The main features of the most important petrochemical projects planned by Ecuador are summarized below.

(a) *Fertilizers*

The firm of Fertilizantes Ecuatorianos S.A. (Fertisa) is setting up a plant for the production of nitrogenous and compound fertilizers. This plant will go into operation in 1965.

The plan is for the plant to begin production in three stages: it will begin by mixing, granulating and packing the fertilizers; after a year, it will start production of sulphuric acid and sulphate of ammonia and, in the third stage, when there is sufficient demand, it will produce ammonia.

Working on a twenty-four-hour basis, 300 days a year, the production capacity of the plant will be 180,000 tons. The capacity of the sulphuric acid plant which it is planned to install will be 100 tons a day.

The total capital cost of the plant, for the first two stages, will be 44 million sucres, of which 35 million will be required for fixed assets. It is estimated that the concern will provide employment for ninety-four persons.

Since the economy of Ecuador is based essentially on agriculture, this project is of undeniable importance and is therefore regarded as a fundamental requirement for the economic development of the country.

(b) *Detergents*

A company, Sindet Productos Químicos S.A., has already been formed and may begin integrated production in 1966. The plans call for the production of sulphuric acid, sulphonates and detergents for industrial and domestic use, the maximum production capacity for these products being, respectively, 1,980, 550 and 3,000 metric tons.

The total capital cost of the concern amounts to 10.6 million sucres — 8.4 million for fixed assets and 2.2 million for working capital.

The project was considered essential to the economic development of the country for the following reasons, among others: the saving of foreign exchange through import substitution, the use of national resources, the employment provided (forty-four persons) and the diversification of industry.

(c) *Polyvinyl chloride*

One project involving actual production of petrochemical raw materials, a polyvinyl chloride plant, is planned for 1969 or 1970, when the country's mineral survey work will have been completed.

There is a sizeable market for this intermediate product, owing to the need for bags for banana exports and the fairly substantial demand for plastic products for other uses.

The minimum economic capacity for this type of plant is 5 million lbs per year and the country would therefore provide a market adequate to permit the launching and operation of this project with a safety margin for variations in consumption.

The project would be conditional on the availability of sufficient stocks of natural gas and on its proving, on analysis, to be suitable for use in the proposed plant. The estimated total capital cost of the project is $5 million and a staff of at least sixty persons will probably be required.

7. MEASURES WHICH WOULD ENCOURAGE THE DEVELOPMENT OF THE PETROCHEMICAL INDUSTRY IN ECUADOR

A study of the problems and obstacles facing the petrochemical industry in Ecuador reveals precisely what measures and policies the country should adopt in order to encourage the development of its petrochemical industry. The most important of these are the following:

(*a*) Determination of the available resources of petroleum and natural gas, by means of a mineral survey of those areas in the coastal and eastern regions of the country which are already known to offer good prospects for petroleum production. It will also be necessary to carry out or review the results of analyses of the crude petroleum and gas available in the country in order to be able to plan any project in this field.

Other types of raw materials which could, in certain circumstances, be used to produce intermediate products that might replace or compete with petrochemical products must also be taken into account. In the case of Ecuador there are other products, such as ethyl acohol and castor oil, from which plastic raw materials to replace petrochemical products could be obtained by various processes.

(*b*) The elimination of monopoly in the petroleum industry through establishment of a national petroleum company to carry out prospecting, and engage in exploitation and utilization of resources in the national interest, rather than on a commercial basis and on the basis of conditions in the world petroleum market. The national concern should commence operations in those areas which offer the best assurance of obtaining good results, such as the Putumayo area or the Puyo area in the eastern region, in which the Shell Company has already carried out prospecting.

(*c*) The revision or amendment of the present Mining and Petroleum Act, which is somewhat out of date, to make the sector more dynamic and promote its development. Two aspects require special attention: the question of gradual reversion to the State, within a reasonable period, of areas for which mining concessions have been granted, if the proposed prospecting and exploitation have not been carried out; and the question of the ownership of natural gas discovered during petroleum production — an aspect which is of the greatest importance in the development of the petrochemical industry.

(*d*) Expansion of the market with a view to planning petrochemical plants of economic size. Economic associations, such as the Latin American Free Trade Association (LAFTA), or market division, specialization or compensation, are some of the means which are being adopted and which are essential in the case of the production of petrochemical products. They are necessary because of the considerable amount of capital required and the large technical production capacities and competition of countries with higher levels of industrialization.

(*e*) The training of skilled technical workers for the petroleum and petrochemical industries is an extremely important aspect of any programmes which may be developed in the future and should be given adequate support, in order that the highly specialized staff which these industries need may be available as early as possible.

8. CUSTOMS CHARGES ON THE IMPORT OF PETROCHEMICAL PRODUCTS

The following is a summary of current customs charges on the import of petrochemical products:

CUSTOMS DUTIES

Specific per kilogramme net or gross, as applicable (see table 5)

Ad valorem on FOB value (see table 5)

CONSULAR FEES

10 1/2 per cent on FOB value

GENERAL ADDITIONAL DUTIES

3 per cent on FOB value

3 1/2 per cent on CIF value

SPECIAL ADDITIONAL DUTIES

6 per cent on CIF value for goods in list I in table 5

16 per cent on CIF value for goods in List II in table 5

OTHER DUTIES AND CHARGES

Harbour dues, wharfage, statistical tax, etc.: $142.5 per ton gross storage fees:

	Sucres (per kilogramme gross)
For 30 days	0.01
From 31 to 60 days	0.06
From 61 to 90 days	0.10
From 91 to 120 days	0.12

Table 5 shows in detail the customs duties applicable to the various petrochemical products, the import lists in which they are classified and the advance deposits required for each product.

TABLE 5. CUSTOMS DUTIES, IMPORT LISTS AND ADVANCE DEPOSITS FOR IMPORTS OF PETROCHEMICAL PRODUCTS

Tariff item	*Name*	*Customs duties*		*Import list*	*Advance deposits per cent on CIF*
		Specific per kilo	Ad valorem *per cent*		
205 a	Hydrocarbon oils and their constituents P.K.G. (per kilo gross) . . .	0.35	5	11	30
206 b 1	Aviation spirit P.K.G.	0.40		1	15
206 b 2	Others (hexane, etc.) P.K.G.	0.50		11	80
206 a 2	Lubricating oils P.K.G.	0.20	10	1	15
207	Petrolatum P.K.G.	1.00	10	11	30
208	Paraffin wax P.K.G.	0.40	10	11	30
211	Asphalt mixtures and emulsions P.K.G.	0.50	10	11	80
217 e	Anhydrous ammonia (ammonia gas).		20	1	15
217 h	Propane, butane and similar products		10	11	80
271	Aliphatic ketones (acetones and others)	0.25	10	1	15
272 b	Urea containing over 46 per cent of nitrogen	Free		1	15
274 a 1	Nitrobenzene, nitrotoluene, monochlorobenzene	0.30	10	1	15
274 a 2	Dichloro-diphenyl-trichloroethane (D.D.T.)	0.05	1	1	15
274 a 3	Other halogenated hydrocarbons . .	0.30	10	1	15
279 a	Plastic materials in bulk, in lumps or in powder form	0.05	1	1	15
279 b	Plastic materials in blocks or bars . .	0.15	3	1	15
279 c	Polyethylene and plastics in laminated form	0.05	1	1	15
280 a	Plastic materials for dental applications	3.00	10	11	30
280 b	Plastic materials for gramophone records	0.30	5	1	15
280 c	Other plastic materials	1.00	10	II	30
285 b	Coumarone resins and artificial resins	0.40	10	I	15
303	Carbon black and other mineral and vegetable carbons	0.05	1	1	15
321	Washing preparations, whether or not containing soap.	5.50	20	II	80
322	Sulphoricinates, sulpholeates, sulphoresinates	0.50	5	1	15
323	Lubricants, produced from oils and fats	0.50	10	I	15
343	Mineral or chemical fertilizers, nitrogenous	Free		I	15
346	Mineral or chemical fertilizers, compound	Free		I	15
369 b	Synthetic rubber (neoprene, buna and similar)	2.00	10	II	30
462 b 1	Synthetic yarns, smooth	1.00	2	I	15
462 b 2	Treated yarns (texturized)	6.00	10	II	80
465 b	Synthetic fibres	1.00	2	I	15
466 b	Synthetic fibre waste.	2.00	10	I	15

Source : Foreign Exchange Department, Central Bank of Ecuador.

TABLE 6. IMPORTS OF PETROCHEMICAL PRODUCTS IN 1963

Tariff item	*Product*	*Quantity (kilogrammes)*	*FOB value (sucres)*	*CIF value (sucres)*
205 a	Hydrocarbon oils and their constituents .	64,233	178,402	238,938
206 b	Aviation spirit, hexane, etc	25,602,752	23,266,964	28,293,123
206 e	Lubricating oils	6,536,972	23,118,469	27,540,192
207	Petrolatum	107,877	394,751	510,264
208	Paraffin wax	3,971,885	8,437,385	10,197,442
211	Asphalt mixtures and emulsions	94,308	303,829	391,553
217 e	Ammonia	39,751	226,055	389,478
217 h	Propane, butane and similar products . .	17,696	177,185	261,672
271	Aliphatic ketones (acetone)	25,612	112,696	161,632
272 *b*	Urea	50	1,760	2,117
274 a	Halogenated hydrocarbons	129,432	1,052,627	1,326,996
279	Phenolic plastic materials.	1,572,744	14,204,098	16,104,746
280	Plastic materials in powder form	7,129	127,901	145,613
285 b	Synthetic resins	569,490	5,257,755	6,117,695
303	Carbon black	459,926	1,700,338	2,254,468
321	Detergents	96,919	838,476	1,003,803
322	Sulphoricinates, sulpholeates	399,446	2,993,935	3,644,090
323	Lubricants containing oil	524,480	2,512,851	2,929,827
343	Nitrogenous fertilizers	5,967,587	6,764,898	8,390,120
346	Compound fertilizers	10,441,115	16,466,584	19,380,792
369 b	Synthetic rubber	361,457	3,156,657	3,554,950
462 b	Synthetic yarns	239,622	16,105,892	17,309,175
465 b	Synthetic tops and fibres	98,905	3,639,608	3,924,779
466 b	Synthetic fibre waste	9	270	372

Source : Anuario de Commercio Exterior.

8. THE PETROCHEMICAL INDUSTRY IN INDIA

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1. INTRODUCTION

The petrochemical industry in India is still in its infancy. The existing organic chemical industry is of non-petroleum origin and is based on traditional raw materials like alcohol from molasses, acetylene from calcium carbide and aromatics from coal. An idea of its historical development can be had from the consumption of the major source materials given in table 1.

During the years 1950-60, only a small quantity of alcohol was used as feedstock in the chemical industry. At present, alcohol industry provides raw material for the manufacture of styrene-butadiene rubber, butyl alcohol, DDT, polyethylene, polystyrene, acetic acid and related chemicals. Acetylene from carbide serves as raw material for PVC. Benzene from coal is used for BHC, DDT, styrene and dye-intermediates.

The first ever use of petroleum for the chemical industry was in 1963, when two fertilizer plants started producing ammonia from naphtha.

This situation has been largely due to the non-availability of petroleum raw materials. Although the refining capacity in India today is about 9.5 million tons, the availability of refinery gases is limited owing to the limited cracking or coking capacity. Natural gas—mainly associated — has been discovered recently and cannot be exploited before the oil is produced and refined. The important petroleum raw material that has recently become available is naphtha. It is expected that in the coming years it will be available in large quantities to serve as raw material for the petrochemical industry.

With the possibilities of sufficient and suitable raw materials in view and in order to meet the growing needs of various chemicals, a Petrochemical Committee under the Chairmanship of Dr. G. P. Kane drew up, in 1961, a ten-year plan for the development of petrochemical industry in India. This was followed by a detailed study prepared by the Institut Français du Pétrole at the request of the Oil and Natural Gas Commission of India. The report of the Institut Français du Pétrole, which was submitted in early 1963, included economic feasibility studies for the various manufacturing units recommended to be included in the different petrochemical complexes. Later, the Planning Commission appointed a Planning Group for Petrochemicals to review the targets and programme of manufacture of various petrochemicals in the light of the latest thinking and developments. The Planning Group submitted its recommendations to the Government in March 1964.

In the meanwhile, steps were taken to license a number of units to be built around two nahptha steam crackers in Bombay. These units are expected to go into production in 1966-67 and, for the first time, petroleum-based polyethylene, polyvinyl acetate, ethylene oxide and derived chemicals, PVC, iso-propyl alcohol and related solvents, butadiene, benzene, phenol, plasticizers, caprolactam and nylon will be brought into the market as forerunners of a massive programme for the development of petrochemical industry in India.

TABLE 1

Product	*Year*	*Consumption million litres*	
Alcohol (power and industrial).	1951	48.6	Bulk used as power alcohol
	1956	66.0	
	1960	90.0	
		Tons	
Calcium carbide	1954	8,000	For welding and lighting
	1956	9,000	
	1960	16,000	
		1,000 litres	
Benzene from coal. . . .	1951	1.45	
	1956	1.56	
	1961	8.20	

2. ECONOMIC AND OTHER CONSIDERATIONS FOR THE DEVELOPMENT OF PETROCHEMICAL INDUSTRY

The petrochemical industry has its influence in every sector of a nation's economy, and has, therefore, to develop alongside other basic industries. The Indian economy, which has registered a remarkable growth during the last fifteen years, has established many new demands for industrial, producer and consumer goods. It has become increasingly apparent that when there are shortages of materials like cotton, wool, rubber, steel, non-ferrous metals, and oils and fats, for the import of which India already spends annually about $400 million, the most economic way to meet the rising demands and sustain or enhance the industrial and economic growth rates is to provide a sound, integrated petrochemical industry that can make available plastics, fibres, rubbers, detergents and other materials at reasonable and competitive prices. India's population of about 450 million people is an index of the potential market. Already, the import bill for petrochemical materials is becoming substantial. But it is estimated that if the petrochemical industry is not built up in India to replace a part of the traditional materials by newer ones, the yearly import bill for petrochemicals, excluding fertilizers, may amount to $250 million to 300 million in 1970-71.

The programme recommended for implementation by the Planning Group for Petrochemicals envisages an investment of about $900 million during the next six to seven years, including about $400 million for the processing and fabrication industries but excluding fertilizers. This appears to be a formidable sum but it is realized that India will pay a really high price if it abdicates a position in an entire industrial field or curtails its development plans. Some of the serious implications are:

Retarded over-all industrial development owing to absence of production and paucity of industrial and producer goods.

Retarded scientific development. India is already lagging behind in respect of process know-how, design and engineering, and fabrication of equipment.

Dependence on foreigners.

Inability to produce specially to meet India's own needs.

Heavy disadvantages in all future export trade since plastics, fibres, etc. are needed in virtually all industries from textiles to automobiles.

3. INSTITUTIONAL MEASURES IN FAVOUR OF PETROCHEMICAL DEVELOPMENT

As large-scale production of petrochemicals in integrated complexes is still to emerge, various fiscal measures to help the development of petrochemical industries have yet to be devised. Regarding duties and taxes which have an important bearing on the consumer price, it has been suggested that, as in the case of oil refineries, a petrochemical complex should be considered as a single bonded warehouse and the duty should be payable only on the finished marketable products. At present, in the chemical industry there are many instances where duty is payable on the basic raw materials while the finished products are also subject to a levy. The double duty thus becomes multiple in nature and places a heavy strain on the cost structure.

According to the present policy of protection, Government have taken appropriate measures to ensure that, wherever necessary, strategic industrial sectors in the process of development are protected from competition from foreign products and receive such other assistance as may be required for a quick consolidation of their position. Tariff protection has been granted in many cases. Government now imposes strict control over items for which indigenous manufacturing capacities exist.

Regarding import and export policy, the keynote is the maximum saving or earning of foreign exchange. Imports are strictly governed by considerations of essential needs and production potential of the indigenous industry. To increase exports, many incentives have been offered, such as:

(*a*) Import of additional raw materials or machinery against export earnings;

(*b*) Concession on inland freight rates and customs and excise duty;

(*c*) Tax concession on export earnings.

The Export Promotion Councils set up jointly by Government, industry and trade are doing useful work.

Government have taken a number of steps to promote investment in the chemical industry. They have established financing institutions like Industrial Finance Corporation of India and. Industrial Credit and Investment Corporation of India which extend credit facilities, and also the Investment Centre which provides guidance to foreign concerns interested in investment in India or Indians seeking foreign collaboration. In addition, Government now provide various incentives for investment. For example:

(*a*) Profits of a new industrial undertaking are exempt from tax up to 6 per cent of the capital employed for a period of five years; dividends declared by such undertaking out of the exempted profits are also exempt from tax;

(*b*) In addition to depreciation allowances, development rebate equal to 20 per cent of the cost of plant and machinery is allowed as a reduction from the taxable income in the year of installation;

(*c*) Interest on loans obtained from approved foreign institutions for import of capital equipment or raw materials is also exempted from tax;

(*d*) The royalties received from an Indian concern by a foreign company are charged to tax at a concessional rate of 50 per cent against 63 per cent in the case of other income;

(*e*) Technicians of foreign nationality taking up employment in India are exempted from tax on their remuneration for a period approved by the Government;

(*f*) The value of periodical home-leave passages provided to employees of foreign nationality is excluded from their taxable income;

(*g*) Agreements for avoidance of double taxation exist with a number of countries to ensure that the benefit of tax concessions is actually retained by the foreign investor;

(*h*) Once foreign capital is admitted into the country no discrimination is made between Indian and foreign capital;

(*i*) Government provide full facilities for remittance of profits and no restrictions are placed on the withdrawal of foreign capital investments;

(*j*) As a rule, the major interest in ownership and effective control of an undertaking should remain in Indian hands; there is, however, no rigid or doctrinaire insistence on this rule as Government do not object to foreign capital having control of a concern if it is found to be in the national interest.

The usual forms of foreign financial participation in India are equity capital and long-term loans. Technical collaboration against payment of fees or royalties is also permitted.

4. SUPPORTING ACTIVITIES FOR PETROCHEMICAL INDUSTRY

(a) *Specialized research institutes*

India has still to go a long way in research and technological development. It has a number of research laboratories and institutes connected directly or indirectly with the chemical industry. But they have not developed to a stage where they can provide substantial assistance in respect of process and design know-how in the face of the sophisticated technology already developed abroad. The industrialization in the past years has been made possible by the help of imported technology and equipment. Intensive efforts are, however, being made to develop indigenous processes and technology for the production of items for which the demand is expected to increase very rapidly. In this connexion, special mention may be made of the network of about thirty national laboratories under the Council of Scientific and Industrial Research, through which laboratories like the National Chemical Laboratory, Poona, Central Fuel Research Institute, Jealgora, Regional Research Laboratory, Hyderabad, and the Indian Institute of Petroleum, Dehra Dun, are directly connected with the organic chemical industry. The recently established Plastics Institute and the Chemical Technology Department of Bombay university are doing useful work in the field of plastics. The Silk and Art Silk Research Association, Bombay, has started working on synthetic fibres. The Indian Institute of Science, Bangalore, and the Shri Ram Institute of Technology, Delhi, are also engaged in development work in chemical technology. The need is to concentrate on specific problems peculiar to India or of a recurring nature, and to conduct the development work as a pilot plant on a semi-commercial scale.

The Indian Institute of Petroleum, Dehra Dun, has been recently established to undertake research and development work on the processing and utilization of crude petroleum and natural gas and on problems in the field of petrochemicals. This Institute also undertakes project evaluation studies and market surveys in the petroleum and petrochemical industries.

(b) *Engineering organizations*

Based on the Indian experience, it has been estimated that the cost of engineering and construction forms on the average about 20 per cent of the total project cost. On the basis of $500 million total investment in petrochemical projects during the next six to seven years, complete dependence on foreign engineering and construction would mean a foreign exchange expenditure of $100 million.

India has so far relied almost entirely on foreign engineering and construction. Although this situation may continue for some time, efforts are being made to create local facilities. The Fertilizer Corporation of India, Fertilizer & Chemicals (Travancore) Ltd, the Delhi Cloth Mills Chemical Works, and the National Rayon Corporation have been developing local design, plant construction and consultancy services. Government are contemplating setting up an engineering company in collaboration with Bechtel Corporation, United States of America. This company is expected to contribute substantially to the execution of the petroleum and petrochemical projects. The Council of Scientific and Industrial Research has established a Central Designs and Engineering Unit, which, to begin with, has started working on some inorganic chemical projects. A couple of engineering companies have also been registered in the private sector; they will work in collaboration with major international firms.

(c) *Equipment manufacturing facilities*

The existing capacities for the construction of plant and equipment are insufficient and will have to be augmented many times if the projects under planning have to depend upon local facilities. At present, most of the equipment required for the oil refining and chemical industries has to be imported, which involves a heavy drain on India's foreign exchange resources. Steps are, however, being taken to increase the existing capacities, enlarge the scope of manufacture and establish new units. F.A.C.T., Alwaye, is expected to set up a manufacturing shop in the near future.

To give an idea of the existing facilities in India, it may be mentioned that special equipment, pumps, compressors, valves, instruments and explosion-proof equipment are made to a minor extent. Reactors vessels of various types of materials are fabricated, but wall thickness is limited. Stainless steel and other alloy steels have to be imported. The position regarding tubular heaters is not very satisfactory. Small diameter pipes are made by a couple of firms. Large diameter pipes, from 8 inches to 20 inches, are made by the Rourkela Steel Plant. Normal construction materials are available in the country and there are well-qualified firms producing steel structures. It may be emphasised that the situation is improving and facilities are being added all the time.

5. STATUS OF THE EXISTING CHEMICAL INDUSTRY

It has been stated earlier that the existing organic chemical industry is mainly based on non-petroleum sources. Some industries, however, have been recently established which use imported petrochemical feedstock such as methanol for formaldehyde, caprolactam for nylon. The capacities in respect of the important existing chemicals and intermediates are given below. Some details are presented in annex I to the paper.

Item of manufacture	*Capacity, tons per annum*
Nitrogenous fertilizers	320,000
Plastics:	
Polyethylene	7,500
PVC	9,600
Polystyrene	6,000
Phenol formaldehyde Urea formaldehyde	3,000
Synthetic fibres:	
Nylon	1,400
Synthetic rubbers:	
SBR	20-30,000
Synthetic detergents	7,200

(continued)

(continued)

Item of manufacture	*Capacity tons per annum*
Pesticides:	
BHC	7,200
DDT	2,800
EDB	100
EDC	400
Carbon black	10,000
Acetic acid	11,000
Butanol	1,500
Formaldehyde	13,200
Acetone	1,600
Ethyl alcohol	170,000
Benzene	26,000

In addition to the above, the following capacities based on non-petroleum sources are under construction:

	Tons per annum
Polystyrene	17,000
PVC	10,000
Benzene	28,000
Phenol	7,000
Alcohol	90,000

A stage has been reached when it is neither possible nor desirable to plan any further production of chemicals from traditional raw materials. First, their availability is limited, and secondly, except for alcohol, the price of which is quite low — of the order of $80 per ton — the price of other raw materials is considerably higher. To give an example, the price of coal-based benzene is about $120 per ton, ex-works. The selling price of calcium carbide is $190 per ton.

With the expansion of the refining industry in the country the fertilizer and organic chemical industry can now look forward to petroleum sources for raw materials. The availability of natural gas is limited and the gases available from the refineries are insignificant. Hence, the petrochemical industry would be based mainly on naphtha as is the case in Japan and Western Europe. The motor gasolene consumption in India being low, as in other developing countries, the increasing refining capacity required mainly for the middle distillates, results in surplus naphtha available for other uses. Recent estimates have shown that whereas the refining capacity in India may increase from 16.5 million tons *per annum* in 1966 to 28 to 29 million tons *per annum* in 1971, the surplus naphtha, after meeting motor gasolene demand may increase from about 1.7 million tons in 1966 to about 3.0 million tons in 1971. The price of naphtha in India is expected to be of the order of $16-17 per ton.

6. FUTURE DEMAND FOR PETROCHEMICALS

The consumption of petrochemicals in India has not reached a level where it can be said to be sensitive to any parameter for future projection. The growth of consumption in the past has been retarded to an appreciable extent by various factors such as low volume production, restricted imports, high prices and shortage of conversion and manufacturing facilities. The revised estimates of demand during the Fourth Five Year Plan (1966-71) prepared by the Planning Group for Petrochemicals assume that the future growth will be unfettered and that deliberate Government policy would help speedier market penetration of new, superior and more economic materials. The targets fixed for the various petrochemical industries are as follows:

Item of manufacture	*Capacity tons/annum*
Nitrogenous fertilizers	2,200,000
Plastics:	
Polyethylene	115,000
PVC	110,000
Polystyrene	50,000
Phenol formaldehyde	18,000
Urea formaldehyde	25,000
Synthetic rubbers:	
SBR, Polybutadiene, Butyl etc.	100,000
Synthetic detergents:	
DDB	20,000
Pesticides:	
BHC	20,000
DDT	20,000
EDC	9,500
Carbon black	60,000
Butanol	16,000
Methanol	60,000
Formaldehyde	77,000
Phthalic anhydride	25,000
Ethyl alcohol	315,000
Benzene	174,000
Phenol (excluding caprolactam use)	10,000

With the continuing growth of demand for chemicals over the next few years, petrochemicals will take the lead and it is estimated that by 1970-71, over 80 per cent of the total production would be derived from petroleum raw materials.

7. FERTILIZER PROJECTS

The first unit for the manufacture of ammonia from naphtha by Texaco process has gone into production in Alwaye, Kerala. The plant is based on 30,000 tons of naphtha transported from Bombay. Another small ammonia plant at Madras uses 9,000 tons *per annum* of naphtha from the Vizag Refinery.

The following fertilizer plants based on petroleum feedstocks are under construction:

Location	*Capacity (tons per annum of nitrogen)*	*Feedstock*
Trombay	60,000	Naphtha, refinery gas
Vizag	80,000	Naphtha
Gorakhpur	80,000	Naphtha
Baroda	80,000	Naphtha and Ankleshwar natural gas
Namrup	45,000	Naharkatiya natural gas
Kotah	100,000	Naphtha

Out of a targeted capacity of 2.2 million tons, about 1.8 million tons of nitrogen are expected to be manufactured from petroleum feedstock by 1970-71. The Fertilizer Corporation of India is undertaking the construction of some of the units. Recently, the Government of

India have received an offer from an American consortium to establish five fertilizer plants with a total capacity of 1 million tons of nitrogen. The scheme proposed by the consortium will help the country to cover a major part of the new capacity to be established for fertilizers by 1970-71.

8. PETROCHEMICAL PROJECTS UNDER IMPLEMENTATION

The first two petrochemical complexes under construction in Bombay, where refining capacity of over 6 million tons exists already, are expected to start production in 1966. The schemes are:

(i) 60,000-ton naphtha cracker complex by Union Carbide (India) Ltd. Ethylene capacity, 18,000 ton *per annum*.

(ii) 225,000-ton naphtha cracker complex by National Organic Chemical Industries Ltd. in collaboration with Shell and Hoescht. Ethylene capacity is 60,000 tons *per annum*.

The product-mix of these complexes is given in annex II to this paper. The total investment in the complexes is of the order of $100 million.

The phenol-acetone project of Herdilias at Bombay will purchase propylene from one of the Bombay crackers. Herdilia Chemicals Ltd. are seeking collaboration from Distillers and Hercules Powder Co. and propose to make diacetone alcohol, phthalic anhydride and phthalates, apart from phenol and acetone. The estimated investment is about $23 million.

9. PETROCHEMICAL PROJECTS UNDER PLANNING

In order to achieve the targets of the Fourth Five Year Plan (1966-71), another four petrochemical complexes have been recommended by the Planning Group for Petrochemicals. They are to be located at Koyali (Gujarat), Barauni, Haldia and in South India. Two refineries, 3 million-ton capacity each, are under construction at Barauni and Koyali by the Government of India and are expected to achieve full capacity in 1966. Two more refineries, with 2.5 to 3 million-ton capacity each are being planned at Madras and Haldia; the new refineries are scheduled to go on stream by 1967 and 1968, respectively. The petrochemical complexes have been phased according to the schedule of new refining capacities and the availability of large quantities of naphtha. The Oil and Natural Gas Commission, a Government-owned body, has already initiated action on the Koyali complex and is at present carrying on negotiations with interested foreign collaborators.

The petrochemical programme here will start with the extraction of aromatics from the catalytic reformate of the refinery in 1967. The aromatics recovered will form base-stocks for the manufacture of caprolactam, nylon, styrene and DMT. The aromatics extraction will be followed by a naphtha cracker with 80-100,000-ton ethylene capacity, for manufacturing end-products like polyethylene, vinyl acetate, PVC, polystyrene, acrylonitrile, DDB, butadiene and benzene. Investigations are also being carried out to include the manufacture of butyl rubber and poly-butadiene in the complex. The naphtha cracker complex is scheduled to go into operation by 1968. The Koyali complex will be followed by the South India and Barauni complexes in 1969. The South India complex is likely to be based on ethylene-acetylene production from naphtha. Barauni will have aromatic extraction, DMT, acrylonitrile and butadiene manufacture. The complex at Haldia, planned for 1970 is again based on a naphtha cracker complex with 100,000-ton ethylene capacity. The product-mix of these complexes is summarised in annex III to this paper.

10. CONCLUDING OBSERVATIONS

The growth rates which India is trying to achieve in the major petrochemical sectors during the next six to seven years are indicated in table 2 below.

TABLE 2. ESTIMATED GROWTH OF MAJOR PETROCHEMICAL SECTORS

	Year			Annual growth rate 1970-71 1965-66 per cent
	1960-61	*1965-66*	*1970-71*	
Plastics	10,000	50,000	340,000	47
Synthetic fibres	Nil	5,000	88,000	77.5
Synthetic rubbers	Nil	30,000	100,000	27

The additional investment, excluding that already committed for the Bombay complexes, and for which resources have to be found during the period 1967-71, is the order of $500 million. This does not include the investment on fertilizers, which may be another $500 million and also on the conversion and fabrication facilities estimated to be of the order of $350-400 million.

These targets are by no means ambitious if one considers that a big country like India is trying to achieve in 1971 what some of the European countries and Japan have already achieved. Although the impact on Indian economy of a mature and sound petrochemical industry will be significant in terms of *per capita* consumption, the achievement will be relatively small. Nevertheless, considering India's limitations scarcity of foreign exchange, lack of design and engineering know-how, trained personnel, marketing competence and practically non-existent end-use research, limited facilities for fabrication of plants and equipment and of conversion of petrochemicals into finished goods the task of achieving the projected schemes is by no means easy. It requires an all-round effort to attract foreign investment and know-how, to create facilities for manufacturing, engineering, conversion and marketing in good time and in advance of plants going into production. Government have already taken steps in many directions, for example, the Institut *Français du Pétrole* has been entrusted with a detailed study regarding the creation of manufacturing facilities for the end-product industry; engineering facilities are being created; active collaboration of major international petrochemical companies is being sought and it is hoped that all the petrochemical projects for the Fourth Five Year *Plan* will be realised in time.

Annex I

EXISTING INDUSTRY

Product	*No. of Units*	*Location*	*Installed capacity (t/y)*	*Domestic consumption 1963 (t/y)*	*Ownership*	*Raw materials*
1. *Nitrogenous fertilizers*	12 (existing)	Bihar, Kerala, Mysore, Madhya Pradesh, West Bengal, Orissa, Punjab, Uttar Pradesh.	320,000	450,000	Private 4 State 8	Coke oven gases, and electrolytic hydrogen
	5 (under construction)	Madras, Assam, Uttar Pradesh, Bombay, Vizag.	365,000		State 4 Private 1	Lignite, natural gas, naptha Refinery gas and naptha
2. *Plastics*						
Polyethylene	2	Bombay, Calcutta	7,500	10,000	Private	Alcohol
PVC	2	Bombay, Kotah	9,000	7,000	Private	Calcium carbide
PVC (under construction)	1	Mettur	6,000		Private	Alcohol
Polystyrene	1	Bombay	6,000	6,000	Private	Alcohol, coke-oven benzene
Polystyrene (under construction)	2	Vizag, Rourkela	17,000		Private	Alcohol, coke-oven benzene
3. *Synthetic fibres*						
Nylon 6	2	Bombay, Kotah	1,800	800	Private	Imported caprolactam
Polyester (under construction)	1	Bombay	2,000		Private	Imported DMT
4. *Synthetic rubber*						
SBR	1	Bareilly	30,000	12,000	Private	Alcohol and benzene (coke oven)
5. *Detergents*	2	Bombay	7,200	800	Private	Imported D.D.B.
6. *Pesticides*						
BHC	3	Bombay, Saurashtra, Calcutta	7,200		Private	Benzene (coke oven)
DDT	2	Delhi, Alwaye	2,800		State	Benzene (coke oven)

Annex II

PRODUCT-MIX OF BOMBAY COMPLEXES

1. *Union Carbide (India) Ltd.*

	t/y naphtha and alcohol
Feedstock	60,000
Products	t/y
Ethylene	10,000
Poly-ethylene (L.D.)	9,100
Propylene	7,000
Benzene	4,500
Butyl alcohol	2,500
Butyl acetate	2,700
Acetic acid	1,300
Ethyl acetate	600
2-Ethyl hexanol	1,500
Dibutyl phthalate	1,500

2. *National Organic Chemical Industries Ltd. and Polyolefins Industries Ltd.*

	t/y of naphtha
Feedstock	225,000
Products	
Ethylene	60,000
Propylene	31,000
Butadiene	7,200
Polyethylene (H.D.)	20,000
Vinyl acetate	8,000
Polyvinyl acetate	12,000
Ethylene oxide	12,000
Ethylene glycol	10,000
Polyethylene glycol	1,000
Diethylene glycol	600
Ethylene dichloride	3,000
Vinyl chloride	30,000
Polyvinyl chloride	20,000
Isopropanol	1,500
Acetone.	11,000
Diacetone alcohol	2,000
Methyl isobutyl ketone	3,700
2-Ethyl Hexanol	8,000
Butanol	8,000
Dicyclopentadiene	700
Benzene	14,000

3. *Herdillia Chemicals*

Products	t/y
Phenol	15,000
Acetone	9,000
Phthalic Anhydride	6,000
[illegible] alcohol	[illegible]
[illegible]	[illegible]

Annex III

PRODUCT-MIX OF FUTURE COMPLEXES

1. *Koyali (Gujarat)*

Feedstock	300,000

t/y of naphtha, Refinery and oil-field gases. Refinery catalytic reformate

Products

(i) Aromatics from refinery catalytic reformate

	t/yr
Benzene	33,000
Toluene	15,000
Ortho-xylene	10,000
Para-xylene	12,000
Cyclohexane	21,000
Caprolactam	15,000
DMT	10,700

(ii) Intermediates and products from naphtha cracker complex

	t/yr
Ethylene	80,000
Propylene	48,000
Polyethylene	40,000
Vinyl chloride	32,000
Polyvinyl chloride	20,000
Vinyl acetate	10,000
Styrene	25,000
Polystyrene	18,000
Dudecyl benzene	15,000
Polyacrylonitrile	15,000
Dicyclopentadiene	1,000

(iii) Products from oilfield, refinery and cracker gases

	t/yr
Butyl-rubber	30,000
Polybutadiene	30,000

2. *South India*

	t/yr of naphtha
Feedstock	100,000

Products

	t/yr
Acetylene	30,000
Vinyl chloride	64,000
Polyvinyl chloride	30,000
Methanol	40,000
Formaldehyde	40,000

3. *Barauni (East India)*

Feedstock	Refinery

streams and gases

Products

	t/yr
Benzene	25,000
Orthoxylene	11,000
Para-xylene	9,000
Butadiene	25,000
Acrylonitrile	10,000
Cyclohexane	25,000
Caprolactam	18,000

4. *Haldia (East India)*

	t/yr of naphtha
Feedstock	400,000

Products

	t/yr
Ethylene	110,000
Propylene	66,000
Butadiene	12,000
Polyethylene	53,000
Ethanol	17,000
EPT rubber	20,000
Ethylene oxide	20,000
Polypropylene	15,000
Methyl ethyl ketone	10,000
Polybutenes	7,000
Benzene	23,000

9. DEVELOPMENT OF PETROLEUM-BASED ORGANIC CHEMICALS IN INDIA

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The Indian organic chemical industry is of fairly recent origin. Making a hesitant start during the Second World War with limited production of coal-based aromatics and fermentation alcohol, it diversified in the fifties to include acetic acid, acetic anhydride, carbon bisulphide, benzene hexachloride, DDT and polyethylene. However, marked growth commenced only during the second Five Year Plan (1956-61). During the decade 1950 to 1960 this sector recorded a rise in output from 1,000 tons to 194,000 tons and in value from $200,000 to $15 million. The present decade promises to be a period of still higher growth in the wake of rising *per capita* income and the burgeoning demands of an expanding economy (table 1). The most notable feature of this progress will be the establishment of a petrochemical industry.

TABLE 1. GROWTH OF THE ORGANIC CHEMICALS SECTOR

	Production (thousand tons)	*Value of output (million $)*
Beginning First Plan (1950-51)	1	0.2
End First Plan (1955-56)	6	2.1
End Second Plan (1960-61)	194	14.9
End Third Plan (1965-66) *	687	161.0
End Fourth Plan (1970-71) *	1,307	344.0

* Estimated.

SHIFT FROM CONVENTIONAL TO PETROLEUM RAW MATERIALS

Production of organic chemicals in India has hitherto been based exclusively on conventional raw materials, namely, fermentation alcohol, coal-based aromatics, and calcium carbide derived acetylene. These raw materials were readily available and specially suited to the needs of a low-volume market. The motivation was production first, price second. There were also distinct economic advantages involved in recourse to these sources. For example, the utilization of large surpluses of fermentation alcohol remained an intractable problem till it was used for the manufacture of chemicals. Alcohol had the additional advantage of ready convertibility into either ethylene or acetaldehyde without the problem of by-products and co-products such as propylene, butenes and butadiene which attend the production of ethylene from petroleum sources, and for which little demand existed at the time.

Fermentation alcohol and acetylene are now in short supply. In the case of alcohol, the start-up of a SBR plant has created shortages which have resulted in available supplies being rationed among consuming units. Import of alcohol is contemplated to prevent serious disruption in output of organic chemicals and plastics. Future prospects are not promising, as availability of fermentation alcohol is linked to uncertain and fluctuating output of refined sugar. Agricultural growth has been notably slow and this sector will be unable to cope with the raw material demands of the surging chemical industry. A deficit of about 80,000 tons of alcohol can be foreseen by 1970-71 unless certain existing alcohol applications, such as production of butadiene, can be switched to alternative sources. Aside from considerations of shortage, the growing sophistication of the domestic market calls for a wider and increasingly complex range of chemicals which do not lend themselves to economic production from fermentation alcohol.

The availability of by-product benzene and naphthalene from coal carbonization is placed at 55,000 and 12,000 tons, respectively, by 1971. The proposed establishment of new consuming units which will boost benzene requirements to 174,000 tons during the Fourth Plan already presages a shortage despite the envisaged expansion of steel capacity.

The ex-plant price of alcohol in India, which is still about the lowest in the world, has recently risen to 4.5 ¢/lb and the trend is upward. Coke-oven benzene at 6.8 ¢/lb and calcium carbide based acetylene are inordinately high priced. High prices of indigenously manufactured commodities are a characteristic of the Indian economy but, if usage and demand for synthetic fibres, detergents and rubber, drugs, plastics and other consumer goods is to accelerate appreciably, these must become available at prices which place them within a much wider reach than at present. In other words, the philosophy of high turnover at low margins must be introduced into the Indian chemical industry. Low raw material prices have an important bearing in this context. The production cost of ethylene from alcohol is approximately three to four times the cost of producing ethylene even from a modest-sized naphtha cracker. Likewise, acetylene recovered from naphtha cracking operations is likely to be considerably cheaper than acetylene generated from calcium carbide. It has been evident from these factors that, in India as in advanced countries, future growth of organic chemicals must be linked to petrochemical feedstocks. The Indian chemical industry, by shifting from conventional to petroleum feedstocks, is following the same evolutionary route as its counterparts have done elsewhere.

Of the available petrochemical feedstocks, namely naphtha, natural gas and refinery gas, the use of naphtha will predominate. In this respect, India will differ from United States practice where natural gas is the prime source of petrochemicals, and will follow the trend in Japan where petrochemicals are almost wholly naphtha-based and Western Europe where over 80 per cent of petrochemicals originate from this source.

Refinery capacity is expected to be 17 million tons by 1965-66 and 30 million tons by 1970-71, while corresponding naphtha production is estimated at around 3 million and 5 million tons. The Indian gasolene demand being small in relation to fuel oil and kerosene requirements, substantial naphtha surpluses are generated. A recent estimate places naphtha availability in the range of 1.3 million tons in 1966 rising to 1.8 million tons by 1971, after meeting priority requirements for fertilizers and the internal and export gasolene demand. As against this, naphtha usage for petrochemicals by 1971 will be around 1.3 million tons.

The principal source of organic chemicals in the years ahead will be ethylene, propylene and benzene derived from naphtha cracking, aromatics recovered from catalytic reformates, butadiene from naphtha crackers, and butane-butenes from naphtha crackers and refinery gas. Good operating economies will be contingent on the profitable utilization of all naphtha cracker streams.

INDIA'S NEED FOR PETROCHEMICALS

India does not yet have a petrochemicals industry but is on the threshold of large developments in this sector. Guidelines for development have been suggested in three reports made to Government within the last two years. The Kane Committee report issued in 1962 was followed by the Henney Report submitted by the Institut Français du Petrole. The latest is a report prepared in March 1964 by the Planning Group for Petrochemicals. These reports highlight the fact that over the next twenty years or so, non-petrochemical sources will be unable to meet even 20 per cent of the requirements of the Indian chemical industry. This is not surprising if it is remembered that in the United States more than 50 per cent of the chemical process industries depend on the output of the petrochemicals segment. Similarly in Japan, where petrochemicals currently account for only 12 per cent of total chemical output, the proportion is expected to rise to over 50 per cent by 1970. The need for petrochemicals is even more pressing in terms of foreign exchange savings. The Henney Report has estimated that in the absence of a petrochemical industry, India's import bill for petrochemicals will total about $110 million by 1966 and reach the alarming figure of $300 million by 1971.

Import substitution is extremely important in a developing economy which is short of capital resources and foreign exchange and has great resistance to change and innovation. In advanced countries, petrochemicals and derived end-products have made notable progress by displacing or supplementing traditional materials in many applications. Striking examples are the growing use of plastics in the field of construction, replacing steel, aluminium and other metals, synthetic fibres in place of cotton and wool, and synthetic detergents in the place of soap. Steel, cotton, wool and oils and fats for soap making are in short supply in India. Imports of these commodities aggregate $340 million annually, broken down as follows: steel, $190 million; cotton, $100 million; wool, $30 million; raw materials for soap, $20 million. Despite this heavy drain on foreign exchange little headway has been made so far in introducing substitutes. Domestic production of petroleum-based organic chemicals is expected to give impetus to large-scale substitution in these areas and to promote foreign exchange earnings by enhancing the exportability and appeal of Indian textiles in overseas markets and extending the range of exportable goods.

MAJOR PETROCHEMICAL PROJECTS

The first petrochemical complex planned for India was by Union Carbide India Limited (UCIL) in 1961. Earlier in 1964, a second petrochemical complex was approved for National Organic Chemical Industries Ltd. (NOCIL). These two private sector petrochemical complexes having a combined naphtha throughput of 285,000 tons are under construction in Bombay and are expected to be in operation during 1966. Ethylene capacity is 18,000 tons for UCIL and 55,000 tons for NOCIL. It is of interest to recall apropos the UCIL cracker that the first four olefin centres established in Japan initially had an ethylene capacity comparable to UCIL's and expanded to 80,000 tons each in a second stage.

Another four petrochemical centres are planned in the western (Koyali), eastern (Barauni and Haldia), and southern (Madras) regions of the country, each in association with a 2-3 million-ton oil refinery which will provide naphtha and refinery gas. Koyali and Haldia are to have ethylene capacities of about 100,000 tons each with start-up in 1968 and 1970, respectively. Barauni will have an aromatics extraction unit, an acrylonitrile plant and a butadiene unit with start-up in 1967. The Madras complex will be based on 30,000 tons of acetylene produced by partial oxidation of naphtha. Although start-up is planned for 1969, it will, in all likelihood, be operative only in the initial years of the Fifth Plan when further demand for petrochemicals materializes. The product-mix proposed for the six petrochemical complexes is outlined in annex 1 to this paper. The choice of products has been conditioned by the special needs of the Indian economy up to the end of the Fourth Plan. It is this consideration that has given first priority among petrochemicals to ammonia for fertilizer production.

The concept of petrochemical centres is not new to India. It is the established pattern for large-scale petrochemical operations in almost all industrial nations. Japan has nine such centres and a tenth is planned, Mexico has at least three, and numerous petrochemical centres have been established in the United States of America, France, the United Kingdom and the Federal Republic of Germany. The advantages of such centres are well known and may be briefly enumerated as follows: (i) pooling of common services and facilities, (ii) pooling of technical know-how of all the participants, (iii) rationalization of off-site facilities, intermediate storage, etc., (iv) utilization of by-products from basic operations for achieving maximum economies, (v) maximum utilization of all naphtha cracker streams, (vi) establishment of optimum size units to realize economies of scale, (vii) avoiding pyramiding of taxes on intermediate streams, with duties payable only on finished products.

The economics of petrochemical operations are largely determined by the utilization pattern for ethylene. Ethylene thus serves as the bell-wether of the petrochemical industry in much the same way as sulphuric acid for the inorganic chemical industry. The present trend is towards increasingly large ethylene plants. The first petrochemical plants installed in Japan had ethylene capacities of 20,000 tons. They were later expanded to 80,000 tons and are now up to 150,000 tons. The emphasis on bigness is most vividly illustrated by Rhone Alpes' proposed one million tons naphta cracker in France with an output of 250,000 tons of ethylene and 130,000 tons of propylene. By these standards, the 100,000 tons ethylene plants proposed for Koyali and Haldia are of medium size, but at this stage of development, this appears to be the optimum size for India. Under-developed countries with high domestic prices, lack of stiff competition and high tariff protection can sustain smaller plants than the advanced countries where these conditions do not prevail.

PROJECTED DEMAND ESTIMATES FOR PETRO-BASED ORGANIC CHEMICALS

Petrochemicals have achieved striking growth rates in many countries. In Japan, for example, which launched into petrochemicals as recently as 1955, the initial growth rate was over 50 per cent per year, but has now stabilized at around 30 per cent. Ambitious plans for petrochemicals have also been made in India. Annex II to this paper presents capacity targets established for the Third Plan for major organic chemicals and tentative estimates of requirements during the Fourth Plan.

One of the major problems in formulating capacity targets for petrochemicals is the absence of reliable market figures. Projections based on past and present consumption levels are liable to error, inasmuch as shortages, high costs, limited imports and other extraneous influences have deterred normal growth. The Fourth Plan targets for organic chemicals may give rise to over-capacity for a short period if demand for end-products does not grow as anticipated. Recent experience has shown that up to a point this situation is less damaging than the small and uneconomic capacities that have been installed in the past due to an over-cautious market assessment. However, large and persistent over-capacity should be avoided possibly by carrying over some schemes into the initial years of the Fifth Plan should surpluses seem imminent. Over-capacity will not only tie up scarce capital, but, by forcing high investment plants to operate only partially, will scale up production costs. On the other hand over-supply will tend to depress prices and thus reduce return on investment to unattractive levels. Acetic acid is currently passing through such a phase in India owing to miscalculation of the market.

The main outlets for petro-based organic chemicals lie in the following applications: (i) plastics and resins, (ii) surface coatings, (iii) drugs and pharmaceuticals, (iv) dyestuffs, (v) synthetic fibres, (vi) synthetic detergents and (vii) synthetic rubber. Demand for petrochemicals will be conditioned by the growth rates of these outlets. Table II presents past and projected production figures for these industrial sectors over a ten-year period to illustrate the demand perspective. It is noteworthy that synthetic fibres, synthetic detergents and synthetic rubber are expected to grow at an annual compound rate in the range of 20 to 38 per cent till 1970-71, while the compound growth rate of plastics between 1960 and 1970 is a striking 42 per cent per year. In this context, a rapidly mounting demand for basic and intermediate organic chemicals can be expected.

A problem that is likely to arise as soon as petrochemical plants are operating is that several organic chemicals, such as benzene, butanol, ethylene, styrene, vinyl acetate and vinyl chloride, will be produced simultaneously from naphtha as well as non-petrochemical feedstocks as shown in table III.

Production from non-petroleum feedstocks will amount to about 23 per cent of total demand. Non petro-based capacity for various products is fragmented among

TABLE II. GROWTH IN SELECTED INDUSTRIAL SEGMENTS

	Production			Annual compound growth rate
	1960-61	*1965-66*[a]	*1970-71*[a]	*(percentage)*
Plastics and resins (Tons)	10,000	74,000	320,000	42
Surface coatings	53,000	140,000	210,000	15
Drugs and pharmaceuticals ($ million)	42	105	168	15
Dyestuffs (Tons)	5,400	9,400	13,400	10
Synthetic fibres (Tons)	Nil	20,000	60,000	25
Synthetic detergents (Tons)	1,200	20,000	30,000	38
Synthetic rubber (Tons)	Nil	50,000	123,000	20

[a] Estimated

TABLE III. ESTIMATED PRODUCTION FROM NON-PETROLEUM FEEDSTOCKS. 1970-71

	Total demand (*thousand tons*)	*Production from non-petroleum feedstocks* (*thousand tons*)
Benzene	170	54
Butanol	16	13
Ethylene	280	11
2-Ethyl hexanol	13	5
Phenol	10	7
Phthalic anhydride	25	7
Styrene	58	23
Vinyl acetate	25	3
Vinyl chloride	116	39
	713	162

several relatively small units, while naphtha-based production is concentrated in a few plants of substantial size. By and large, the size and economies of the naphtha-based plants will give them a marked competitive advantage over those using alcohol or acetylene. Expansion of conventional plants to economic capacities may mitigate this problem to some extent.

Much of the recent slow-down in the organic chemical industry in India can be attributed to uncertainty regarding the respective roles of the private and public sectors in the petrochemical area. India lacks the foreign exchange and the advanced technology required to implement a large petrochemical programme without external assistance. It must look for these essentials to foreign private investors whose collaboration is being sought by Government as well as by indian entrepreneurs. However, the terms and scope of private participation and the detailed petrochemical manufacturing programme and time schedule had not been clearly defined till recently and some uncertainties still persist. Nevertheless, it is now fairly certain that, besides the two private sector petrochemical projects approved for Bombay, all new petrochemical complexes will be joint ventures of the public and private sectors, with the former generally holding majority interest. This conforms to the pattern in Mexico, where Pemex, the State oil monopoly, is the major partner in all petrochemical projects. The Government does not apparently intend entering the finished product business such as synthetic fibres and detergents and converted plastic products, confining its interest to basics and intermediates.

The *raison d'être* for Government's entry into petrochemicals is the same as for the oil companies' venture into the chemicals business. Government will be the largest petroleum refiner in India with control over the bulk of petrochemical raw materials. By converting naphtha or refinery gas to petrochemicals it can realize much higher profits than by selling the raw material stock. Another reason for Government's participation is the high capital investment required in petrochemical industries. Few private entrepreneurs in India can mobilize financial resources of the required magnitude.

INVESTMENT

The investment needs for India's petrochemical programme are exceedingly large. It has been estimated that by 1971 a fixed investment of about $ 560 million will be required for basic petrochemicals, excluding ancilliary plants and conversion facilities. The foreign exchange component of this may be of the order of $ 350 million. Taking conversion and off-site facilities into account, investment may well approach $ 1 thousand million. The total investment proposed in the chemicals industry during the Fourth Plan is $ 3.36 thousand million. Petrochemical plants and associated facilities will account for 30 per cent of the total industry investment. The proportion would be considerably higher if fertilizer plants were excluded.

It is of interest to note that by 1962, Japan's investment in petrochemicals stood at $ 600 million. India expects to spend almost the same amount on petrochemicals during the first five years of the industry as Japan did in the corresponding period of its petrochemical development. It remains to be seen if this order of investment will spark off the same spectacular growth in India as it has done in Japan.

A breakdown of the $ 560 million investment estimate is provided in table IV.

PROJECTED PRODUCTION AND USAGE OF MAJOR PETRO-BASED ORGANIC CHEMICALS

A brief review of production plans and end usage for major petroleum-based organic chemicals through 1970-71 is presented below.

Ethylene chemicals

Ethylene

Naphtha cracking capacity planned for 1970-71 has been predicated on ethylene demand of approximately 280,000 tons. The bulk of this ethylene will be required for the following plastics: polyethylene, 120,000 tons; polyvinyl chloride, 110,000 tons; polystyrene, 45,000 tons; vinyl acetate, 20,000 tons. Petrochemical ethylene will replace calcium carbide derived acetylene for future PVC production. Certain existing PVC plants are considering a switchover to ethylene to improve their economics. Ethylene will also be used for making vinyl acetate in Koyali. Much of this is to be used for polyvinyl alcohol fibre, the balance going into emulsion paints.

TABLE IV. BREAKDOWN OF FIXED INVESTMENT IN PETROCHEMICALS

	Estimated investment by 1971 (*$ million*)
Naphtha cracking/aromatics recovery	60
Organic chemicals	205
Plastics	190
Synthetic rubber	105
	560

Ethylene oxide and derivatives

A 12,000-ton direct oxidation ethylene oxide plant is being installed in the NOCIL complex which will use all but 4,000 tons of the product captively. This is about the optimum economic-size ethylene oxide unit. The main use will be for conversion to ethylene glycol required for polyester fibre for which a plant is under erection in Bombay. Further expansion of polyester fibre capacity is likely. Diethylene glycol produced as a co-product will be utilized for UDEX extraction of aromatics. Small quantities of polyethylene glycols and glycol ethers will meet the limited domestic requirement. About 1,200 tons of ethanolamines will go into detergents, textile chemicals, and gas scrubbing. Nonionic detergents such as ethoxylated nonyl phenols and ethylene oxide adducts of fatty alcohols, which require about 0.5 kg of ethylene oxide per kilogramme of detergent, should develop into an important outlet. It is proposed to install a 20,000 ton ethylene oxide plant in the Haldia complex around 1970 to serve Fifth Plan requirements.

Propylene chemicals

Propylene

About 150,000 tons of propylene will be produced in association with 280,000 tons of ethylene from high-severity naphtha cracking. This will just match estimated Fourth Plan propylene demand of approximately 140,000 tons. Additional propylene, if required, can be obtained from refinery gas in Bombay and Barauni. It is planned to use propylene for a wide range of chemicals.

Polypropylene

About 15,000 tons of polypropylene capacity has been proposed, of which 5,000 tons are to be for non-fibre uses. Several manufacturing proposals are under review but when and where facilities will be installed is still uncertain. This application requires polymerization grade propylene.

Acetone and derivatives

Acetone capacity of 11,000 tons is included in the NOCIL complex *via* isopropanol, using propylene from its own cracker. Additionally, around 9,000 tons of acetone will result as a co-product of cumene-phenol. Propylene for this plant is likely to be supplied from one of the Bombay naphtha crackers. Main uses for acetone will be for a 8,000-ton methyl methacrylate facility proposed for Bombay, acetate rayon, dissolved acetylene and pharmaceuticals. Principal acetone derivatives to be made are 5,000 tons of diacetone alcohol for brake fluids and surface coatings and a similar quantity of methyl isobutyl ketone as a lacquer solvent. Further acetone capacity is to be installed at Haldia if required during the Fifth Plan.

Phenol

Two plants with a total capacity of 17,000 tons have been approved for phenol which should adequately cover estimated Fourth Plan demand of 12,000 tons. Cumene phenol will account for 15,000 tons, the balance coming *via* chloro-benzene. Plastics and resins, pesticides, surfactants and medicinal preparations will comprise the main end-uses.

Propylene oxide and derivatives

It is proposed to establish in Bombay, a 10,000-ton propylene oxide plan which is the minimum economic unit. The source of propylene is still undecided, although several alternatives exist for augmenting present propylene capacity in Bombay. Its chief use will be in polypropylene glycols required for polyurethane foams. However, production of toluene diisocyanate will have to be planned simultaneously. Existing urethane foam capacity is not fully utilized as raw materials have to be imported and the product is high priced. Another outlet is propylene glycol for polyester resins where also existing capacity is partly idle. It will, however, require some time and considerable market development to attain full plant output for propylene oxide.

Acrylonitrile

There are to be three acrylonitrile plants with an aggregate capacity of 27,000 tons. One unit with 3,500 tons output is based on the acetylene-HCN process while the other two, to be located at Barauni and Koyali, will employ the Sohio/Distillers propylene-ammonia route. End-uses will consist of 17,000 tons of acrylic fibre to serve as substitute for wool, ABS rubber, and acrylic esters for emulsion paints.

Butanol

Butanol will be made from alcohol as well as by the OXO process, as indicated in table III. However, propylene-based output will be limited to the NOCIL complex while alcohol-based capacity is distributed among at least three plants, each with a small capacity. Butanol and butyl acetate are among the most widely used solvents in India in surface coatings and also enter into the manufacture of antibiotics and resins.

2-Ethyl hexanol

Requirements of phthalate plasticizers are placed at 22,000 tons, principally in conjunction with PVC production. Largest demand will be for dioctyl phthalate. About 8,000 tons of 2-ethyl hexanol will be made by the OXO process in the NOCIL complex and a small quantity will be alcohol-based. Co-product iso-octanol from the OXO process will go into DIOP plasticizers.

Dodecyl benzene

Both propylene and benzene being available in the Koyali complex, 20,000 tons of dodecyl benzene capacity is proposed for this location. There has been some question as to whether India should establish plants for dodecyl benzene at a time when the West is rapidly moving towards biodegradable detergents. Large-scale use of detergents and mechanised washing have resulted in problems of foaming and stream pollution in industrially advanced countries. These conditions do not prevail in India at present. Wider markets for detergents can be developed only if the price is low, whereas biodegradable detergents are generally expensive. As the price of propylene in India is likely to be appreciably higher than in the United States or Europe this may influence the economics of dodecyl benzene in relation to straight-chain alkylates. If the price differential is not substantial, it will be worthwhile bypassing dodecyl benzene altogether or to base future plants on the linear paraffins. The Gujarat crudes are reported to be particularly suited to the separation of straight-chain paraffins by molecular sieve technology.

Butadiene

Petrochemical butadiene is to be used mainly for polybutadiene rubber and to replace alcohol-based butadiene in the existing SBR plant if possible. It is to be recovered from the C_4 streams available from the Bombay and Koyali crackers and also produced by the dehydrogenation of n-butane and n-butene in the C_4 fractions from naphtha cracking and in refinery gas at these locations and possibly in Barauni. A 25,000-ton polybutadiene plant for Bombay has received tentative approval and will draw on the two naphtha crackers as well as refinery gases to meet its butadiene requirements. Besides the two plants referred to above and possibly an additional polybutadiene plant at Koyali, decisions are still awaited as to the type and capacities of synthetic rubber to be developed in India. Over-all rubber requirements have been placed at 225,000 tons in 1970-71, of which 120,000 tons will have to be synthetic rubber. A substantial deficit therefore remains to be met with polybutadiene, polyisoprene, EPT, or butyl rubbers whichever may be the final choice.

Acetylene

Fourth Plan acetylene demand is estimated at 54,000 tons, of which 24,000 tons are to be generated from calcium carbide. Its principal uses will be for welding and for making PVC and PVA. About 700 to 1,000 tons of acetylene are to be recovered from the UCIL cracker in Bombay. Much of this will be converted to acetylene black for use in UCIL's dry battery manufacture. The Fourth Plan deficit is proposed to be covered by producing 30,000 tons of acetylene by partial oxidation of naphtha in the Madras complex.

Aromatic chemicals

Basic aromatics

The Bombay naphtha crackers will provide about 20,000 tons of benzene. An additional 80,000 tons may be available from Koyali, Barauni, and Haldia. With an estimated 55,000 tons of benzene coming from coal carbonization plants by 1971, aggregate supply will be 155,000 tons against a projected demand of 170,000 tons. O-xylene and p-xylene will be recovered to the extent of 22,000 and 17,000 tons, respectively, at Koyali and Barauni. The former will supplement coal-based naphthalene in producing 25,000 tons of phthalic anhydride and the latter is required to make 20,000 tons of dimethyl terephthalate at Koyali and Barauni for polyester fibre.

Other organic chemicals

Among other chemicals to be developed from petrochemical feedstocks are 60,000 tons of methanol and 33,000 tons of caprolactam for nylon 6. Methanol, to be used mainly for 77,000 tons of formaldehyde, is to be produced by steam reforming of naphtha. A 30,000 tons methanol plant is being installed in Bombay and a second plant is proposed in the Madras complex towards the end of the Fourth Plan. Caprolactam capacity of 15,000 tons *via* cyclohexane is to be installed at Koyali or Bombay. With increasing demand, additional capacity of 18,000 tons is proposed for Barauni at a later stage.

DETERMINANTS OF GROWTH

The establishment within five to seven years of a petrochemical industry which will be among the largest in a developing nation and of respectable size even by international standards is a gigantic task for a country like India which is short of capital. To raise sufficient local finance within so short a span would itself be an immense undertaking for private entrepreneurs, but with Government as a major partner, internal resources should not pose a problem. The real difficulty is foreign exchange. In a developing country the cheapest sources of foreign finance are government-to-government credits and aid, but the available quantum is far short of requirements and subject to many political uncertainties. Furthermore, foreign government finance does not normally bring with it technological, management and marketing skills which are as necessary as capital. Foreign private equity investment, although a relatively expensive way of bringing foreign capital into an undeveloped country, is the most expedient answer. It has been estimated that every dollar of foreign investment would call for repatriation of three to five dollars within ten years after start of full production depending on the profitability of the enterprise in contrast with about $1.60 in the case of foreign loans. The success of the petrochemical programme hinges on the ability of Government, and to a lesser degree of Indian private enterprise, to attract large scale private investment from some of the major foreign petrochemical companies. The attractions are many, including a vast potential market, high tariff barriers, liberal tax concessions, repatriation of dividends and capital gains, and above all, political stability. It augers well for the growth of the petrochemical sector that Government has adopted a pragmatic approach towards foreign private collaboration in petrochemicals. While still committed to the policy of a dominant public sector, Government has demonstrated willingness to encourage private investment on realistic terms. Union Carbide Corporation and Shell International are partners in Indian petrochemical complexes and several other international companies are exploring the field.

Japan, which has relied heavily on foreign technology from the United States and Western Europe to establish petrochemicals production, provides an interesting example which merits careful study in India. It has used know-how licensing agreements involving royalty payments as well as foreign equity participation with signal success.

The petrochemical programme is closely linked to the creation of new refinery capacity that is to form the nucleus of the planned petrochemical complexes. These refineries should be installed on schedule to preclude a shortage of naphtha. Timing is of the utmost importance also in the establishment of petrochemical plants, particularly for basic organic chemicals and intermediates. Delays in implementation produce a chain reaction throughout the chemical and allied industries, creating raw material shortages and retarding the growth of plastics, synthetic fibres, detergents, dyestuffs, drugs, and related segments. Many Third Plan targets are already threatened on this account. Petrochemicals have been included in a priority list of key industries recently published by Government. The object is to cut through procedural delays and facilitate speedy issue of industrial licences and other approvals to a selected group of industries considered basic to the national interest.

Phasing of the various petrochemical complexes should be flexible to keep in step with demand. Prolonged conditions of shortage or surplus will hinder growth.

There is more to entering the petrochemicals business than installing production facilities. In a shortage-ridden market such as India's, it is easy to be misled by the notion that if production exists, customers can always be found. The hazards of this philosophy have been exposed in the case of fertilizers, where unsold production has piled up in factories while agricultural productivity stagnated for want of soil nutrients.

If sales of petro-based synthetic organic chemicals are to match installed capacity by 1970-71, sustained and intensive effort needs to be directed towards creating wider demand and developing new outlets for end products. The traditional conservatism of the Indian consumer must be breached to promote acceptance of the vast array of new products which petrochemical technology will place at his disposal in coming years. This is particularly true in the case of plastics, synthetic fibres, and detergents which are relatively new to the Indian market and often regarded as luxuries to be abjured in a poor country. In the absence of deliberate stimuli to accelerate growth of demand, the full benefits of large-scale petrochemical production may remain unrealised. Economies of scale do not accrue *per se* from big plants but by operation of these plants close to the rated capacity.

All this points to the importance of the marketing function in India's petrochemical operations including competent technical service to customers. The desirability of a shift from production-orientation to market-orientation is clearly evident.

It would help to reduce the gap between installation of capacity and development of demand if market promotion for new products could be undertaken with imported material sufficiently in advance of production. For example, a beginning can be made to introduce acrylic, polyvinyl alcohol, and polypropylene fibres to the textile industry, and the newer synthetic rubbers to the tyre industry, in anticipation of forthcoming production.

The price of naphtha has a significant influence on the cost of petrochemicals. For example, the cost of ethylene rises by about $ 3.60 per ton for each dollar/ton increase in naphtha price. Discussions have long been in progress to evolve an acceptable price. The private oil companies have recently suggested a price ceiling of $ 16.60 per ton net, ex-refinery on the basis of parity with the price of imported Bunker C fuel oil. Inclusive of 5 per cent excise duty, this works out at $ 17.43 per ton. Government has appointed an Oil Price Working Group which is soon expected to recommend a fair basis for fixation of naphtha price. As Government will be the largest producer as well as the largest consumer of naphtha, it is expected that a reasonable price formula will be devised, so that petrochemical production in India can start with an economical base.

Prices will play a decisive role in influencing demand for petrochemicals. Current Indian prices for organic chemicals and plastics are exceedingly high in relation to international prices as brought out in table V.

High prices generally reflect high production costs, and there are many factors that tend to inflate manufacturing costs in India. Perhaps the most significant of these is the existence of numerous plants of small size with low levels of output. High prices and chronic shortages of raw materials often preclude full operation at even these low capacities. Many plants are based on raw materials or processes no longer considered economical. Fixed investment costs in plants are generally higher in India than in Western countries, leading to higher depreciation charges. Utilities also are costlier. Compounding all this are various excise duties and levies on basic, intermediate as well as finished products. Much needs to be done to bring down manufacturing costs in India. Plants for petroleum-based organic chemicals, by taking advantage of the economies of scale and the abundant availability of economically priced raw materials, should serve to lower the prevailing high-cost structure of the Indian chemical industry.

Prices must decline in coming years if domestic consumption is to grow rapidly, although it cannot be expected that they will reach anywhere close to international levels by 1970-71. Even in Japan, which already produces several times the volume of petrochemicals that

TABLE V. PRICE COMPARISON — INDIA *vs* ABROAD

	*India price** *(¢/lb)*	*India price as % of other nations*		
		U.S.A. (percentage)	*Fed. Rep. of Germany (percentage)*	*Japan (percentage)*
Benzene	6.75	200	150	150
Ethyl alcohol	4.43	50	70	55
Naphthalene	8.51	260	250	230
Acetone	18.90	290	350	210
n-Butanol	48.50	360	340	350
Dioctyl phthalate	33.20	260	180	—
Formaldehyde (37 %)	11.20	300	275	330
Polyethylene (low density)	66.50	430	330	380
Polystyrene (general purpose)	45.00	310	275	215
PVC resin	77.00	480	485	610
SBR rubber, 1500 grade	38.60	170	180	180

* Current domestic ex-factory price, inclusive of excise duty.

India will attain by 1970-71, many petrochemicals are priced 10-35 per cent higher than in the United States.

For petrochemical operations, the acceptable ratio of sales to investment varies from 0.6 to about 1.0 depending on the product. The average for the Japanese and Canadian petrochemical industries is around the lower limit, although Canada hopes to raise it close to 0.75. In the Indian organic chemical industry the ratio for 1963-64 ranges from a low of about 0.36 for dyestuffs to a high of 0.82 for pharmaceuticals. The Indian petrochemical industry should endeavour to attain a high sales/investment index not so much by maintaining high prices as by seeking expanded sales volume. Having said this, it should be mentioned that in the field of petrochemicals Government's policy in regard to prices, taxation, duties, etc. should not restrict normal profitability. Petrochemicals must provide an attractive return on investment to justify the huge expenditure involved.

With the advent of petrochemicals, the Indian organic chemical industry has made the transition from adolescence to maturity. Great expectations have been aroused that the petrochemical industry in India will foster industrial advancement and contribute to a higher standard of living. Unified and co-ordinated effort between Government and private enterprise will, no doubt, bring about the realization of these hopes and generate far-reaching benefits to the Indian economy.

Annex I

PLANNED PETROCHEMICAL COMPLEXES UP TO 1970-71

Project	*Product-mix*
1. UCIL	Ethylene, polyethylene Propylene Butadiene Acetylene, acetylene black Benzene Acetic acid, n-butanol, butyl acetate, ethyl acetate, 2-ethyl hexanol, dioctyl phthalate *
2. NOCIL/POLYOLEFINS	Ethylene, polyethylene, Polyvinyl chloride, polyvinyl acetate, ethylene oxide, ethylene glycols Propylene, isopropanol, methyl isobutyl ketone, acetone, Diacetone alcohol, butanol, 2-ethyl hexanol Butadiene Benzene
3. KOYALI	Ethylene, polyethylene, polyvinyl chloride, vinyl acetate, polystyrene Propylene, polypropylene, acrylonitrile, dodecyl benzene Butadiene, polybutadiene, butyl rubber Benzene, cyclohexane, caprolactum o-xylene p-xylene, dimethyl terephthalate
4. BARAUNI	Propylene, acrylonitrile Butadiene Benzene, cyclohexane, caprolactum o-xylene p-xylene
5. HALDIA	Ethylene, polyethylene, ethylene oxide, ethanol, EPT rubber Propylene, polypropylene n-butene, methyl ethyl ketone Iso-butene, polybutenes Butadiene, polybutadiene Benzene
6. MADRAS	Acetylene, vinyl chloride, polyvinyl chloride Methanol, formaldehyde

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* Alcohol-based.

Annex II

PROJECTED PRODUCTION OF SELECTED BASIC AND INTERMEDIATE ORGANIC CHEMICALS

Basic chemicals	*Present capacity (operating and approved)*	*Third Plan capacity (targets – 1965-66)*	*Proposed Fourth Plan capacity (targets -- 1970-71)*	*Figures in tons (Percentage petrochemicals based capacity 1970-71)*
Basic chemicals				
Ethylene	78,000	47,000	280,000	97
Propylene	42,000	18,000	140,000	100
Butadiene	37,000	25,000	120,000	75
Butane/Butenes	—	60,000	130,000	100
Acetylene	24,000	24,000	54,000	56
Benzene	80,000	80,000	170,000	68
Toluene	19,000	4,000		
o-Xylene	—	9,000	22,000	100
p-Xylene	—	—	17,000	100
Naphthalene	12,000	12,000	15,000	—

Annex II *(continued)*

Basic chemicals	*Present capacity (operating and approved)*	*Third plan capacity (targets – 1965-66)*	*Proposed fourth plan capacity (targets – 1970-71)*	*Figures in tons (Percentage petrochemicals based capacity 1970-71)*
Major organic chemicals				
Acetic acid	24,000	29,000	57,000	—
Acrylonitrile	4,000	2,000	27,000	92
Aniline	3,500	4,000	9,000	100
n-Butanol	16,000	6,000	16,000	42
Caprolactum	5,000	12,000	33,000	85
Cyclohexane	—	—	32,000	100
Dimethyl terephthalate	—	3,000	20,000	100
Dodecyl-benzene	—	8,000	20,000	100
Ethanol	270,000	200,000	315,000	7
Ethylene oxide	12,000	5,000	15,000	100
2-Ethyl hexanol	13,000	5,000	13,000	62
Formaldehyde (37 per cent)	13,000	30,000	77,000	100
Isopropanol and derived solvents (Acetone, Diacetone Alcohol, Methyl isobutyl ketone)	24,000	12,000	28,000	93
Maleic anhydride	1,500	2,000	3,500	100
Methanol	33,000	25,000	60,000	100
Methyl ethyl ketone	—	—	10,000	100
Phenol	17,000	20,000	17,000	60
Phthalic anhydride	15,000	13,000	25,000	72
Propylene oxide	—	—	10,000	100
Styrene	33,000	33,000	58,000	43
Vinyl acetate	11,300	2,000	25,000	87
Vinyl chloride	65,000	32,000	116,000	68

10. THE PETROCHEMICAL INDUSTRY IN IRAN

Participants from Iran

I. Introductory

1. The development of petrochemicals in Iran

The production of chemicals from petroleum hydrocarbons on an industrial scale commenced in the second decade of this century, and developed with remarkable rapidity during and after the Second World War. It now forms the largest branch of the chemical industry, the value of its output being far greater than that of all the other branches put together. The main reasons for this exceptional growth may be sought in recent scientific and technological advances; in the relative abundance and price stability of petroleum hydrocarbons, in the great possibilities for the substitution of traditional raw materials by petrochemicals, and in the fact that such raw materials are becoming rather scarce and the prices of petrochemicals are becoming more favourable.

The developed countries established or expanded their petrochemical industries mainly during the 1950s. In Iran, the internal demand for petrochemical products during this period was too small to justify the establishment of a petrochemical industry, even if a part of its output could have been exported. However, there was an urgent need to utilize the country's abundant reserves of gaseous and liquid hydrocarbons, and accordingly a feasibility study for the manufacture of petrochemicals was entrusted to a well-known international company. Since that time, a number of technical and economic feasibility surveys have been carried out, both by foreign consultants and by Iranian engineers. These have covered a variety of petrochemicals — including carbon black, nitrogenous fertilizer and plastics — in the production of which the hydrocarbon gases are utilized both as raw material and as fuel. On the other hand, the feasibility of setting up industries, such as cement making, in which the natural gas is used as fuel only, was also investigated. Studies covered the feasibility of single-product manufacture, as well as the establishment of multi-product complexes, and were based either on supplying the home market or on partial or total export. All the above surveys were under the sponsorship of the National Iranian Oil Company or other Government agencies.

Almost all of these investigations were directed towards certain definite objectives, with one or more factors — such as the type of product, the feedstock, the location of the plant — being fixed in advance. This naturally meant that the studies were of special and limited application. Apart from the nitrogenous fertilizer plant in Shiraz, based on natural gas from Gach Saran oilfield (details of which will be given in the second part of this paper) no other petrochemical plants have yet been built.

In 1963, the Government appointed the Institut français du pétrole (IFP) with the National Iranian Oil Company as the executive agent to make a general survey of the possibilities of establishing a petrochemical industry in Iran. This survey was completed by the end of 1963, when the IFP's preliminary report and recommendations were submitted to the Government. The Institute recommended that the establishment of a petrochemical complex was justified for the manufacture of plastics, synthetic rubbers, synthetic fibres and detergents in quantities sufficient to satisfy internal demand in 1970; it also indicated the possibility of producing certain intermediate and finished products in excess of the internal demand, in order to export the surplus at prices not in excess of world export prices.

The feasibility of several schemes was worked out in detail, and a number of alternatives were proposed. The complex that has been favourably considered would require an investment of about $100 million. On the basis of this study contacts were made with a number of companies engaged in petrochemical activities in order to investigate the terms and conditions of obtaining licences and technical know-how, as well as the possibilities of co-operating with producers of petrochemicals on a joint-venture basis. These contacts have had encouraging results, and have led to a number of proposals for the sale of licence rights and know-how and for the establishment of joint ventures. In addition to the above study, a number of other studies have been carried out on the possibility of setting up industries, based on natural gas, for the production of liquid ammonia, elemental sulphur, carbon black or liquefied petroleum gases. The studies have clearly indicated that the above products can be produced at costs that would make them competitive in certain external markets.

A number of Government organizations had previously been responsible for the initiation and development of the petrochemical industry. Recently, however, the National Iranian Oil Company was appointed by the Government as the agency dealing with the development of this industry. All existing agencies, as well as the Shiraz fertilizer plant, will therefore be transferred to the National Iranian Oil Company, which is expected to form a subsidiary company to deal with its petrochemical activities.

2. ECONOMIC REASONS FOR ASSIGNING PRIORITY TO THE PETROCHEMICAL INDUSTRY

(i) *The vast size of Iran's gas and oil reserves*

Iran possesses the world's largest proved reserves of natural gas, as well as one of the world's largest reserves of petroleum. The magnitude of the country's gas reserves may be judged from the fact that in the case of a single field such as Agha Jari, even after all the oil has been produced and not taking into account the gas produced in association with the oil, the remaining gas in place would amount to some $27 \cdot 10^{12}$ standard cubic feet. This would yield an output of 1,000 million standard cubic feet a day for a period of over seventy years. Much the same can be said of Iran's other oilfields — Gach Saran, Pazenun, Ahwaz, Bibi Hakimeh, Faris, Karanj, Rag-i-Safid, etc.

The volume of gas currently flared in the southern oilfields of Iran is around 1,000 million standard cubic feet a day. This amount is equivalent in heating value to over 160,000 barrels a day of oil; it is also in excess of the total volume of gas at present utilized in the United States for the production of petrochemicals. It is therefore clear that there is ample scope for the utilization of this gas both as fuel and as raw material. The flared gas also contains a substantial proportion of natural gas liquids, which apart from their potential value as fuel are among the most desirable feedstocks for petrochemicals.

In addition to this tremendous volume of excess gas, various streams of Abadan refinery — one of the largest refineries in the world — can be utilized for the manufacture of a variety of intermediate and finished petrochemical products.

(ii) *The saving in foreign exchange*

It has been estimated that by 1967-68 the output of the planned petrochemical complex should replace imported petrochemicals costing $20 to $25 million annually. The complex is also expected to produce, in its initial years of operation, products in excess of the local demand. These can be exported, thus bringing into the country additional foreign exchange. The net saving in foreign exchange, however, would be less than the value of total sales, since a portion of the total manufacturing cost would involve foreign exchange expenditures.

(iii) *The existence of other favourable economic factors*

The development of the oil industry in south-west Iran, as well as the country's general development, has led to the creation of a considerable social and economic infrastructure in that area. In addition, the gradual depletion of some of the older fields, from which oil has been produced over a period of more than forty years, makes it possible to utilize large existing facilities and employ the skilled manpower available for the development of the petrochemical industry.

(iv) *The establishment of secondary industries*

The creation of a petrochemical industry would of necessity lead to the establishment of secondary industries. A petrochemical industry, on account of its complexity and high capital cost, is more likely to be established by government initiative; the setting up of secondary industries, on the other hand, would present many opportunities for private enterprise. The manufacture of plastic articles, and of cloth woven from synthetic fibres, are examples of industries which are well within the capabilities of the private sector to finance and operate. The Government is anxious to encourage private capital to assist in the industrialization of the country, and since these secondary industries afford many opportunites for lucrative investment, the necessary capital could easily be attracted.

2 (A). DIFFICULTIES INVOLVED IN THE DEVELOPMENT OF PETROCHEMICAL INDUSTRIES AND THEIR POSSIBLE SOLUTIONS

(i) *The relatively large minimum economic size of the plant*

Petrochemical plants in general are of large minimum economic size. Iran, with a population of around 22 million and a comparatively modest annual *per capita* income (about $185) has not hitherto provided a sufficient market for the establishment of a reasonably sized petrochemical plant. The installation of petrochemical plants for the limited domestic market alone would result in a high unit cost of production as compared with the prevailing import prices of such products.

(ii) *The difficulty of exporting*

In order to be able to install plants above the minimum economic size, consideration may be given to the question of finding export outlets to supplement the limited domestic market. In this connexion, however, it should be noted that the industrialized countries possess huge integrated plants for the production of petrochemicals. The products of such plants — especially when they are operated above their nominal capacity — are of low cost, and this factor, combined with the marketing experience and resources of the large companies, results in products being offered at terms that the smaller plants find it almost impossible to meet. The after-sale technical assistance provided by the large established companies is an additional attraction to customers. The chances of entering the highly competitive international market are therefore small. A practical solution to this difficulty would be co-operation among developing countries of the same region, with each country specializing in the production of certain petrochemicals for the combined market.

(iii) *The capital-intensive nature of the industry*

A large initial capital per unit volume of output is a disadvantage for an industry in a developing country, where there are many other projects to be considered, and where scarcity of capital is usually one of the main factors limiting development. The petrochemical industry is in fact one of the most capital-intensive industries — employing very few workers.

(iv) *The heavy burden of research*

New petrochemical techniques are continually being introduced, and constant development and research are needed in order to keep up with the advance of world standards. The petrochemical industry consequently spends a higher percentage of its sales proceeds on research and development programmes than almost any other industry. The cost of these programmes, as well as the scientific and technical manpower required, are usually beyond the resources of a developing country. Moreover, since a petrochemical plant in such a country would tend to have a limited output, the burden of research on each unit of production would be prohibitive. The possibility of entering into joint ventures with the large petrochemical companies, or making arrangements to benefit from their research and development resources, may be a way out of this difficulty.

(v) *The necessity for utilization of by-products*

One of the characteristics of the petrochemical industry is its dependence both on itself and on other chemical industries for the utilization of its by-products. For this reason, petrochemical plants are not usually set up as single units, but usually take the form of integrated units or "complexes" in which the product or by-product of one unit is consumed by the next as raw material. This naturally leads to diversification of the manufactured products. This lack of a chemical industry to provide or consume by-products and/or intermediates, and the limitation of the market for diversified products, are both factors hindering the development of a petrochemical industry. These adverse factors may be overcome through the development of the chemical industry as well as through co-operation among the developing countries of the same region.

3. INSTITUTIONAL MEASURES IN FAVOUR OF PETROCHEMICAL DEVELOPMENT

The Government of Iran follows an active policy in favour of acceleration of industrial development. The establishment of a petrochemical complex has been given a high priority. Though the foreign trade policy of the Government does not, in general, place quantitative restrictions on imports, however, in certain cases such as textiles, a number of durable consumers' goods, etc., imports have been stopped completely.

In the absence of local production of petrochemicals, the Government has encouraged increased imports of basic petrochemicals and the establishment of processing industries in order to create a local market for petrochemicals. The present rate of tariff and various other dues ranges between 25 and 35 per cent of the value of the basic petrochemicals imported, while in the case of other types of goods such rates are much higher (reaching even about 100 per cent of the c.i.f. value in some instances) in order to discourage the import of goods competing with local products. It is assumed that this policy will be reconsidered when the national petrochemical industry comes into being, even to the point of banning imports if the local output meets the requirements of the country. It may, therefore, be anticipated that a large degree of protection will be considered by the Government for the petrochemical industry following the production of such products in Iran.

In addition to the above measures, the Government extends credits for the development of industries through the industrial banks, provided that the private sector can muster at least 30 to 50 per cent of the necessary capital. In fields in which the local technical know-how is insufficient or the necessary capital requirement is so large that it cannot be mobilized by the domestic private sector, the Government encourages the participation of foreign private investors in joint ventures with local firms. Such a policy applies to the development of the petrochemical industry as well. However, in view of the high priority given to the development of this industry, should the domestic private sector be unwilling to undertake the risks involved or should it fail to mobilize the necessary capital, the Government would be prepared to undertake directly the setting up of the petrochemical industry. In such a case, the Government would prefer to enter into joint ventures with experienced foreign firms, especially if the latter undertake to assist in the setting up of larger-size plants with a view to exporting part of the output.

The existing laws on the encouragement and attraction of foreign capital include sufficient provisions for the protection of foreign investment and guarantee the repatriation of both the original capital and the investment income without any restriction. Such guarantees, including the supply of foreign exchange for the transfer of funds, are issued by the authorized government bodies. However, any such participation, or even recourse to loans, for the setting up of the petrochemical industry by the Government will be on a competitive basis.

In the fields in which there is excess capacity for the production of industrial products, minerals, etc., the Government encourages in various ways the development of foreign outlets in order to expand local production. In general, it may be stated that whenever competing products from other countries receive favourable treatment from their governments, or whenever foreign firms themselves follow different price policies or apply different measures in favour of their exports, the Government of Iran resorts to the necessary measures, including direct and indirect subsidies, in order to enable Iranian goods to compete with the foreign products on equal terms.

4. SUPPORTING ACTIVITIES FOR THE PETROCHEMICAL INDUSTRY IN IRAN

N.I.O.C. Research Centre

With the growing development of the oil and petrochemical industries and the projected expansions in these fields in Iran, a serious need was felt for the creation of a centre of research for petroleum and petrochemistry.

The establishment of such a centre (concerning which detailed information is given in the annex to this paper) was started in 1959. Since then, much effort has been devoted to the training of personnel capable of carrying out research in the field of petrochemistry. Apart from the training programmes, the Centre has rendered services towards the development of petrochemical industries in Iran, and has also carried out some interesting basic research.

The research laboratories are furnished with the greater part of the analytical equipment and facilities needed for research work. Construction of a modern building specifically designed for the Research Centre is contemplated. It is planned to develop the Centre in such a way that it will keep pace with the development of the petrochemical industry in Iran.

In addition to the Research Centre, a specialized course in petrochemistry has been taught since 1962 in the Faculty of Engineering, University of Tehran.

5. EXPECTED LINES AND RATES OF DEVELOPMENT

The demand for certain petrochemical products in Iran has reached such a volume, and is expected to grow at such a rate, that the erection of plants to manufacture these products locally is considered to be justified. The rate of growth of consumption will depend partly on the country's general economic development, and partly on the substitution of the traditional raw materials by these products. In determining the size of the petrochemical plants it has been considered economical to take into account the local demand for several years after they have begun to operate. It will be necessary, in the first few years, to export part of the output.

A general economic growth rate of 6 per cent annually is forecast for the period of Iran's Third Development Plan, which runs from 1962 to 1967. On the basis of this forecast, it is estimated that the gross national product will reach $7 thousand million by 1973, and that, allowing for the growth of population, this increase will result in a rise in the country's *per capita* income from the present level of around $185 to $240 by 1973.

It is not easy to estimate the extent to which petrochemicals may be substituted for traditional materials. However, in view of the fact that the use of petrochemical products is new to the Iranian economy, it may safely be stated that there is considerable scope for substitution.

The demand forecast for the principal petrochemical products for the domestic market up to 1973 has been made in the following way.

(i) The projected gross national product was used as a basis to forecast the future trend of demand for products already well established in Iran. The results were compared and checked with the forecasts of the demand of other countries having a comparable gross national product.

(ii) The trend of imports into Iran of goods based on petrochemicals, and of the manufacture of such goods within the country, was analysed by means of

Extrapolation of the demand trend for the past five years.

Cross-checking the consumption of certain products with the available forecasts of demand for related items. (For example, the growth rate of rubber consumption is dependent on the vehicle registration rate and on gasolene and diesel oil consumption.)

Comparison of the rate of growth in Iran with that of other countries.

(iii) The substitution effect was estimated by calculating the future consumption of major petrochemicals in the manufacture of goods not as yet produced locally — e.g. plastic pipes for irrigation, and plastic sacks for cement and fertilizers.

(iv) The estimates thus made were compared with forecasts for other countries in a similar economic situation.

The demand forecasts for major petrochemical products thus arrived at are as follows:

	1968 (metric tons)	1973
Plastics	14,000	26,000
Synthetic fibres	5,000	10,000
Detergents	3,000	5,000
Synthetic rubbers	17,000	25,000

The selection of the specific types of plastics, synthetic fibres and rubber to be manufactured is at present under consideration and will be made shortly.

Based on the above forecasts, the economic feasibility of a number of industrial complexes has been studied. The results of these studies show that even on the basis of 1968 demand the construction of a petrochemical complex would be justified.

As mentioned earlier in this paper, the preliminary steps have been taken to set up a petrochemical complex in Iran, to go on stream by 1968. It is believed that the impetus given to industry by the local production of plastics, fibres, rubbers and detergents would lead to a much more rapid increase in internal demand than has been forecast. Moreover, if it is considered more economical to build plants with capacities capable of supplying the estimated demand for 1973, this would enable Iran to export its excess petrochemical production during the first few years of operation.

II. The Shiraz nitrogenous fertilizer plant

The Shiraz nitrogenous fertilizer plant, Iran's only existing petrochemical plant, is situated at Marvdasht, about twenty-five miles north-west of Shiraz in the southern part of Iran. The plant has an installed annual capacity of 40,000 metric tons of ammonium nitrate (26 per cent N) and 40,000 tons of urea (46 per cent N), and now employs a total of 724 persons — 429 permanent and 101 temporary workers, 61 trainees and 133 engineers, scientists and office staff. Production commenced in the autumn of 1963, and output during the remaining months of the year amounted to nearly 8,000 metric tons of ammonium nitrate and 3,000 tons of urea, the bulk of which was consumed internally.

Exports commenced in 1964, and in the first eight months of the year 10,000 tons of ammonium nitrate and 3,000 tons of urea were exported. Future prospects, both for exports and for internal sales, appear promising. Iran has a total area of 165 million hectares, 17 million hectares of which are arable land. At present about 5 million hectares are under cultivation, of which 2.3 million hectares are irrigated and 2.7 million hectares non-irrigated. Assuming that the minimum annual amount of nitrogen required is 30 kgs. per hectare of irrigated land, internal demand could amount to at least 69,000 tons of nitrogen a year. The uniform selling prices in Iran are at present 6,500 rials ($85) per metric ton of 26 per cent N ammonium nitrate and 10,000 rials ($132) per ton for 46 per cent N urea, delivered to the customer.

The Shiraz fertilizer plant is owned by the Petrochemical Corporation, a wholly government-owned organization which was formed as a subsidary of the former Ministry of Industry and Mines (now the Ministry of Economy). According to a recently passed law, however, all government-owned petrochemical activities in the country, including the Petrochemical Corporation, are to be transferred to a specially formed subsidiary of the National Iranian Oil Company. The plant uses the catalytic desulphurization, catalytic steam reforming and Casale ammonia synthesis processes. The nitric acid plant, with a capacity of 136 tons a day (53 per cent acid) and calcium ammonium nitrate plant are based on the process of Société belge de l'Azote. The urea unit uses the Montecatini process.

The raw material used is natural gas from Gach Saran oilfield. The gas, which has a well-head sulphur content of 1.3 per cent by weight, is first desulphurized in the Gach Saran gas-treating plant, after which it is transmitted to Shiraz by pipeline. The average composition of the gas as it enters the pipeline is about 86 per cent methane, 8 per cent ethane, 4 per cent propane and 2 per cent butane plus (all in mol. per cent). Owing to the fact that natural gas is produced in excess in Iran and that over 1,000 MMSCFD has to be flared, the well-head price of the gas may be assumed to be small. The over-all transmission cost (including operating costs, amortization and a 6 per cent return on the capital investment) is around $0.12 per 1,000 cubic feet of gas delivered.

The gas pipeline has a diameter of ten inches and is designed for a working pressure of 1,000 lb/square inch at a capacity of 48 MMSCFD. At present, however, it is operated at 20 MMSCFD. When the schemes for the distribution of gas in the city of Shiraz, the increased distribution of gas to the industries of the Shiraz area and the planned expansion of the fertilizer plant are completed, the capacity of the pipeline will be fully utilized.

Plans have already been made for a considerable increase in the fertilizer plant's capacity, including an 80 per cent increase in urea capacity and the annual production of 5,000 tons of explosive grade ammonium nitrate and 5,000 tons of 92 per cent nitric acid (nitration grade). Future plans envisage the production of about 50,000 tons a year of ammonium phosphate in a multi-product plant that would also produce 50,000 tons of triple super-phosphate.

The above expansion plans are based on the internal requirements of the country. However, as mentioned previously, projects are currently under study to assess the possibility of installing larger-size ammonia and urea plants oriented towards export markets. Thus it is hoped that the countries of this part of the world may benefit at a reasonable cost from Iran's natural gas resources, which are mainly being wasted at present.

Annex

THE NATIONAL IRANIAN OIL COMPANY'S RESEARCH CENTRE

INTRODUCTION

The National Iranian Oil Company has been entrusted with the major responsibility of developing petrochemical industries in the country. There are, of course, many responsibilities which the Company needs to assume in order to fulfil all its obligations and free itself completely from dependence on other sources for scientific, technical and other services. It was considered that the establishment of a Research Centre would greatly help towards self sufficiency in such services. In fact, it was soon realized that in view of the projected petrochemical activities in Iran and the valuable indirect benefits which would be derived from the existence of such a Centre (such as the improvement of the scientific standard of the country and the provision of a good training ground for scientists and technicians), the centre was an absolute necessity. Steps were accordingly taken to establish the National Iranian Oil Company Research Centre.

In this report, the origin, purpose, structure activities and development of the Centre are briefly discussed.

Because of the present shortage of scientific manpower in the country, the development of the Research Centre has been planned both with a view to employing suitable scientists as they become available and to training others to meet its growing requirements.

The National Iranian Oil Company Research Centre realizes the important role it has to play in the development of petrochemical industries in Iran. In fact, it was in anticipation of the day when Iran would start a petrochemical industry that the nucleus of the Centre was formed. The role of the Centre is to participate in the industry itself, to help train other engineers and, above all, to provide Iran with the technical and research know-how she will need if she is to develop her industry into a progressive instrument fully adapted to her special needs.

ORIGIN

The Research Centre of the National Iranian Oil Company (NIOC) was created in 1959 in collaboration with the Institut français du pétrole (IFP). While the initial efforts were mostly directed to petrochemistry, some refining problems have also been tackled, and the Centre has developed in such a manner that it is now currently working on the two aspects of the oil transformation industry, refining and petrochemistry.

PURPOSE

In creating the NIOC Research Centre, it was anticipated that the time would come when the petroleum and petrochemical industries would require laboratories able to perform services and carry out research work related to their activities. An indirect benefit expected to be derived from such a centre was the training provided for scientists and technicians.

The purpose of the Centre is, therefore, summarized into the following duties:

1. To initiate and execute research and studies in the oil and petrochemical industries, in accordance with the objectives of the NIOC and of the country in general.
2. To give complementary training to engineers and technicians who are intended to take over responsibilities in the oil and petrochemical industries and also to young graduates who are chosen for training in research work.
3. To collect all necessary data and provide the petroleum and petrochemical industries with the information they require.

ORGANIZATIONAL STRUCTURE

The Centre is organized into several groups which together form its nucleus. These groups and the related laboratories, shown in the attached chart, deal with the following activities: petrochemistry, separation techniques, analytical techniques, petrochemical products application, petroleum products application.

At the present time the total technical staff number thirty. They consist of three categories: a group of highly experienced Iranian engineers and technicians selected from various organizations; a number of engineers and chemists who have already had experience in research work in Europe and the United States, and a number of selected young graduates of Tehran University who have been trained in the Centre for research work.

The laboratories, furnished with the greater part of the equipment and facilities needed for research in the fields of petroleum and petrochemicals, are temporarily located in one of the buildings of the Faculty of Engineering of Tehran University. The Pilot Plant and Engines Station are being set up in the Rey area — where all research laboratories and related services will be centralised in the near future.

ACTIVITIES

The activities of the Centre are planned so as to fulfil the purposes outlined above.

The various laboratories, while giving services to the NIOC, actively pursue the study of problems concerning the development of the oil and petrochemical industries.

Experienced engineers have trained many young graduates from Iranian colleges, some of whom have remained in the Centre to participate in its activities.

A library has been set up and provided with international technical and scientific books, papers and periodicals.

The work of the laboratory is as follows:

(a) *Petrochemistry studies*

The initial programme was established in order to combine the training objective with industrial or economic studies. The research projects have therefore been chosen to cover the fundamental types of chemical reactions commonly encountered in industrial processes:

Thermal reactions in gaseous phase;

Photochemical reactions in liquid phase;

Heterogeneous catalytic reactions;

Homogeneous catalytic reactions in liquid phase.

The experience acquired allowed the chemical research group, in the initial phase of its development, to undertake a new programme based on the raw materials available in Iran and the products required by the country.

(b) *Separation techniques*

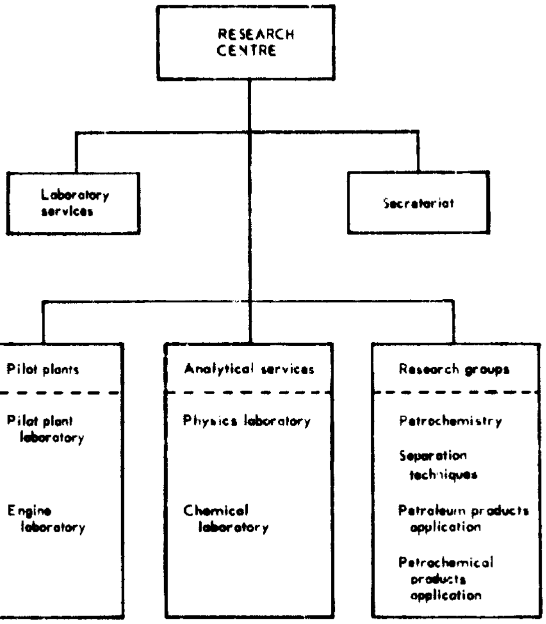
This section was to study industrial separation operations, the preparation of feedstocks, separation of products from reactants or catalysts, recycling and purification of products from undesirable substances, etc.

In a training period, some fundamental principles of the separation processes, especially equilibrium measurements, were studied. The group concerned deals with all separation problems arising in chemical research, and now works actively on the evaluation of Iranian crude oils.

(c) *Analytical techniques*

To carry out the analyses that have to be made in the course of research, a laboratory in the Centre was furnished with the equipment normally required to perform any analysis of petroleum and petrochemical products, with particular emphasis on physical methods.

THE PRESENT WORKING ORGANIZATION



A specialized personnel has been trained in the use of the following techniques:

Vapour phase chromatography;

Infra-red spectrometry;

Ultra-violet spectrophotometry;

Flame photometry;

X-ray spectrography and diffractometry;

Polorography;

Chemical microanalysis;

Standard tests on petroleum products.

(d) *Products applications*

The group working in this field tackles problems pertaining to the utilization of petroleum products — fuels, lubricants, greases, bitumens. Test engines for fuels and lubricating oils were recently added to the group's equipment.

The studies of the group were also extended to the field of petrochemicals, in which the group undertook the comparative study of petrochemical products such as insecticides, plastics and fertilizers.

In order to extend the group's research activities and its services to industrial plants, it was decided to establish a Pilot Plants Station. The following equipment was supplied:

Catalytic reforming unit;

Hydrotreating unit;

Distillation units (atmospheric pressure and vacuum);

Mixing settler.

ANTICIPATED DEVELOPMENTS

The laboratories will be installed in a new building in which it is planned to house 100 persons as permanent technical personnel. This will enable the Centre to pursue and develop its activities within the triple objective assigned to it.

In the field of petroleum and in connection with the establishment of a refinery in Tehran, the Centre will:

Control the laboratory of the refinery;

Study the utilization of petroleum products;

Conduct laboratory and pilot plant tests on refining processes;

Train personnel in these various activities.

In the field of petrochemistry, it is anticipated that the development of the Centre will fulfil the requirements of the petrochemical industry that Iran is developing. The Centre's contribution is expected to take several forms:

(1) The purely technical contribution of solving problems within the scope of the laboratory, i.e.:

(*a*) The analytical control of raw materials, chemicals, catalysts and of intermediate and final products — for which the Analytical Techniques Group will receive complementary equipment.

(*b*) The study by the Products Application Group of products utilization problems, including the testing of the base stocks for plastics, rubbers, fibres, detergents, etc., as well as the evaluation of the by-products of the manufacturing processes.

(*c*) The investigation of problems arising from the processes used in Iranian industries, the solution of which require short-range research in a small-scale plant; treatment of Iranian raw materials, improvement of products, tests for transformation of intermediates into finished products, study of by-products, etc. The Petrochemistry and Separation Techniques Groups together with the Pilot Plant laboratories are assigned to these tasks.

(*d*) Long-range researches on petrochemical processes, or on petrochemicals, which do not yet exist in Iran, by the Petrochemical Processes Group in order to provide the industry with the know-how it needs to develop such processes later on.

(2) Another aspect of the work of the Centre is the training of engineers and technicians who will be required by the industry. Such training will be provided specially for the future personnel of industrial plants and control laboratories.

In addition to the training for Iranian industries, it is planned that the Centre will be put at the disposal of the ECAFE member countries for training and services, in connection with the creation in Iran of a Regional Institute of Petroleum. This point is being taken into account in planning the expansion of the Centre.

11. THE DEVELOPMENT OF THE PETROCHEMICAL INDUSTRY IN ISRAEL

Joseph C. Löbel and Benjamin Toren, Ministry of Commerce and Industry

1. Short historical survey

Three major steps can be highlighted in the development of the petrochemical industry in Israel.

(1) The erection of the Haifa Refineries Ltd., in 1939, with a capacity of over 4.5 million tons.

(2) The establishment in 1952 of the ammonia plant by Fertilizers and Chemicals Ltd., producing ammonia and derivatives from petroleum products.

(3) The establishment in 1963 of Israel Petrochemical Enterprises, producing ethylene, polyethylene and carbon black, as well as the establishment of other petrochemical plants by other companies and the production of PVC by the Electrochemical Industries (Frutarom).

This third and most important stage of development has its organizational and economic reasons. Owing to pressures from neighbouring countries the Israeli Government was compelled to buy the refinery, which thus made further developments in the petrochemical field a matter of natural progress.

The economic aspect is explained by the extremely dynamic nature of the Israel industry as a whole. Industrial production between 1958 and 1963 rose by 14 to 15 per cent *per annum*, which is one of the highest rates of growth known over the globe in both developed and developing countries. This rapid development included the petrochemical consuming industries, such as 110 manufacturers of plastic products, 54 rubber goods manufacturers, five detergent sulfonation plants, and two tyre manufacturers exporting to more than 40 countries throughout the world.

The *per capita* consumption of plastic materials in Israel rose from 2.3 kg in 1958 to 5.5 kg in 1963, which represents an annual average rate of increase of 19 per cent. On top of this *per capita* increase, there is a high increase in population in Israel.

This rapid increase in the consumption of petrochemical raw materials makes it possible to base the development of the new petrochemicals on local markets, as well as on exports.

To indicate the size of the local market and its development, statistical data on production and imports of some major petrochemical products are outlined in table 1.

The main source of raw materials for the petrochemical industry in Israel is the petroleum industry, i.e., Haifa Refineries Ltd. (HRL).

The major part of the oil refined by HRL is imported. Up to now one region containing relatively small quantities of oil has been discovered in Israel. There are hopes, however, that additional sources will be found.

The present production of HRL supplies nearly the total local requirements of refined oil production with the exception of certain quantities of fuel oil. HRL has the following plants: atmospheric and vacuum distillation units, thermal cracking, thermal and catalytic reformers, and the required stabilizing, asphalt extracting, washing, TEL addition etc.

With a view to promoting exports of their goods and reducing imports, HRL are now erecting the following plants: a lubricating oil installation with a capacity of 1,000 bbl/day; a hydrogenation plant with a capacity of 18,000 bbl/day.

It is estimated that HRL will reach its full capacity of over 4.5 million t/yr in 1966; the present production is about 3-3.5 million t/yr for internal market and export.

The feedstocks used for the petrochemical industry are: LPG for ammonia, reformer gas, LPG and naphta for ethylene, cracker gas and residues for carbon black.

There are possibilities of producing aromatics (BTX), but no decision has yet been taken on this subject.

With regard to the natural gas source, several gas fields have been discovered west of the Dead Sea, these are relatively small compared with to Israel's fuel requirements.

In 1963, natural gas was used for burning purposes, but no petrochemical product is as yet produced from natural gas in Israel.

Israel also has considerable sources of bitumen rock which have not been exploited up to the present.

Petrochemicals, however, are also strongly linked with the chemical industry since some chemicals are used as raw materials for the production of petrochemicals, such as chlorine, bromine and others.

Israel has a favourable position regarding the availability of raw materials for the production of the three elements used for fertilizers: N-P-K, all located next to each other in the southern development region of the country (the Negev). Nitrogen (N) may in the future be produced from natural gas or fuel.

Phosphate Rock (P) is mined in Israel with a content of 22 per cent P_2O_5 and will be upgraded by the calcination process to over 35 per cent P_2O_5 (now under construction). Another field with up to 28 per cent P_2O_5 will be exploited soon. The phosphate rock production rose to 240,000 tons in 1962, and the processed fertilizers reached 175,000 tons.

TABLE 1

DEVELOPMENT IN IMPORTANT PETROCHEMICAL PRODUCTS CONSUMPTION, 1959-1963

	1959	*1960*	*1961*	*1962*	*1963*	*Source of supply*
Intermediates						
Ammonia	19,000	23,400	25,800	26,100	26,600	Local product
Formaldehyde	—	—	2,400	3,000	3,500	Local product
Methanol	—	—	1,700	2,300	2,700	Import
Phenol	1,300	1,450	1,600	2,800	2,600	Import
DDB	2,000	2,400	2,800	3,100	3,300	Import
Nitrogenous fertilizers						
Ammonium sulphate	64,700	73,900	68,300	66,500	69,300	Local product
Ammonium nitrate and calcium nitrate	—	—	—	6,500	16,700	Local product
Plastic materials						
a. *Thermoplastics*						
Polyethylene all kinds	820	1,130	1,700	3,300	3,500	Import
Polystyrene all kinds	890	1,140	1,400	1,690	2,450	Import
PVC	1,330	1,710	2,060	2,800	3,500	Import
Others	410	320	370	410	650	Import
b. *Thermosettings*						
Melamine formaldehyde	130	130	180	190	240	Import
Urea formaldehyde	220	260	300	220	280	Import
Phenol formaldehyde	350	380	410	440	550	Local product
Polyester	50	70	400	450	600	Local product
Phenol formaldehyde and urea formaldehyde	400	700	1,000	1,200	1,400	Local product
Synthetic glues	2,250	2,500	2,700	3,500	3,700	Local product
Synthetic fibres	520	500	760	590	700	Import [a]
Polyamides		200	800	1,200	1,300	Local product
Synthetic rubbers	1,090	1,960	4,140	4,620	4,000	Import
Carbon black	2,150	2,850	2,400	3,200	3,100	Import

DEVELOPMENT OF PETROCHEMICAL PRODUCTS CONSUMING INDUSTRIES, 1959-1963 (tons)

	1959	*1960*	*1961*	*1962*	*1963*
Synthetic detergents					
Liquid	9,600	9,500	10,100	10,800	11,300
Powder	5,300	6,100	7,000	7,700	8,300
Solid	800	1,000	2,300	2,100	2,500
Tyres and tubes	8,800	10,800	11,800	13,000	13,000
Plywood (m^3)	35,200	40,100	46,600	54,300	59,800

EXPORT OF PETROCHEMICAL PRODUCTS, 1959-1963 (tons)

	1959	*1960*	*1961*	*1962*	*1963*
Plastic materials					
Phenol formaldehyde	—	—	—	400	200
PVC	—	400	500	550	600
Polyesters	—	60	160	295	60
Liquid ammonia	—	1,000	3,700	4,200	4,000

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[a] Including imports of polyamides.

Potash (K) and other compounds from the Dead Sea

The Dead Sea constitutes a tremendous reservoir of mineral resources. The mineral concentration of the Dead Sea is about 30 per cent, approximately seven times that of the Mediterranean.

Its brine is a concentrated solution of the chlorides and bromides of magnesium, sodium, calcium and potassium. (The estimated mineral reserves are as follows: magnesium chloride 22,000 million tons; sodium chloride 12,000 million tons; calcium chloride 6,000 million tons; potassium chloride 2,000 million tons; magnesium bromide 1,000 million tons.)

Although the Dead Sea Works have succeeded in exploiting the Dead Sea as a source of chemicals, thus setting up an industrial centre there, the mineral wealth of the Dead Sea has, as up to the present, only been lightly tapped.

Potash production reached 140,000 tons in 1962. There are also important quantities of gypsum, dolomite, limestone, flint clay, quartz, etc., which may be put to use in the future.

2. Economic factors

Although Israel is at the present a country of only 2.5 million inhabitants, the development of the processing and manufacturing petrochemical industries is in full swing and it is expected that these industries will continue to develop owing to increased demand and available resources.

Local market consumption has to be regarded as a very important factor in the petrochemical industry because exports are hampered by discriminatory pricing on international markets. This means that exports can be based mainly on a growing local market.

The dynamic development of the local market makes this problem easier from year to year as local demand is coming near to the minimum economical petrochemical size. A very interesting solution to promote the petrochemical industries in adjacent developing countries may be in the form of reciprocal co-operation, or bilateral (or multilateral) planning agreements. This means the erection of a large plant producing petrochemical products in the most suitable country and fulfilling requirements for other countries on condition that the importing country receives reliable export outlets for its own petrochemical products in exchange.

In spite of a high standard of research, lack of technological know-how has hampered the development of the industry; furthermore foreign know-how for new processes is not always freely available.

Owing to the high risk associated with the establishment of petrochemical plants, especially in the early stages, in Israel, private investors did not initiate the development of the industry as rapidly as would have been justified economically. The Israel Government was obliged to close this gap by national initiative, but this public ownership has not become a policy, but rather fulfils a temporary need until private initiative catches up through its own dynamic development.

The financial help offered in this field by the United States Export-Import Bank eased the problem of capital. However, it is felt that future development should be based mainly on private capital.

A substantial import surplus makes it imperative that every industry, including the petrochemical industry, be oriented towards a rapid improvement of the balance of payments. Therefore any project is evaluated in accordance with its net contribution to import savings or to exports. This, however, is not the only factor in an investment decision, as the local cost per net dollar earned should be reasonable.

3. Institutional measures

The petrochemical industry in Israel is in its first stages. This initial low level of development and the discriminatory price policy of the stronger producers abroad make it necessary for the Government to give the petrochemical industry in Israel some protection by import tariffs. This need is strengthened by the fact that Israel does not have an anti-dumping law.

Import restrictions are in force for a short period of time, while a policy of decreasing protection and liberalization of imports is enacted for the industry as a whole. This policy is oriented towards better quality and higher productivity.

Promotion of exports is achieved by indirect measures, such as export guarantees, marketing surveys or short term export credits at reasonable cost. The promotion of foreign investments in the Israel industry is achieved by the following means:

(*a*) The Industrial Development Bank of Israel extends long-term credit to new investments at a reasonable rate of interest.

(*b*) Investments which are considered conducive to the development of the economy receive for a certain period of time income-tax reductions and are permitted to charge accelerated rates of depreciation.

(*c*) The Government Investment Authority tries to interest foreign investors in industrial development projects mainly when capital is imported together with industrial know-how, management skills and market channels.

4. Supporting activities

A. SPECIALIZED RESEARCH INSTITUTES

One of the most important features of the petrochemical industry is the continuous introduction of new products and the rapidly changing production processes which are achieved through research.

Regarding the research, Israel is in a highly favourable situation thanks to:

(1) The standard of research, which is on a high level owing to the presence of highly qualified chemists and other scientists.

(2) The wide potential of research, which has, as yet, been only lightly exploited.

(3) The lower cost of research as compared with the United States and Western Europe.

There is no specific scientific institute carrying out research in the petrochemical field, although some scientific institutes are engaged in research in related fields. We mention below the main institutes carrying out basic and applied research in Israel.

(*a*) The Authority of Research and Development of the Hebrew University, Jerusalem, is a representative organism of different faculties of the Hebrew University entrusted with initiating and co-ordinating all major research projects. Within this institution, the Authority carries out negotiations and is responsible for contracts with the Government and private and foreign agencies, it concerns itself with patent rights, and obtains necessary equipment for research and facilities as well as introducing new research areas. Some of the applied research carried out at present at the Hebrew University in connexion with petrochemicals is: ethylene polymerization (Ziegler catalyst), anionic polymerization of vinyl monomers, graft polymers, doped catalyst etc.

(*b*) The Weizman Institute of Science, Rehovot, is engaged chiefly in fundamental research in chemistry, physics, biology and mathematics. Of particular interest is the development of practical processes for separation of oxygen — 17 and 18 isotopes.

(*c*) The "Yeda" Research and Development Co. Ltd., which is founded on the scientific potential of the Weizman Institute of Science, aims at promoting principally applied research for industry and other technical fields. The main projects in the petrochemical field are: base catalysed reactions of unsaturated hydrocarbons, alpha, beta unsaturated esters and nitriles; separation of optical isomers; cyclobutene derivatives; telomerization of ethylene with carbon tetrachloride, adduct — formation of olefins and vinyl monomers with halomethanes, preparation of copolymers of styrene, etc.

(*d*) The Technion Research and Development Foundation Ltd., Haifa, carries out scientific and technical research in chemistry and other fields. The main projects in the petrochemical field of this institute are: The use of hydrochloric acid for chlorination of ethylene, esters of sebacic acid and phthalic acid: the production of chemical intermediates, phenol and cresols and polyamides and polyesters; the reactions of amides an dcarbonates with polyfunctional carbonyl compounds, addition of activated acids (anhydrides) to carbon nitrogen double bonds; problems of aromaticity through organometallic chemistry, etc.

(*e*) Israel Mining Industries Ltd, deals with applied research, mainly in the field of mineral extraction and basic chemistry and has started research in the petrochemical field, regarding the use of carbon black from off-gases, chlorination of polyethylene, use of carbon monoxide and air.

(*f*) Bar-Ilan University, Ramat Gan, has some departments carrying out research related to the petrochemical field such as on organic products from bitumen.

It must be emphasized that between the stage of laboratory research and the stage of industrial application there are two phases: the pilot plant phase and the so-called "processing" phase which require considerable projecting and designing effort and significant financial means.

These three factors: laboratory research, pilot plant and design have to be co-ordinated in order to fit into a plan for the development of the petrochemical industry.

The annual budget for research reached I£36 million in 1961 and I£75 million in 1963, of which 10 per cent and 20 per cent, respectively, was ordered by other countries (especially the United States of America).

B. Engineering organizations

Many companies have their own engineering organizations which include teams of technical staff, design engineers and draughtsmen. These teams have gained wide experience and know-how in planning the construction and running-in of enlarged existing installations or erecting new technological plants and installations, on the basis of plans of foreign consultants and under their supervision.

This guidance and experience will now enable local engineers to plan and carry out further development works and new plants independently, for local and foreign companies.

Three examples for Israel know-how available abroad are mentioned here:

(*a*) The construction of a lubricating oil plant of 1,000 bbl/day at a very low investment cost was based on local and foreign design and engineering, which might be supplied to other countries.

(*b*) The know-how to build plants for manufacturing phosphoric acid by a solvent process using hydrochloric acid as the acidulating agent.

(*c*) A chemical company has developed its own process for making dicalcium phosphate.

In Israel there are also a number of engineering consulting companies in the industrial, process and civil engineering fields which are capable of erecting preliminary projects based on internal or foreign know-how and also all stages of planning up to execution details. This technique of evaluating, planning and supervising industrial projects for developing countries now forms an increasing export item, because engineering costs in Israel are low and because experience has been gained which is applicable to developing countries.

No central institute for design to promote Israel and foreign know-how and engineering for home and abroad has as yet been established, although Israel is in a highly favourable situation as regards the availability of design engineers with experience from a very large number of countries.

C. Equipment production facilities

A large amount of conventional equipment of the chemical and petrochemical industries is being manufactured in Israel at competitive price and quality.

This includes ordinary reactors, filter presses, stills, rotating furnaces, dryers, handling equipment and boilers produced from cast iron, steel, stainless steel, copper and aluminum.

This equipment industry is also developing very rapidly, as an increase of six times the 1962 level is planned for 1970.

5. Projected development

In this industry, perhaps more than in any other, rapid development may be regarded as a precondition for survival. This is explained in the first place by the very rapid introduction of new products. Further, the decrease in costs and prices of existing products after expiration of patents and/or the growth in size of new plants or new technology, make it possible to stay in this business only on a rapidly growing local and foreign market and an improving know-how at all stages.

The planned development of the petrochemical industry in Israel tries to answers this need. The following table indicates the dynamic nature of local demand, which serves as a basis for the introduction of new products.

THE RATE OF DEVELOPMENT IN DEMAND OF MAJOR PETROCHEMICAL PRODUCTS

Estimated annual rate of increase, 1964-1970

Plastic materials	*Percentage*
Thermoplastics	15-20
Thermosettings	5-10
Synthetic glues	20-25
Synthetic fibres	15-20
Synthetic rubbers	15
Carbon black	15
Synthetic detergents	5-10

The development envisaged lies in three main directions:

(*a*) Development and consolidation of existing products;

(*b*) Development of new products;

(*c*) Creation of a scientific and technological basis for further development in the future.

Some of the preliminary thoughts on new products for the local industry include the following: (1) aromatics (possibly benzene, toluene, xylene, cyclohexane); (2) ethanol; (3) methanol; (4) Polyethylene low pressure, perhaps in combination with polypropylene; (5) styrene; (6) polystyrene; (7) phenol; (8) caprolactam; (9) DDB; (10) DOP.

The Programme for Israel's Industrial Development, 1965-1970, projects a gross output for the petrochemical industry for 1970 of I£63.5 million ($21 million), of which $4 million will be exported. The industry is expected to employ 420 people and invest about I£100 million ($35 million) of which about half has already been invested.

6. Description of petrochemical plants

(*a*) BASIC INTERMEDIATES

Israel Petrochemical Enterprises Ltd.

There is only one such enterprise, which produces the three main products: ethylene, polyethylene, and carbon black. The capital invested in construction equipment, etc. for producing these three products is 13.2 million dollars. The enterprise is based on foreign know-how and employs 190 workers,[1] consisting of 140 skilled, 25 technical and 20 engineers. The enterprise is 75 per cent publicly owned and 25 per cent privately owned.

(1) *Ethylene*

There is at present one plant for the production of ethylene in Israel Petrochemical Enterprises Ltd. This installation has a production capacity of 12,000-15,000 tons. The consumption of ethylene is mainly for the production of polyethylene, PVC and for ethylene dibromide.

Local raw materials required for the production of ethylene (mainly refinery gas and LPG) is in sufficient supply.

There is a plan to expand capacity to approximately 24,000 tons *per annum*, at a capital cost of $1.5 million. The additional quantity of ethylene will be used mainly for the production of polyethylene.

(2) *Polyethylene*

The installation has an annual capacity of 6,500 tons of high-pressure polyethylene. Consumption of high-pressure polyethylene was approximately 3,400 tons in 1963. This is a considerable increase. The consumption estimated for 1964 is 4,500 tons and for 1966/67 6,300 tons.

It is expected that the enterprise will export each year about 1,500 tons polyethylene. The capital invested by the enterprise amounts to 5.6 million dollars, 45 per cent of which is in local and 55 per cent in foreign currency. The raw material for the production of polyethylene is ethylene.

It is planned to expand the capacity of the polyethylene installation up to 17,000 tons *per annum*, with the investment of approximately $2.5 million. The surplus beyond local requirements will be exported.

(3) *Carbon black*

The enterprise produces carbon black using as raw materials residues from the HRL. The product is used mainly in the tyre and rubber industries. The planned plant capacity is 9,000 tons, *viz.*, 5,000 tons for local consumption and 4,000 tons for export *per annum*.

(*b*) NITROGENOUS FERTILIZERS

Chemicals and Phosphates Ltd.

There is one plant for the production of these products. That enterprise produces the following products: ammonium nitrate, calcium nitrate, ammonium sulfate, ammonium nitrate solution.

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[1] All employment figures include direct labour only. The difference between the figures given for total direct employment, and the sum for the specific professional grades is the amount unskilled labour of employed.

The capacity in 1963 was as follows: 17,000 tons ammonium nitrate and calcium nitrate, 70,000 tons ammonium sulfate and 4,000 tons ammonium nitrate solution.

Local consumption of these products was: ammonium nitrate, calcium nitrate — 12,500 t/yr; ammonium sulfate — 67,500 t/yr; ammonium nitrate solution — 4,000 t/yr.

The present export is: approximately 2,500 tons of ammonium nitrate and calcium nitrate and approximately 2,500 tons of ammonium sulfate.

In the production of these products the enterprise employs approximately 100 workers, of which 50 are skilled, 14 technical, and 6 engineers and scientists.

The enterprise is 10 per cent privately owned and 90 per cent publicly owned. The required raw materials are oil fractions to come from the HRL.

A production of 15,000 tons of diammonium phosphate in Arad is being planned at present. In the more distant future it is planned to expand the output of diammonium phosphate in Arad to 100,000 tons and that of nitrophosphate to 125,000 tons. The production of potassium nitrate is being planned at 100,000 tons *per annum*.

(*c*) PLASTIC MATERIALS—THERMOPLASTICS

Electrochemical Industries (Frutarom)

1. *PVC*

There is one privately owned enterprise in this branch, with a capacity of 8,000 tons, put into operation in 1963. The local market requirement was approximately 3,800 tons in 1963. Thus a part of the output is exported. The installation employs 25 workers, of which 10 are skilled, 5 technical, 4 engineers and 4 scientists.

The know-how for the emulsion polymerization method was acquired abroad, but the suspension polymerization method was developed in the enterprise itself. Raw materials are ethylene, chlorine, etc. There is a plan for the expansion of capacity to 12,000 tons *per annum*.

2. *Polyethylene*

(See above, Israel Petrochemical Enterprises Ltd., under basic intermediates)

(*d*) PLASTIC MATERIALS—THERMOSETTING

(1) *Polyester resins*

There are two enterprises producing these products: Machteshim Ltd'., which is publicly owned and Resins and Polyesters Ltd., which is privately owned. The capacity of the enterprises is 2,600 tons. The know-how in the enterprises is foreign and local. The main raw materials are phthalic anhydride, fumaric acid, styrene etc.

There is no plan at present for the expansion of production of polyester. The enterprises employ 24 workers, of which 7 are skilled, 9 unskilled, 5 technical and 3 engineers and scientists.

(2) *Phenol formaldehyde*

Serafon

There is one privately owned enterprise producing phenol formaldehyde at present. The enterprise produces moulding powder and phenol formaldehyde on foreign know-how. The capacity is approximately 1,500 tons. In 1963 production was 650 tons. Local consumption was 450 tons and 200 tons exported. The installation employs approximately 15 workers, of which 4 are skilled, 7 unskilled, 3 technical, and one an engineer.

Raw materials are phenol, imported from abroad and formaldehyde produced in Israel. There are no plans at present for additional expansion of capacity.

(*e*) SYNTHETIC FIBRES

(1) *Nylon*

Consumption of synthetic fibres has increased about seven and half times in five years (from 230 tons in 1958 to 1,790 tons in 1963). There is at present one privately owned enterprise for the production of nylon. The enterprise produces nylon 6 yarn. The capacity is 1,200 tons. In 1963, production was 1,000 tons. Local consumption was 900 tons and export 100 tons.

The installation employs approximately 20 workers, of which 5 are skilled and 2 are scientists and engineers. The raw materials from which nylon yarn is produced is caprolactam, which at present is imported. There is no plan for expansion of output at present.

(2) *Acrilan*

Acrilan belongs to the group of the acrylonitrile polymers. There is the possibility of specific substitutions of the various types of fibres, but not all synthetic fibres have the same qualities. These different fibres are suited to specific uses.

An enterprise was recently established for the production of acrylonitrile which has a capacity of 1,000 tons per annum, and began production 1964. The enterprise, based on foreign know-how, plans to export 80 per cent of its output. Invested capital will amount to $3 million. It is 60 per cent privately owned and 40 per cent publicly owned. The production is based on the raw material — acrylonitrile.

Expansion of the capacity to 2,500 tons *per annum* is being planned.

(*f*) CARBON BLACK

(See above, Israel Petrochemical Enterprises Ltd., under basic intermediates)

(*g*) SULPHUR

Sulphur is expected to be produced in the HRL in the near future. According to preliminary estimates, capacity will be 10,000 tons as compared with a local consumption of 50,000 tons *per annum*. There is no plan for additional expansion of capacity at present.

(*h*) DETERGENTS

There are 5 plants producing detergents: Zohar, Shemen, Neka, Kadima, Tassbin. Total production in 1963 amounted to 23,000 tons, of which 700 tons were exported. The present raw material is DDB. For the future at least some of the raw materials will be soft biodegradable detergents, to avoid the pollution of sewage water.

12. THE DEVELOPMENT OF JAPAN'S PETROCHEMICAL INDUSTRY

Hideo Adochi and Histoshi Yonaga, Japan

It was in 1950 that Japan's chemical industry began to pay increasing attention to petrochemical industry, and it was after 1954/55 that its petrochemical schemes were realized.

As the country's chemical statistics show, Japan is one of the world's biggest producers of calcium carbide. As a result, acetylene industry based on calcium carbide had been considerably developed. Therefore, during the period when foreign countries were busy with petrochemical construction, the acetylene-based industries still occupied a firm and strong position in Japan. After that, however, Japan was forced to shift to petrochemical production owing to external and internal circumstances, such as the fact that overseas petrochemical industries were producing low cost products, including products which could not be made by Japan's existing industries; internally the carbide price had increased because of a rise in the cost of power and consequently acetylene-based products no longer had a price advantage over overseas petrochemicals.

In 1955, the Japanese Government mapped out its concrete programme to aid and foster the nation's petrochemical industry. The construction of petrochemical plants to produce basic products was started and proceeded progressively during the period from 1957 to 1960, which is generally called the first-stage plan.

The production structure of the major products related to the field of petrochemicals was as follows, as at 1955:

	Calcium carbide (per cent)	*Fermentation (per cent)*	*Coal, coke (per cent)*	*Fats and oils (per cent)*	*Gas and petroleum (per cent)*
Acetic acid	100				—
Acetone	3	97			—
Butanol	10	90			—
Octanol	95			5	—
PVC	100				—
Benzene			100		—
Toluene			100		—
Methanol			80		20
Ammonia			82		18
Soap				100	—
Synthetic detergents					—

Almost all products were made by processes based on imported molasses (fermentation), coal and coal tar, animal and vegetable fats and oils. Therefore, such petrochemical products, especially ethylene and propylene derivatives, which could not be made by these processes or, if they could, would have involved high costs of production, had to be imported in spite of the increased demand. The annual import value totalled around 19 million dollars in 1957, and 26,000 tons in quantity.

At first four naphtha-cracking centres were constructed, and surrounding those centres a complexity was built by fifteen private companies as well as one synthetic rubber plant owned half by the Government and half by private concerns. A total investment of 230 million dollars was made in these projects, out of which foreign currency expenditure was estimated at about 57.5 million dollars. An ethylene plant and an aromatic plant, with capacities of about 90,000 tons/year and 56,000 tons/year, respectively, were completed, and the total production of the plants reached 190,000 tons annually, making it possible to cut the approximate annual import worth 12 million dollars in 1960.

The production of these products not only met the increasing domestic demand but also stimulated the producers to shift to petrochemical processes. The following table shows how the demand progressed from 1958, when petrochemical production was started, till 1963.

This table shows how petrochemical production grew rapidly from 1958 to 1963, and conventional products based on other raw materials were fast replaced by those based on petroleum.

After two years of favourable operation since the beginning of petrochemical production, though full production was not yet reached, the market prices of

	Demand increase from 1958 to 1963	*Production ratio based on petrochemical process (per cent)*	
	(1958 = 100)	*1958*	*1963*
Acetylene	552	—	6
Ethylene	2,430	—	100
Polyethylene	2,180	—	100
Styrene		—	100
Acetic acid	274	—	10
Acetone	400	39	81
Butanol	293	21	65
Octanol	418	—	59
Methanol	301	55	100
Ammonia.	153	32	74
Synthetic rubber . . .		—	100
PVC	381	0	0
Benzene	396	8	33
Toluene	622	42	72
Soap	65	—	48
Synthetic detergents . .	845		

products based on conventional processes decreased by 42 per cent on an average. This fact shows that the petrochemical process is more advantageous than conventional processes, which can hardly compete with it. For comparison's sake, the price decrease in the over-all manufacturing industry was 2 per cent on an average, and 13 per cent in the whole chemical industry, during the same period. As can be seen from the results, the initial stage of petrochemical development was a great success.

Reverting to the progress in the petrochemical industry, if 1958 is the year when the first petrochemical plan went on stream, the succeeding years, during which expansion of existing plants and completion of the complexes with ethylene units as a nucleus were accomplished, can be called the second stage of development. The prices of petrochemical products have continued to decrease steadily year by year since the beginning of the operation, which has gradually made the industry approach the international competitive level.

Since the establishment of the petrochemical industry, full equipment facilities have been provided and production has increased supported by the strong domestic demand. In 1963 the production value recorded 510 million dollars, a 45 per cent increase on the previous year. The petrochemical industry accounted for 14.8 per cent of the value of the whole chemical production (if petrochemical production includes, in a broad sense, natural gas-based or coke oven gas-based products, the percentage becomes 20 per cent) in the same year.

Of the major petrochemical products, polyethylene showed a remarkable increase, with 140,000 tons in 1962 and 220,000 tons in 1963. And polystyrene, polypropylene and synthetic fibres were increased rapidly beyond expectation from 40,000 tons to 80,000 tons, 0 to 20,000 tons and 70,000 to 100,000 tons respectively.

Regarding export and import, dependence on imports has lessened remarkably with the progress of petrochemical production. As a result, the first purpose, that of preventing imports, has been attained steadily from year to year. How much foreign currency has been saved? It is calculated that from 1957 to 1963 the estimated annual production value reached 1,340 million dollars. If foreign technology fees and imported petroleum value are subtracted from this, the balance is 1,060 million dollars. This is the estimated value saved. It is noteworthy that imports which increased gradually from 1957 reached a peak in 1961, but began to decline in 1962 and in 1963 reached 70 million dollars, that is an 8 per cent decrease from the previous year. Petrochemical products are now imported only where production capacity is inadequate. However, production is being expanded, so in the near future Japan will be completely independent of imports.

Meanwhile, major exported products are polyethylene, polystyrene and synthetic rubber. Although their exported value increased from 7 million dollars in 1962 to 13 million dollars in 1963, it accounts only for 3 per cent of the total petrochemical production. However, petrochemical products are naturally raw materials or intermediate products for other industrial products, so, taking into account the export of processed products, such as synthetic resins or synthetic fibres or other finished goods, it can be said that the petrochemical industry makes a considerable indirect contribution to exports.

The demand for petrochemical products is expected to increase heavily in the future. To meet such an increase, the capacity of the petrochemical industry will be constantly expanded and will continue to develop. For example, the actual demand of ethylene, the nuclear product of the petrochemical industry, was 260,000 tons in 1962 and 340,000 tons in 1963, but it will expand to 630,000 tons in 1964 and reach 1.2 million tons by 1967, at an average growth rate of 34 per cent. These figures are caculated in terms of ethylene consumption, based on the estimated increase in demand for its derivatives which is expected to grow rapidly. For instance, during the corresponding period, petrochemical products will account for 25 per cent of the total chemical production, and if the production from natural gas is taken into consideration it will account for 40 to 50 per cent. From this estimate, it can be said that the petrochemical industry has a very bright future.

The ethylene capacity required by 1967 will be about 1.4 million tons if the appropriate operation is rated at 85 per cent, but the actual ethylene capacity including plants under construction, is 900,000 tons currently, so capacity will be 500,000 tons short by 1967. This capacity shortage could, however, be met to a considerable extent by the expansion of existing units, but there are some units whose expansion will reach a limit by the fiscal year 1964-1965 on account of the size of their complexes. Therefore, the establishment of new naphtha centres in new areas is under consideration.

Actually, however, there are more serious problems. Japan had been shut out from the world situation by her closed economy until 1962, when trade was liberalized drastically. After this she was confronted with the world-wide tariff cut, and at the same time suffered from so-called block economies, such as the European Economic Community and others. Finally, she has recognized that it will hardly be possible to survive without exports, and that the most important thing is to promote industry so that it becomes powerful enough to compete in the international market.

Although Japan's petrochemical industry has made rapid progress by the introduction of foreign technology, and thus helps to strengthen the whole chemical industry, the prices of the products are still higher than those of highly developed nations. In order to solve this problem, though this is not peculiar to Japan, it is important to:

Increase plant capacity, which is relatively smaller than that of foreign countries;

Bring the operation to full scale by creating or stimulating demand;

Make effective and collective utilization of inevitable by- or co-products.

As a concrete measure, Japan is considering establishing a highly integrated production system like a complex, as we call it, with olefin manufacture as the core, so that many chemical plants can benefit from the products manufactured there. This is the only way that olefin manufacture can be increased, and that the development of technology, effective investment and complete use of co-products can be facilitated.

Currently, Japan has five established naphtha centres and four additional centres are nearing completion. The expansion of these centres, as well as their co-ordination with a further four which are being planned, will be an important problem, and Japan's chemical industry must solve it for the healthy growth of the industry.

Meanwhile, apart from the construction of the new naphtha centres, the effective utilization of by-products at the established centres, in an effort to integrate their production, is going well. And the products which were only made by petrochemical processes are also being produced commercially one after another through technological collaboration with foreign companies. Newer processes are also being adopted for production direct from the primary petrochemical products. Besides the new or increased production of processed products, such as ethylene, propylene and butylene derivatives, production of synthetic rubbers and newer elastomers has also started in addition to production of polyacrylonitrile, polyester, polyurethane plastics and synthetic fibre materials. Therefore almost all the products produced overseas are being manufactured in Japan.

However, the petrochemical problem may not have been solved simply with the progress in industrialization; there is still room for doubt whether the ventures are economically competitive from an international point of view. The progress of foreign technical development is very rapid, and, moreover, there are still products which Japan does not manufacture, e.g. ethanol, glycerine, allyl compounds, isoprene rubber, EPR. In spite of the fact that the production of these products would contribute much to the utilization of co-products, they are not manufactured because of the situation in the domestic market, and also for lack of technology.

The foregoing sets forth various problems that lie in the current development of Japan's petrochemical industry. The petrochemical process is far more advantageous than other processes based on conventional raw materials, and petrochemical development will contribute greatly to the over-all development of the chemical industry. Especially, plastics, synthetic rubbers and elastomers, synthetic fibres which are substitutes for natural fibres and other manufactured products will play an important role in the future. However, it is by no means easy to discover how to construct and develop the ventures. It is needless to say that it involves substantial investment and advanced technology. It will require extraordinary efforts if Japan is to try to introduce fair competition among countries, taking into consideration various factors such as the size of their domestic market, and the extent of their market development, their export potentiality, the size of the overseas export market, and their international competitive power. And it will require great efforts, too, to carry out smooth conversion and to construct or strengthen the domestic industries. It must be confessed that Japan's petrochemical industry is still lagging behind the world's biggest industries in technical experience, capital power (a complex based on an ethylene plant of 100,000 tons/year needs a total investment of around 150 million dollars), size of the domestic market purchasing power (standard of living) and industrial competitive power. The attainment of experience in technology cannot be accomplished in a day. Taking to account that even one product takes as long as twenty to thirty years from its laboratory research until it is commercially developed, the most important task for the future is the intensification of basic research and the concentration of efforts in technological development.

13. THE POSSIBILITIES FOR DEVELOPING PETROCHEMICALS IN LIBYA

B. Manguch, Ministry of Petroleum Affairs, Libya

1. INTRODUCTION

It can be safely stated that no petrochemical industry exists in Libya. The prospects for such an industry to flourish were non-existent prior to the discovery of petroleum in commercial quantities in 1959.

On the eve of independence, at the end of 1951, Libya's economic and social problems were numerous and they appeared, to some observers, to be insurmountable. As a result of war damages and the ex-colonial era, there were deficits in almost all sectors of the economy. Those deficits were then subsidized by foreign loans, in order to make it possible for the State to run its machinery and to undertake some developments.

Libya has a large geographical size but a relatively low population density (1.75 million square km with only 1.5 million inhabitants). This is a sparsely populated country because a vast expanse of its land is arid desert unfavourable to living conditions. Most of the inhabitants, therefore, are concentrated around the coastal strip where they lead a mixed nomadic and agricultural life. This economy has various characteristics, foremost among them, are low *per capita* income, low productivity and primitive work techniques.

In those hard circumstances, the Libyan Government studied the possibility of initiating a wide search for mineral deposits in order to assess the potentiality of the country. This led to the drafting of petroleum legislation and its enactment in mid-July 1955. The liberal clauses of the Law brought about an intensified search by more than twenty-two oil companies, and this, therefore, heralded successive hydrocarbon discoveries, which made Libya, in less than four years of exploratory drilling, one of the major oil producers, with an export figure reaching a million barrels of oil per day.

Oil revenues have served as a propelling stimulant to the whole economy and have injected into it a new stream of life and vitality. This has enabled the State to overcome the lingering deficits of the past ten years, and to launch a new five-year development plan with 70 per cent of the oil income being allocated to the plan. This plan is motivated by the intention of creating a diversified economy with a strong and stable base. The present emphasis in the plan is on agricultural development and agriculture-based industries, since Government officials believe that agriculture is the nucleus for any economic development in the country.

This development programme is, essentially, a tentative one, because more experience has to be acquired in the course of its execution. The effectiveness and maturity of this plan will be determined in a variety of ways: its adaptability to local needs, its over-all impact on the economy and the short and long aims realized.

2. FACTORS RETARDING THE GROWTH OF A PETROCHEMICAL INDUSTRY

The big obstacle, here, is the limited market demand because of the small and scattered population. It is clear that a sizable local market is necessary before the manufacture of chemicals from petroleum can be justified economically. Although *per capita* consumption of a variety of commodities is increasing, possible future trends and tendencies cannot be predicted with any accuracy. The primary market for petrochemicals lies in the consuming industries: plastic processing plants, rubber plants, paint and detergent manufacture.

The problem of small market size has been tackled in a number of ways with an appreciable amount of success. One technological approach is the integration of several processes into a single petrochemical complex where the units are small and compact with minimum piping and ancillary equipment, so that the cost of construction is kept low. These units possess some manual controls with a less-centralized control system and employ more personnel than is normally required for a completely integrated system. The other, more realistic, approach is the creation of joint ventures, either between some government agency and a private company with access to foreign markets and know-how, or run by a private company with at least 50 per cent participation by the national investors. The establishment of joint enterprises is now universally adopted in order to secure a particular process technology from a company which has no market outlets or the necessary capital for the venture.

It is becoming much harder to break into the already highly competitive market so, in order to embark on an export scheme of any nature, one must bear in mind the fluid state of the venture and the risks that beset it. Market research must, therefore, be intensified in the developing countries in order to co-ordinate a petrochemical policy which is adaptable to the shift in the international scene.

The other obstacle to any export scheme, in the developing countries, is the high f.o.b. price of the would-be exported products, which makes them less competitive. This is, in fact, a direct result of construction and wage costs, which are high, and because of the low rate of productivity.

The next problem is the shortage of technicians and plant personnel who can operate and supervise various production stages in any petrochemical plant.

This is essentially a chronic problem in most developing countries and much more has to be done to alleviate it.

The complexity of the present-day petrochemical plant is evident in the use of electronic gadgets and various other plant innovations which are opening new dimensions requiring specialized scientific skills to meet the fast technological developments. A crash training programme for a period of two to three years must be introduced with particular emphasis on topics that are related to process technology and plant design. This might prove to be a successful measure in overcoming personnel shortages and, in turn, will help towards the growth of petrochemicals. The United Nations and other international bodies have a major role to fulfil in devising training programmes in the field of petrochemicals to meet the technological needs of the developing countries of Africa and Asia.

3 STIMULI FOR THE GROWTH OF PETROCHEMICALS

The Libyan tariff policy is a flexible one, special protective measures may be reverted to in order to boost the sales of a locally manufactured product against any outside competitor. The customs duty on imported raw material is of the order of 2 per cent, while the duty on manufactured goods is about 20 per cent. Some newly established plants are exempted from taxes and some others pay low tariffs for a period of two to three years.

The Ministry of Industry is also subsidizing loans to private industrial ventures and establishing training facilities in many towns and villages. Over L£ 7 million is allocated to the industrial sector in the Five-Year Plan. This sum will be used to subsidize industrial projects and, in particular, the new research centre for industrial purposes. The functions of this centre will be numerous; they will include, among others, developing new processes, evaluation of products on the market, and determining the technical feasibility of using a particular process on a large scale. The financial commitment to the industrial sector, in the Plan, is neither specific nor sufficient, in the sense that no specific capital outlays are being allocated to specific industrial development ventures. The second stage of the development programme should be specific in its commitment of various allocations, in particular to the industrial sector.

There are two industrial State-run training schools, and more are being established. Various skills and crafts are taught, such as welding, engineering drawing and mechanics. These technical schools should co-operate more closely with various industrial enterprises in order to formulate a joint syllabus that will satisfy both the requirements of the industry and the educational authorities. For instance, the addition of new and selected topics in chemistry and chemical engineering is becoming a necessity to cope with the increasing demand for such requirements in the process technology field in particular, and in the petrochemical industry as a whole.

The other important factor in this context is the impact of the petroleum development in general. The wide and complex nature of this development is being felt everywhere and is especially evident in the multitude of techniques employed in all stages of the industry. These techniques are no less sophisticated than those practised by the other petrochemical industries.

The Libyan labour force employed in the oil business amounts to approximately 13,000, with more than 3,000 engaged in skilled and semi-skilled jobs, and others are trained for new skilled jobs either inside or outside the country. However, this progress is by no means satisfactory and more acceleration in the co-ordination of various training programmes between the oil companies concerned and the Ministry of Petroleum is expected.

The outstanding issue which has arisen is the co-ordination of any industrial development, petrochemical or otherwise, among the various government departments to avoid duplication of efforts and to expedite the execution of development projects. A co-ordinating body should be invested with the task of directing, supervising and preparing studies for industrial projects and should have the necessary financial backing to enable it to call upon consultant's services or to employ qualified experts. This body should be set up as soon as possible to straighten out the present state of conflict and overlapping of various departmental interests in Libya. It will combine three ministries, namely, Petroleum, Industry and Planning, and will bring the technical staff of each ministry together to formulate a real and consistent industrial programme for the betterment and welfare of the nation.

4 FORECAST OF PETROCHEMICAL DEVELOPMENT IN LIBYA OVER THE NEXT FIVE YEARS

The associated gas produced from the Libyan oilfields will provide over the next five years the predominant raw material for any petrochemical development in the country. The amount of associated gas produced and flared exceeds 190,000 mmcf per annum. The trend in gas utilization by tankers has become an economically viable and safe venture. The recent development in neighbouring Algeria concerning gas transportation schemes has paved the way for Libya to enter into this new race in order to establish markets for her gas, since the shift from oil to gas might acquire major significance in the future.

Associated gas is rich in hydrocarbon components which form the basis for petrochemical industries. However, the main purpose of most of the projects submitted is concerned with liquefaction and transportation of the associated gas as liquefied natural gas (LNG) or liquefied methane (LMG). This is because petrochemical industries consume only a fraction of the huge oil and gas reserves available, the remainder being used as a source of energy.

The European markets are the most obvious target for any gas export scheme; this is a direct result of the geographically favourable position of Libya to Europe. A market analysis has been prepared by COMES (Société commerciale du méthane saharien) concerning the demand in various European countries for natural gas. The market demand for gas was estimated to be between 150,000-190,000 *mmcf per annum* for Spain, France, Italy and Switzerland. Even with the advent of Dutch and Algerian gas, the market is still encouraging and exceedingly attractive.

The other factor that has an outstanding bearing on the utilization of Libyan gas is the proximity of the gas sources to sea terminals. In fact most of the prolific oilfields with high gas/oil ratio are only 80 to 100 miles away.

It is anticipated that the establishment of gas utilization projects such as liquefaction plants will eventually lead to the development of petrochemicals, as marketing outlets are found and *per capita* consumption of various petrochemical products increases.

Oil companies have made no significant contribution to petrochemical studies or petrochemical development in the country. Therefore, the Libyan Government must take the initiative and invite a consultant firm with the pertinent technical experience to study the Libyan situation and to offer its recommendations concerning the steps to be taken in any development programme. Similiar studies have been made in many countries, including Saudi Arabia, United Arab Republic, India and Iran.

(a) *Utilization of Dahra associated gas*

Plans submitted by international oil companies, particularly Continental Oil Company, are mainly for synthesizing ammonia and shipping it in liquid form. Specially built tankers will be used to transport ammonia to marketing centres. The gas source is situated 85 miles from these centres. This venture will probably consume all the available Dahra gas. Continental Oil Company shares the Dahra field with two other companies and therefore an agreement has to be worked out between the three partners and the Government.

The Dahra field produces more than 50,000 mmcf per annum with the over-all composition 68 per cent C_1, 15 per cent C_2, 5 per cent C_3, 0.9 per cent C_4, 0.7 per cent C_5, and the rest N_2 and CO_2. However, other products might become economically attractive to make, such as urea, carbon black, and polyolefin manufacture. The outlet to the sea will be through the Es Sider Oil Terminal.

(b) *Zelten gas scheme*

This will be an Esso enterprise and will be destined mostly for the export of methane. The field is 100 miles from the Brega Oil Terminal, and produces over 90,000 mmcf per annum all of which is flared. A sample analysis of this gas is as follows: 56 per cent C_1, 20 per cent C_2, 12.3 per cent C_3, 6.4 per cent C_4, 0.72 per cent H_2S and the rest N_2 and CO_2.

5. CONCLUSION

From the foregoing brief discussion, the following remarks can be made:

(*a*) Owing to the limited Libyan market, any economically viable venture has to be established on a joint basis in order to secure know-how and marketing outlets.

(*b*) An appraisal of the Libyan situation for petrochemical possibilities must be made very soon with the help of a renowned and established consultant agency. This will assist in future development and planning.

(*c*) The associated gas which is available in vast quantities will be a major contributor to any petrochemical development; progress studies on the liquefaction and transportation of associated gas from Zelten and Dahra fields are being undertaken by major oil companies. No petrochemical projects are being considered so far, apart from an ammonia plant.

(*d*) The training of skilled personnel in the sphere of petrochemicals is not adequately catered for in most developing countries and, therefore, intensive training courses must be co-ordinated to meet the requirements of these countries for skilled people.

Annex

PRODUCTION OF LIBYAN OILFIELDS — THROUGH MID-1964

Company	*Field*	*Year*	*Bbls of oil produced*	*API*	*Associated gas produced (in mcf)*
Esso Standard	Zelten	1961	6,641,886	40.4	4,250,807
	Zelten	1962	46,012,020	40.4	29,447,693
	Zelten	1963	91,262,136	40.4	58,730,136
	Zelten	1964 (mid)	70,177,209	40.4	44,913,412
Esso Syrte	Raguba	1963	15,929,585	43.2	13,699,443
	Raguba	1964 (mid)	11,533,492	43.2	9,918,803
Oasis	Dahra	1962	21,120,807	42.1	23,444,162
	Dahra	1963	43,267,661	42.1	48,027,103
	Dahra	1964 (mid)	22,574,015	42.1	25,057,157
	Waha	1963	15,392,362	37.5	7,234,410
	Waha	1964 (mid)	20,911,857	37.5	9,828,573
	Samah	1963	2,097,987	34.8	241,268
	Samah	1964 (mid)	6,170,125	34.8	709,564
	Zaggut	1963	256,026	36.5	80,932
	Zaggut	1964 (mid)	1,357,933	36.5	426,174
Mobil Oil	Hofra	1963	1,028,995	43.6	926,096
	Hofra	1964 (mid)	4,221,364	43.6	3,799,228
Amoseas	Beida	1964 (mid)	1,726,125	34.8	130,000

14. MALAYSIA COUNTRY STUDY

Lim Ho Pheng, Federation of Malaysia

I. INTRODUCTION

As petrochemical industry thrives best in regions where chemical industry constitutes an important factor, it is understandable that in Malaysia, as perhaps in many other newly developing countries, the development of petrochemical industry must necessarily await, or at most parallel, the development of chemical industry into an important sector of the economy, for only in such an environment will there exist a substantial market for raw materials of petroleum origin.

In Malaysia, the contribution of manufacturing industry to the gross national product is not yet substantial, being about 7 1/2 per cent in 1961. However, since then, rapid progress has been made in creating new industries particularly in Singapore[1] where even in 1961, manufacturing sectors contributed about 14 per cent to its G.N.P.

Although petrochemical industry does not as yet exist in Malaysia, indications are that within the next few years a start in this direction would be made, though small in scale and limited in scope. At this stage too, there is in Malaysia a segment of chemical industry which could provide an outlet for certain raw materials of petroleum origin. This section is growing and might well be augmented by new industries capable of providing a larger consumer market.

II. CHEMICAL INDUSTRY IN MALAYSIA

A selected section of Malaysia's chemical industry is reviewed here in relation to the part it could play in stimulating the development of petrochemical industry in this country.

Table 1 shows the share of chemical industry in the net value of principal industrial output in Malaya alone.

Of the more than 300 establishments engaged in various types of chemical industry, only a small number are manufacturers of industrial chemicals. In this small group there are a few industries, such as industrial acid production and synthetic detergent manufactures,

TABLE 1. NET VALUE OF OUTPUT OF SELECTED MANUFACTURING INDUSTRIES, MALAYA, 1959-1962
(M$ thousand)

	1959 [a]	*1960* [a]	*1961* [a]	*1962* [b]
Chemical products manufacturing industries	15,083	20,004	24,582	34,096
Processing of rubber and coconut oil in factories off estates	43,730	47,542	43,255	45,143
Food manufacturing industries	16,139	21,729	21,150	22,653
Beverage manufacturing industries	9,658	11,249	11,145	11,800
Tobacco products manufacturing industries	10,624	17,866	22,220	27,882
Wood products manufacturing industries	28,207	38,089	35,098	40,508
Rubber products manufacturing industries	12,377	14,313	15,265	15,705
Non-metallic mineral products manufacturing industries	5,933	7,643	9,033	11,971
Basic metals and metal products manufacturing industries	7,041	8,678	10,709	14,179
Machinery manufacturing industries	2,799	3,695	4,245	7,111
Transport equipment manufacturing industries	2,552	3,169	3,572	4,433
Other industries and establishments	12,451	16,020	21,038	26,304
TOTAL, selected industries	166,594	209,977	221,312	261,785

[a] Interim Review of Development in Malaya under the 2nd Five-year Plan, December 1963, p. 44.
[b] Malaya, Dept. of Statistics. *Survey of Manufacturing Industries, Federation of Malaya 1962.*

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[1] Singapore became a State of Malaysia on 31 August 1963.

which are potential end-users of "first-generation" petrochemicals.

Industrial acids

Sulphuric acid. Plants for the manufacture of sulphuric and formic acids already started operating a few years ago. The sulphuric acid plant has a maximum capacity of 70 tons per day or about 20,000 tons a year. But it is currently working under capacity and the production is estimated at 5,000 to 6,000 tons per annum. A large portion of this is used as one of the raw materials for producing formic acid at an adjacent plant. The rest is supplied to Malaya's rubber industry and two detergent plants capable of producing a total of 11,000 tons of alkyl aryl sulphonate detergent.

Further increase in the consumption of this acid could be anticipated during the next few years as more industries requiring sulphuric acid are being set up, particularly in the Jurong industrial site, Singapore [2]. A United States firm is reported to be building a fertilizer and chemical plant at Jurong [2]. The plant will be situated on thirty acres of industrial site in Jurong and is expected to start operation in 1965. When completed, it will produce 250 tons of sulphuric acid per day, ammonium sulphate, ammonia, ground phosphate and granulated mixed fertilizers.

Other industries being established in Jurong which would require sulphuric acid for processing or as one of their raw materials are: monosodium glutamate production, PVC production, iron and steel production, oil refining and the manufacture of household detergent of the alkyl aryl sulphonate type.

Meanwhile, the building of another sulphuric acid plant in Jurong had already started in early 1964. This plant will have an annual production capacity of 5,000 tons of sulphuric acid and 10,700 tons of other acids and compounds.

Formic acid. The formic acid plant in Petaling Jaya, Malaya, is currently producing 3,000 tons of acid *per annum*, mainly for domestic consumption by the rubber industry.

Hydrochloric acid. A hydrochloric acid plant [3] is to be set up on a twelve-acre site in Jurong within the next few years. It will have a production capacity of 6,000 tons of hydrochloric acid and 4,400 tons of chlorine *per annum*.

Nitric acid. In view of a move to manufacture certain types of nitrogenous fertilizer in Malaya, local production of nitric acid might be anticipated. The ammonia for this manufacture could come from a plant to be constructed by an international oil firm adjacent to its oil refinery at Port Dickson, Malaya.[4]

Manufacture of synthetic detergent in the Federation of Malaysia. In Malaya itself there are at present two factories producing synthetic detergents, mainly for household use. Their combined annual production is slightly more than 10,000 tons. Another plant is reported to be constructed in Jurong with an annual production capacity of 9 to 18 million pounds of detergents. The bulk of detergent being produced at present consists largely of the alkyl aryl sulphonate type. However, the alkyl benzene is not being manufactured locally nor is there any plan to produce it in the next two or three years.

III. PROSPECTS FOR THE ESTABLISHMENT OF A SMALL PETROCHEMICAL INDUSTRY IN MALAYSIA

The development of petrochemical industries is foreseeable in the next few years, particularly in Singapore and Malaya. Considering the size of market that would be created for raw materials of petroleum sources, the degree of industrialization in Malaysia and the demand for various petroleum oil products which Malaysia's refining units have been designed to meet, the petrochemical industries that could be set up here will be very limited in size and scope, except in one or two instances where plants to be set up are comparable in size to international standards.

In the early stages, the growth of petrochemical industries in Malaysia could evolve around the following products:

(*a*) (i) Sulphur.
    (ii) Sulphuric acid (to provide outlets for sulphur produced).
(*b*) [(i) Hydrogen] (as a first-generation petrochemical)·
    (ii) Ammonia (to be synthesized from hydrogen or CH_4- rich stream as one of the raw materials).
    (iii) Nitric acid (using ammonia as raw material).
    (iv) Nitrogenous fertilizers (as end-users of ammonia and nitric acid).

Current local markets exist on a very modest scale for the products listed below. Whether these could expand substantially to justify establishment of petrochemical plants cannot be safely forecast yet.

(*c*) Carbon black (for Malaysia's tyre-manufacturing industry).
(*d*) Acetylene; Ethylene (for manufacture of plastics, ethyl alcohol and acetic acid).
(*e*) Plastics — Vinyl chloride (from ethylene)
    Polyvinyl chloride and adhesives.
(*f*) Detergents.

Sulphur. From the present trends of development in the Malaysian industrial sector, it would appear that the annual demand for sulphur in the next five years will probably exceed 5,000 tons and might even reach 30,000 tons per annum, The latter figure is based on the assumption that the various projects mentioned above will materialize.

Gases produced by Malaysia's oil refineries could form a potential source from which sulphur might be economically recovered. There are at present five petroleum oil refineries in Malaysia with the sixth one still under construction and expected to begin operation in 1966. Two of the refineries are situated in Port Dickson, Malaya, two in Singapore (the third is still under construction here) and one in Lutong Sarawak. Each of these

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[2] See *Far Eastern Economic Review*, 27 August, 1964.

[3] See *Ibid.*, p. 392.

[4] See *Ibid.*, 30 July 1964, p. 209.

refineries is capable of processing 20,000 barrels of crude oil a day, or one million tons a year.

The following is a summary of available data on the above refineries:

Pulau Bukom Refinery[5] (Shell)

Location: Pulau Bukom island, a few miles from Jurong industrial site in Singapore.

Cost of refinery: $M 30 million.

Sources of crude oil Supply: Seria, Brunei, Persian Gulf, Middle East.

Production capacity: capable of processing 3,000 tons of crude oil a day or one million tons a year.

Products manufactured:[6] liquid petroleum gas; motor gasolene -- all types; kerosene; aviation turbine fuel; diesel oils -- all types; gas oil; fuel oils -- all types; bitumen; refinery gas.

Processing units:	*Present capacity*
One atmospheric distillation unit	37,000 b/d or 5,000 t/sd
One catalytic reforming unit	480 t/sd
One hydrotreater	1,800 t/sd

Port Dickson Refinery[7] *(Shell)*

Location: Port Dickson, Malaya, about 75 miles from Petaling Jaya, Malaysia's biggest industrial town, and 200 miles from Tasek, the second largest industrial site in Malaya.

Cost of refinery: $M52 million.

Sources of crude oil supply	Data here are essentially similar to those on Pulau Bukom Refinery (see above)
Production capacity	
Products manufactured	

Esso Refinery, Port Dickson. This refinery is of about the same size as the Shell refinery in that area. However, it produces a greater variety of products, including petroleum naphthas, solvents and special boiling point spirits. It has an atmospheric distillation unit, a catalytic reforming unit, and two hydrotreaters.

The quantity of refinery gas streams and the production capacity of those refining units which are of immediate interest here (e.g. the catalytic reforming unit, the desulphurizer unit), have not been made available by the oil companies[8]. In the absence of these data, only a rough estimate could be made of the amount of sulphur that could be recovered from each of the refineries in Malaya. Taking 2 per cent as the average sulphur content of crude oils processed in Malaysia, the total quantity of sulphur present in 1 million tons of crude oil (which is the average annual capacity of each refinery in Malaysia) is about 20,000 tons.

Out of this, the amount that could be recovered depends to a large extent upon the volume of gases generated by the refinery's various processing units and this, in turn, is determined by the market demand for certain fractions of petroleum oil, particularly the light ones such as liquefied petroleum gases, gasolene, special boiling point spirits, white spirit and kerosene and, to some extent, diesel oils. The total production of the above products in each of the existing refineries in Singapore[9] and Malaya is estimated at 430,000 tons *per annum*. Assuming that the oil fractions yielding this quantity contain 0.5 to 2 per cent of sulphur, the amount of the latter that could be recovered in each refinery lies between 2,150 and 8,600 tons. A unit to recover 2,000 tons of sulphur is probably not economical to operate in most parts of the world. In this respect, the disadvantage of having five refineries of 1 million tons capacity each, instead of one refinery with 5 million tons capacity, is apparent. However, because of the high cost of imported sulphur (average of $M273 a ton C.I.F. 1962) and the very favourable investment opportunities in Malaya a "minimum economic size" could well be around 2,000 tons *per annum*. The actual recoverable quantity could be much higher than the estimated minimum of 2,150 tons.

Sulphuric acid. A plant with a maximum capacity of about 60 tons a day is already operating in Malaya, and one or two more are reported to be under way in Singapore. The Malayan plant employs contact process and uses imported sulphur as a raw material. It is likely that the new plants to be constructed, will also employ a contact process requiring the use of sulphur or sulphur dioxide as a starting material. When all these plants are operating, they should be able to provide a market for between 5,000 to 30,000 tons of sulphur a year.

Manufacture of hydrogen ammonia and nitrogenous fertilizers. At present ammonia is not being produced in Malaysia although plans are under way for the construction of two plants, one in Jurong, Singapore (see below) and the other in Port Dickson.[10]

The Port Dickson plant is to be constructed by Esso Standard, Malaya, which also operates a petroleum oil refinery in that area. It is expected to go into operation in 1966. When completed, the plant will have an estimated annual capacity of 50,000 tons. This would be sufficient to supply the total requirements of liquid anhydrous ammonia for the whole of Malaysia's agriculture. Table 2 shows the annual import of ammonia into Malaya[11] alone. This is currently being used almost entirely in the rubber latex industry and not for manufacture of nitrogenous fertilizers, whereas the Esso plant is intended to supply the requirements of both.

It is not known in detail how the hydrogen required for the manufacture of ammonia is to be produced. The possibilities are that part of the hydrogen will be obtained from a catalytic reformer in an adjacent oil refinery and part either from refinery gases which have

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[5] See *Pulau Bukom*, published by Shell (Malaya) Limited.

[6] See annex I to this paper.

[7] See *Shell Refinery, Port Dickson*, published by Shell (Malaya) Limited, see also annex I to this paper.

[8] Shell (Malaya) Limited has subsequently supplied some additional data, See annex I to this paper.

[9] Excluding the Pulau Bukom refinery in Singapore.

[10] See *Far Eastern Economic Review*, 30 July 1964, p. 209.

[11] The States of Malaya form a part of Malaysia.

TABLE 2. IMPORT OF AMMONIA INTO MALAYA

Year	Cwt	Value C.I.F. ($M)
1960	71,787.64 (or 3,589.4 tons)	3,617,177
1961	60,870.79 (or 3,043.5 tons)	3,190,768
1962	84,427.03 (or 4,221.4 tons)	4,037,372

been stripped of all components except methane or by gasification of fuel oil.

In this respect, the manufacture of hydrogen itself (though only at sites for ammonia production) could be considered as a petrochemical manufacture.

Manufacture of nitrogenous fertilizers (urea, ammonium sulphate, ammonium nitrate etc.). In 1962, Malaya alone consumed 95,017 tons of nitrogenous fertilizers worth $M16,429,457 and 12,188 tons of nitrates of potassium and sodium worth about $M1,951,187. Table 3 shows Malaya's import of various fertilizers in 1962.

TABLE 3[a]

Type of fertilizer	Quantity (tons)	Value (C.I.F.) $M
Crude fish fertilizers	761.15	90,059
Other vegetable or animal fertilizers	3,331.71	194,939
Natural phosphate	68,925.46	6,948,570
Synthetic phosphate fertilizers . .	5,418.12	939,351
Synthetic nitrogenous fertilizers . .	95,006.72	16,425,199
Natural nitrogenous fertilizers . .	10.50	4,258
Mixed fertilizers	40,928.70	8,594,835
Potassic fertilizers	10,589.65	1,787,532
Crude potassium salts	1,587.54	159,397
	226,559.55	35,144,140

[a] SOURCE: Federation of Malaya, *Annual Statistics of External Trade, 1962.*

The annual consumption of inorganic fertilizers in the whole of Malaysia currently stands at 280,000 tons[12] and is increasing. Of this, a large portion is of the nitrogenous type.

A subsidiary of a well-known international chemical firm is to construct a multi-million dollar chemical complex in Malaya. The biggest plant in this complex will produce nitrogenous fertilizers using ammonia to be supplied by the Port Dickson plant.[13]

Another nitrogenous fertilizer plant is also reported to be underway in Jurong, Singapore,[14] but it is not known where it will obtain its supply of ammonia.

Carbon black

The consumption of carbon black is small as table 4 shows, being about 1,436 tons *per annum*, and this is used largely by Malaysia's tyre manufacturing plant in Petaling Jaya.

A second factory is to start operation by the end of 1964 in Jurong, Singapore. It will have an annual target of approximately 200,000 pieces of tyres and tubes. When in production, it could increase the consumption of carbon black considerably. However, considering the fact that each of the factories requires, or would require, more than ten varieties of carbon black for their tyre manufacture, the possibility of some of these varieties being produced economically by a local petrochemical plant cannot be accurately predicted at present.

Acetylene, ethylene, plastics. If all goes well, Singapore will have its first PVC plant in 1967 with a production capacity of 7,500 tons of resin a year. The resin will be used in the manufacture of domestic piping, wall panels, footwear, floor-tiles, bags and cable coating. This plant will consume 10,000 tons of calcium carbide, to be produced locally (at 20,000 tons *per annum*). Currently, acetylene is more economically generated from calcium carbide than from a petrochemical plant because of the relatively small quantity required. However, with the possible establishment of one or more shipyards in Malaysia, and a potential growth of markets for vinyl and polyvinyl floor-tiles and pipes, the manufacture of acetylene and ethylene from petroleum sources might become feasible. A great deal will depend on the development and rapid growth of end-user industries for these two petrochemicals. Trends towards this are not apparent yet as the end-user industries are themselves either in the planning stage or about to be established.

IV. INSTITUTIONAL MEASURES AND INVESTMENT OPPORTUNITIES IN MALAYSIA

Malaysia has no specific measures aimed at encouraging the development of petrochemical industry in particular. There are however, general government policies and programmes which seek to stimulate development and expansion of all industrial sectors. In pursuit of this the Government, both at Federal and State levels, is providing various aids to help private enterprise, and these include the expansion of basic facilities, provisions under the Pioneer Industries Act, development of industrial sites, provision of loans for industrial finance, and tariff protection and concessions.

Expansion of basic facilities. Vast sums of money are being spent to provide an adequate infrastructure of power transport, water supplies, telecommunications, port facilities and other capital projects. Malaya alone

TABLE 4. IMPORT OF CARBON BLACK INTO MALAYA, 1961-63

Year	Cwt.	Value C.I.F. ($M)
1961	14,910.6	617,207
1962	16,088.7	834,745
1963	28,719.0	1,257,286

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[12] *Far Eastern Economic Review*, 27 August 1964.

[13] *Ibid.*, 20 July 1964, p. 209.

[14] *Ibid.*, 27 August 1964, p. 3.

has set aside more than M$1,240 millions for the above purposes under its second Five-year Plan, 1961-65.[15]

The Pioneer Industries (Relief from Income Tax) Ordinance 1958 of the States of Malaya and the Pioneer Industries Act 1959 of Singapore allow businessmen to apply for any industry to be considered as a pioneer industry. If no objection is raised within a given period, approval will be given and all preferential treatment under the Act will be applied, including exemption from the payment of income tax for periods ranging from two to five years depending on the amount of capital invested in fixed assets. Since the enactment of Pioneer Industries Act in 1958-59, 240 establishments have been granted pioneer status. These include 105 in Malaya with a nominal capital of $M646 million and a called-up capital of $M158 million.[16]

Development of industrial estates. Four industrial estates, one each at Petaling Jaya, Sungei Mak Mandin, Tasek and Johore Bahru, have been developed in Malaya. Another big estate is also being established in Jurong, Singapore in a well co-ordinated manner. All these industrial estates are fully serviced, and sites, and sometimes standard-type factories, are available at low rates.

Industrial finance. Malaya, Singapore and the Borneo Territories of Malaysia have each set up an organization to channel public and private funds towards industrial investment.

The Malayan Industrial Development Finance Limited was established in 1960, with part of its share capital subscribed by the Federal Government and the remainder subscribed by private investors, both local and foreign. As a result of recent reorganization, it has lending resources of up to $M250 million

Singapore has its own Economic Development Board, which was set up in 1961 with a grant of $M100 million. It is very highly efficient and as a concept it is unique in South-East Asia. It underwrites issues of stocks, shares and bonds, provides medium and long-term loans and participates in the management of enterprises. It is responsible for industrial extension services, technical research, project feasibility surveys and advising the Singapore Government on industrial policy.

V. LIMITATION FACTORS AND POSSIBLE PATTERN OF DEVELOPMENT IN MALAYSIA

The size of population. For a developing country, Malaysia has a relatively small population of about ten and a half million, out of which approximately three and a half million are economically active. In the Borneo Territories, 80 per cent of the economically active population is engaged in agriculture, forestry and fishing, while in Malaya and Singapore they are 58 per cent and 8 per cent respectively. Manufacturing and construction occupy 20 per cent of the labour force in Singapore, but only about 11 per cent in Malaya and less than 6 per cent in the Borneo Territories. Against this, however, the *per capita* income and the Gross Nationa Product at market prices (1961) are high, being abou $M860 and $M8,590 million, respectively.

Size of market. The Malaysian manufacturing industr is, on the whole, still very young and small by internationa standards, though it is expanding rapidly. It cannot except in very few instances, provide substantial outlet that could be economically supplied by raw material of petroleum origin. Very often, raw materials of othe sources are much more competitive. This is becaus the large capital investment or the high fixed costs pe unit of output of petrochemical plants require tha such plants be operated on a large scale (which is hug by the standards of most industries) to be economicall feasible. Further, a petrochemical plant should, in general form part of an integrated complex so that various by products arising from the manufacture of any produc could be further processed for sale. In effect, therefore the consumer markets[17] should be both large and varied These conditions are still lacking in Malaysia.

Size of Malaysia refineries and their limitations. Malaysian refineries are small and have very few processin units and hence cannot produce enough by-product from which petrochemicals could be processed. In th event of any substantial demands for petrochemical being created, additional processing units or plant are necessary and feedstock materials might have t be imported.

A conducive climate can however be gradually built up Malaysia could work towards this by expanding it existing consumer industries[18] or developing new ones Malaysia's paint manufacturing industry and soa and detergent manufactures are examples of existin industries that could be further expanded. The ne industries being undertaken, such as polyvinyl resi production and vinyl floor tiles and other product turned out from polyvinyl resin might have great potentialities.

Further stages should, of course, include developmen of export markets but this aspect is very much dependen upon developing plants of economic size.

VI. CONCLUSION

The manufacture of ammonia, nitric acid and nitrogenous fertilizers from raw materials of petroleum source are being planned, with one of the oil companies takin an active role in the projects.

A petrochemical plant to recover sulphur from th refinery streams should be economically feasible in th next few years.

The petrochemical manufactures of certain varietie of carbon black, plastics (polyvinyl or certain plastic adhesives for Malaysia's fast-expanding plywood industry) alkyl aryl benzene, acetylene and ethylene cannot b accurately forecast at this stage. Further intensiv

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[15] See annex II to this paper.

[16] Malaysia Anniversary Supplement, *The Straits Times* (31 August 1964).

[17] The phrase " consumer markets " applies to markets or outle capable of using raw materials of petroleum origin.

[18] See section II.

surveys are necessary. However, a great deal will depend on the growth of industries that will be consumers of the above chemicals.

Currently the petroleum oil and refining industry in Malaysia is controlled by five international companies. The development of petrochemical industry would be difficult without their co-operation or direct participation. On the other hand, without government pressure or incentives, few of them are likely to extend their interest into the petrochemical field as they would probably prefer to import these chemicals from their plants elsewhere.

Annex I

Production figures of a Port Dickson oil refinery:[a]

	Tons per annum
Motor gasolenes (all types)	125,000
Kerosene (all grades)	50,000
Aviation turbine fuel	30,000
Gas oils and diesel oils	300,000
Fuel oils	160,000
Bunker fuel	293,000
Refinery fuel (gas and liquid)	40,000

Processing units	*Capacity (tons/day intake)*
1 Crude distilling unit	3,000
1 Hydrotreater for kerosene and lighter distillates	1,000
1 Platforming unit	300
1 Bitumen unit	100

Refinery gases

20,000 tons of gas per annum, of which 2,000 tons is used for liquid petroleum gas; the balance is used as refinery fuel.

Hydrogen

Hydrogen produced in the refinery is used for desulphurization of products. The present trend is that in future there will be no surplus.

Sulphur

Potential availability approximately 8 tons/day.

Some information on a Singapore refinery:[a]

Processing Units	*Tons/day*
1 Crude distiller	5,000
1 Hydrotreater	1,800
1 Platformer	480
1 High vacuum unit	550
1 Blowing unit	240

Refinery gases	*To refinery fuel (tons/year)*
Methane and ethane ex platformer	10,000
Propane ex crude distiller	8,000
Propane ex platformer	5,000
Butane ex platformer (for bottling)	5,000

Hydrogen sulphide: When the planned hydro-desulphuriser is on stream, the potential availability of H_2S in H_2S rich refinery gases would be about 13 tons/day H_2S.

Hydrogen

The hydrogen produced in the Platformer will be all used for hydrotreating purposes when the planned hydro-desulphurizer plant comes on stream.

Sulphur

The potential quantities of sulphur would be about 4,000 tons *per annum* when the planned hydro-desulphurizer is on stream.

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[a] SOURCE: Data supplied by Shell (Malaya) Limited.

Annex II

PRINCIPAL ECONOMIC INDICATORS, FEDERATION OF MALAYA

(Physical units or values, and index numbers)

	1960	*1961*	*1962*	*1963 Jan.-June*
Population (thousands)	7,017[a]	7,250[a]	7,491[a]	7,611[a]
	(100)	(103.3)	(106.8)	(108.5)
Gross domestic product (G.D.P.) in constant 1959 dollars ($ million)	5,191	5,458	5,672	
	(100)	(105.1)	(109.3)	
G.D.F. per capita ($)	751	765	770	
	(100)	(101.9)	(102.5)	
Gross national product (G.N.P.) at market prices	5,665	5,604	5,786	
	(100)	(98.9)	(102.1)	
G.N.P. per capita ($)	819	783	785	
	(100)	(95.8)	(95.8)	
Exports f.o.b. ($ million)	2,924	2,622	2,621	1,333
	(100)	(89.7)	(89.6)	
Imports c.i.f. ($ million)	2,151	2,231	2,447	1,305
	(100)	(103.6)	(113.8)	
Agriculture:				
Rubber production (thousand tons)	708	737	751	365
	(100)	(104.1)	(106.1)	
Rubber price average (RSS 1, cents per pound)	108.1	83.5	78.2	76.4
	(100)	(77.2)	(72.3)	

Annex II *(continued)*

	1960	*1961*	*1962*	*1963 Jan.-June*
Rice production (thousand tons)	480	525	498	
	(100)	(109.4)	(103.8)	
Oil palm production (thousand tons)	90	93	106	56
	(100)	(103.3)	(117.8)	
Mining:				
Tin production (thousand tons) .	52	56	59	30
	(100)	(107.7)	(113.5)	
Iron ore production (million tons)	5.6	6.7	6.5	3.7
	(100)	(119.4)	(116.1)	
Manufacturing:				
Cigarette production (thousand pounds)	7,879	9,517	11,021	6,366
	(100)	(120.8)	(139.9)	
Soap production (thousand hundred-weights)	356	378	384	221
	(100)	(106.2)	(107.9)	
Cement production (thousand tons)	282	326	321	174
	(100)	(115.6)	(113.8)	
Pioneer companies (number) . .	55[a]	71[a]	87[a]	99[a]
	(100)	(129.1)	(158.2)	(180.0)
Pioneer companies (called-up capital, $ million)	29[a]	54[a]	69[a]	134[a]
	(100)	(186.2)	(237.9)	(462.1)
Transportation:				
Motor vehicles registered all types (thousands)	185[a]	219[a]	253[a]	273[a]
	(100)	(118.3)	(136.6)	(147.6)
New roads completed (miles) . .	260	461	764	240
	(100)	(177.3)	(293.8)	
Communications:				
Telephones (thousands)	76[a]	82[a]	90[a]	94[a]
	(100)	(107.9)	(118.4)	(123.7)
Post offices (number)	212[a]	213[a]	221[a]	221[a]
	(100)	(100.5)	(104.2)	(104.2)
Mobile post offices (number) . .	23[a]	33[a]	42[a]	46[a]
	(100)	(143.5)	(182.6)	(200.0)
Electric power:				
Installed Capacity (thousand kW)	328[a]	338[a]	327[a]	380[a]
	(100)	(103.0)	(99.7)	(115.9)
Transmission lines (miles) . . .	3,928[a]	4,263[a]	4,757[a]	5,221[a]
	(100)	(108.5)	(121.1)	(132.9)
Generation (million kWh) . . .	1,200	1,300	1,500	800
	(100)	(108.3)	(125.0)	
Education (fully assisted schools):				
Primary enrolment (thousand pupils).	974[a]	1,051[a]	1,074[a]	1,100[a]
	(100)	(107.9)	(110.3)	(112.9)
Secondary enrolment (thousand pupils).	96[a]	111[a]	147[a]	164[a]
	(100)	(115.6)	(153.1)	(170.8)
Class-rooms (thousand)	23[a]	26[a]	26[a]	28[a]
	(100)	(113.0)	(113.0)	(121.7)
Primary teachers (thousand) . .	35[a]	39[a]	41[a]	40[a]
	(100)	(111.4)	(117.1)	(114.3)
Secondary teachers (thousand) .	3.6[a]	4.3[a]	5.7[a]	6.3[a]
	(100)	(119.4)	(158.3)	(175.0)
Health (Government services only):				
Hospital beds (thousand)	21.1[a]	21.5[a]	21.7[a]	21.7[a]
	(100)	(102.0)	(102.8)	(102.8)
Dispensaries (number)	355[a]	356[a]	373[a]	373[a]
	(100)	(100.3)	(105.1)	(105.1)

Annex II *(continued)*

	1960	*1961*	*1962*	*1963 Jan.-June*
Health centres (number)	133 [a]	134 [a]	146 [a]	155 [a]
	(100)	(100.8)	(109.8)	(116.5)
Health sub-centres (number)	8 [a]	11 [a]	50 [a]	84 [a]
	(100)	(137.5)	(625.0)	(1,050.0)
Midwives' clinics (number)	26 [a]	55 [a]	373 [a]	422 [a]
	(100)	(211.5)	(1,434.6)	(1,623.1)
Dental clinics (number)	146 [a]	149 [a]	245 [a]	245 [a]
	(100)	(102.1)	(167.8)	(167.8)
Doctors (number)	391 [a]	419 [a]	438 [a]	451 [a]
	(100)	(107.2)	(112.0)	(115.3)
Water Supplies:				
Number of supplies	140 [a]	141 [a]	148 [a]	156 [a]
	(100)	(100.7)	(105.7)	(111.4)
Output (million gallons per day)	84 [a]	87 [a]	92 [a]	
	(100)	(103.6)	(109.5)	
Irrigation:				
Areas that can be double-cropped (thousand acres)	38 [a]	78 [a]	85 [a]	95 [a]
	(100)	(205.3)	(223.7)	(250.0)

SOURCE: *Interim Review of Development in Malaya under the Second Five Year Plan*, December 1963.

[a] As at end of period. Figures in parentheses are indices based on 1960 as 100.

15. THE MEXICAN GOVERNMENT AND THE PETROCHEMICAL INDUSTRY IN MEXICO

Petróleos Mexicanos, Mexico

I. Petroleum legislation

Article 27 of the constitution of the United States of Mexico, currently in force, grants to the nation the direct domain in petroleum and the hydrocarbons, solid, liquid and gaseous. This article further establishes that no concessions will be granted nor will the existing ones be valid; therefore the nation will carry out the exploitation of its products in the terms indicated by the regulations of the article.

These regulations put an end to the petroleum concessions that had previously been granted to private individuals and companies for the exploitation of petroleum in the country. They also established the exclusive role of the Government in this industry and set the basis for a rational exploitation of petroleum. Furthermore, these regulations also allow the nation to control its resources and direct its operations towards securing the maximum benefit in the present and the best plans for the future. In the section on petroleum, they state the following:

Section 1. There is vested in the nation the direct domain, untransferable and imprescriptible, of all the hydrocarbons which are located in the national territory (including the international shelf), in deposits or reservoirs, whatever their physical state may be, including the intermediate states, as well as the mineral crude oil, products which accompany it or derive from it.

Section 2. Only the nation can undertake exploitation of the hydrocarbons which constitute the petroleum industry in the terms of the following section. In this Law, the meaning of the word "petroleum" comprises all natural hydrocarbons referred to in section 1.

Section 3. The petroleum industry comprises:

(*a*) The exploration, exploitation, refining, transport, storage, distribution and the first sales of petroleum, gas and all products which are obtained from the refining of these.

(*b*) The manufacture, storage, transport and distribution and the first sales of manufactured gas.

(*c*) The manufacture, storage, transport, distribution and first sales of the petroleum derivatives which are susceptible of serving as industrial raw materials.

The nation will carry out the exploitation of petroleum and all other activities referred to in section 3, by means of Petróleos Mexicanos, a public decentralized institution whose structure, function and internal organization are determined by the laws, regulations and other provisions, or by any other provision, that in the future may be established by law.

These provisions grant to the nation the exploitation of the non-renewable resources, a fact of great economic significance for the country. In fact, a government monopoly was established to carry out these operations with the best technology available in the different divisions of industry, with the fundamental object of serving the country and providing important backing for its industrial and economic development. However, the participation of private individuals and companies is not totally excluded. Section 6 authorizes Petróleos Mexicanos to enter into construction contracts and service contracts with individuals or companies when this is called for in the interest of securing the best performance for its activities. This section further stipulates that the payment for such construction and service contracts will be made in cash, for under no circumstances will percentages of the products or participation in the results of the exploitation be granted.

Therefore, as far as the petroleum industry is concerned, the participation of private individuals and companies is reduced to the performance of specified services, mainly technical and also to the execution of construction contracts. The form of participation allowed to individuals and companies in connextion with the petrochemical industry is dealt with below.

II. Petróleos Mexicanos

A. THE INSTITUTION ESTABLISHED TO CARRY OUT THE EXPLOITATION OF THE PETROLEUM WEALTH IN MEXICO IS PETRÓLEOS MEXICANOS

This institution, established by the Government, has its own legal personality, its own assets and financial and technical autonomy. Heretofore, this institution has been the only means through which the Government has carried out the supply of petroleum and its derivatives to the country. Its operations and services are based on the principle of the utilization of the best possible technology to carry out the rational exploitation of this non-renewable resource (petroleum) of such importance in the world today.

Section 4 of the regulation of article 27 of the Constitution determines the position of Petróleos Mexicanos, considering it the mechanism that the nation uses to carry out the exploitation of natural hydrocarbons, to obtain all those derivatives and products that the country demands for its development and also to distribute them widely and opportunely in all those places where they might be required.

B. ACHIEVEMENTS OF PETRÓLEOS MEXICANOS

Petróleos Mexicanos was established in 1938. During the twenty-six years of its existence, it has experienced different types of problems, difficulties and achievements.

In the early years, attention was concentrated on the organization and consolidation of the Mexican petroleum industry.

The phase of growth began after the industry was consolidated. This phase presented Petróleos Mexicanos with a series of problems attributable mainly to growth itself, burdened, as the organization was, by low prices for its products established for social and industrial development purposes.

Then came the phase of achievements. Petróleos Mexicanos can certainly be proud of a long list of achievements carried through under difficult and critical conditions.

Petróleos Mexicanos in recent years has shown a great interest in the development of the petrochemical industry in Mexico. The support of the organization, an institution of outstanding achievements, is the best assurance of the success of the petrochemical industry.

The refining capacity of Mexico has an interest for the petrochemical industry. In 1938, refineries were located mainly along the coast of the Gulf of Mexico at Tampico and Minatitlán. These refineries were established mainly for exports and to supply a small local demand. Petróleos Mexicanos, faced with the task of promoting industrial development throughout the country, first enlarged the Mexico City Refinery and built the Salamanca Refinery in the central part of the Country; the coastal refineries were modernized and their capacity was increased considerably; simultaneously, cracking capacity and secondary processes were increased in all refineries. Later on, the gasolene plants were built, the first major one was Poza Rica, then Pemex City, Reynosa and La Venta. Refineries and gasolene plants have become important suppliers of raw materials for the petrochemical industry.

III. Petrochemical industry

The technical development of the refining process of the petrochemical industry has responded well in quantity and in quality to the demands of the market for fuels and other products. The industry undertakes cracking processes and hydrocarbon synthesis by the application of physical-chemical methods based on the thermochemical properties of hydrocarbons. These developments were the origin of so-called petrochemistry, which is nothing more than a section of the chemical industry, using hydrocarbons as raw materials. These raw materials are chemical compounds derived from petroleum or natural gas. As technology developed, the refineries obtained an ever-increasing amount of by-products, generally gases, which, because of their convenient disposal and low cost, became ideal raw materials for the preparation of chemical products, products that displaced from the market those products which were being processed by the use of other technology and more expensive raw materials.

As the refineries were increasing in size and in complexity through the use of new processes, a growing amount of waste gases was made available: gases that constitute the ideal raw material for the petrochemical processes. This abundant availability favours the construction of petrochemical units of large capacity that reduce production costs and allow the sale to the public of articles at a low price.

Parallel to the development of the petrochemical processes based on the use of waste gases from the refineries, natural gas (methane and ethane) began to be used as an important raw material for the petrochemical industry. Also, the products obtained from absorption plants (gasolene plants) began to be important raw materials (propane, butane). A country that has natural gas reserves has a very important resource for the development of petrochemical industries.

Those countries which do not have natural gas and, on the other hand, do not have an abundant production of gases as by-products of refineries, because these are of small capacity, have to turn to the use of specific processes for the production of these gases by the disintegration of naphthas, distillates or light fractions of petroleum.

The impressive progress of the petrochemical industry in Mexico through the activities of Petróleos Mexicanos has placed the country in an excellent situation for the establishment and development of petrochemical industries.

Mexico possesses great reserves of natural gas in different parts of the country. Petróleos Mexicanos operates four refineries, of capacities from 80,000 to 175,000 barrels per day, which produce products that can be utilized as raw materials for petrochemical plants of adequate capacity. This situation, coupled with an increasing market, consequence of the growth of population and of its progress in general, assures the success of present and future operations. The great progress of the operations in the Pemex refineries has indicated the need for them to participate in the chemical industry, not only as an economic measure, but also as a conservation measure for the best utilization of a non-renewable resource. Thus, rather than the gases produced being moved or otherwise disposed of they are utilized in the fabrication of useful chemical products.

IV. Petrochemical legislation

From the contents of section 3, clause III, of the regulations of article 27 of the Constitution, it is clear that the nation reserves to itself the exclusive right to process the basic industrial raw materials from the petroleum. However, the Government, conscious of the significance for Mexico represented in the development of the petrochemical industry and using it to promote properly this very important economic activity, enacted legislation for the petrochemical industry in general, establishing the limits of the basic petrochemical industry in chapter VIII of the regulations of article 27 of the Constitution, which provides as follows

> *Section 26*. The petrochemical industry consists of the production of compounds not within the limits of the basic products of refining to which Section 23 refers, starting partially or totally from natural petroleum, hydrocarbons or those which are products or by-products of refining operations.
>
> *Section 27*. It is vested in the nation, through Petróleos Mexicanos or through institutions or corporations subsidiaries of Pemex or associated with it, established by the Government, in which no private individual can have any investment in the manufacture of the products susceptible of serving as basic raw materials which are the result of the petrochemical processes, based on the first important chemical transformation or on the first important physical process which takes place, starting from products of by-products or refining or of natural hydrocarbons of petroleum or that have fundamental, social or economical interest for the Government.
>
> *Section 28*. The elaboration of products which result from further petrochemical processes to those mentioned in the previous section, constitute the field in which the Government, private investors independently associated with the Government through Petróleos Mexicanos, or subsidiary institutions or corporations of Petróleos Mexicanos or associated with this institution, established by the Government, can operate, in a non-exclusive form.
>
> *Section 29*. In cases of doubt as to whether the processing of a specific product belongs or not within the field reserved exclusively for the nation, decision will be taken by agreement of the Federal Government, with the participation of the Secretarias del Patrimonio Nacional and Industria y Comercio, after hearing the opinion of Petróleos Mexicanos.

Thus, two petrochemical fields are established. The basic one, which can be called Government petrochemical industry, is constituted by installations that convert the components of natural gas, petroleum or its derivatives into intermediate or semi-elaborated products. The second field, which may be called private petrochemical industry, corresponds to the group of plants which carry out the further transformation of those intermediate or semi-elaborated products into petrochemical products for sale to the public.

There are cases in which, as a result of the first transformation, products (ammonia) ready for sale to the public will be obtained where there is no need to make further transformation and obviously it is not possible to allow the participation of the private sector in this operation, which is carried out exclusively by the Government.

From the regulations of sections 27 and 28 quoted, it is convenient to specify the cases in which the Government processes the petrochemical raw materials by itself the cases in which it becomes associated with the private sector for further processing and those cases in which it permits the exclusive processing of raw materials by the private sector.

To establish the most suitable criteria, the Government must consider the following

(1) *Social action*. If a specific installation is to be established in order to manufacture products at low cost so as to improve the standard of living of the population in general or of important sectors of the population, as, for example, to make available fertilizers to the farmers, unquestionably this type of activity belongs to the Government.

(2) *Regulating action*. The Government assumes the responsibility of supplying the raw material common to various industries and it is concerned with carrying out a just distribution, not a discriminatory one, of such material.

(3) *Industrial promotion action*. The Government promotes the development of the petrochemical industry in order to assist in the general industrialization of the country. It is in such cases that the Government participates with private investors in the establishment of the necessary installations for the further processing of the basic raw materials obtained. In other cases, it simply supplies the private sector with the basic raw materials for their further conversion by the private sector into products for sale to the public in general.

(4) *Protective action*. The Government has the function of helping Mexican investors to have greater participation in the development of the petrochemical industry, and it puts limits to the share of foreign capital in petrochemical corporations.

From what has been said it is obvious that the national interest must be the predominant factor in the development of the petrochemical industry.

However, the Government cannot be restricted in action for the national interest, neither can it establish rigid rules that inhibit industrialization.

These criteria and the provisions stipulated in sections 27 and 28 of the regulations described above, are the guide lines which determine the activity of the Government in the processing of the basic petrochemical products and the participation of the private sector in the processing of secondary products, always subject to national economic and social interests and the aim of improving the standard of living of the population in general.

The progress of the petrochemical industry gives an increased value to the hydrocarbons, previously used mainly as fuels, if account is taken of the conversion of fuel products into basic petrochemical products, which are subsequently converted into a large group of industrial and domestic products, such as synthetic fibres, fertilizers and plastic products.

Lastly, the nation is interested in developing strong export markets and, in order to achieve this purpose and to obtain certain types of technology, it has been convenient to associate with international corporations, which participate as minority investors with Mexican capital in control, for the accelerated development of the industry and to obtain a larger production at a lower cost. This type of enterprise also allows a wider distribution at a lower price, this being a recommended form of operation in the international field.

V. Permits and the Petrochemical Commission

Section 30 of the regulations of article 27 of the Constitution determines the position of the Government in relation to the granting of permits to the private sector for the manufacture of products derived from the petrochemical industries. These permits are granted by instructions from the Federal Government, with participation of the Secretarías del Patrimonio Nacional and Industria y Comercio, after hearing the opinion of Petróleos Mexicanos.

These Regulations provide for the establishment of a technical group known as the National Petrochemical Commission which is headed by the Ministers of Patrimonio Nacional and Industria y Comercio, and the General Director of Petróleos Mexicanos.

Its purpose is to study the applications presented by corporations interested in the establishment of petrochemical industries. The Commission consults with specialized personnel on the technical, legal and economical aspects in studying the information submitted, which must contain the following:

A. *The product and its manufacture*

- (*a*) Chemical and physical characteristics.
- (*b*) Description of process.
- (*c*) Raw materials, cost of electricity and fuels which are required for each unit of product.
- (*d*) Suppliers of the main raw materials.
- (*e*) Flow diagram and material balance.
- (*f*) By-products.
- (*g*) Patents and licences of process to be used.

B. *Market (national consumption)*

- (*a*) Volume and costs of internal production for previous ten years.
- (*b*) Cost and volume of imports during the previous ten years (it is suggested that information available on the importation of substitute products be included).
- (*c*) Use of the product and substitutes available.
- (*d*) Principal consuming industries.
- (*e*) When available, the geographical distribution of actual market.
- (*f*) Criteria used in order to estimate future consumption of the product.

C. *Plant location*

Site in which the plant is to be constructed and factors that determined its location.

D. *Plant capacity and investments required*

- (*a*) Size of the plant.
- (*b*) Criteria used to determine its capacity.
- (*c*) Total investments forecast (the various aspects must be detailed and the investments must be divided into national currency and foreign exchange).
- (*d*) Working capital.

E. *Production costs*

- (*a*) Direct costs.
- (*b*) Indirect costs.
- (*c*) Sales price.

This information must be presented in the greatest possible detail, so that the different items of costs can be identified, such as the cost of production, royalties for patents, licences and technical services, distribution costs, financial charges, investment yields and others.

F. *Distribution of the products*

- (*a*) Internal market: zones, sectors of population or industries. Volumes.
- (*b*) Foreign market: countries, volumes and prices.

G. *Financial aspects*

- (*a*) Capital required.
- (*b*) Mexican capital.
- (*c*) Foreign capital.
- (*d*) Principal shareholders, individual holdings and nationality.
- (*e*) Source of finance (internal and external).

The function of the Petrochemical Commission covers the following aspects:

1. To study the applications and to approve them, refuse them, or postpone decisions on them, as the case may be, mainly after taking into account special considerations, such as the lack of market, the lack of adequate investments or the lack of effective technology.

2. To discuss with the interested parties to obtain their agreement to change the projects presented to different ones, taking into account the knowledge of the market for the establishment of a given industrial plant, with the object of avoiding the formation of monopolies or the duplication of investments, as the case may be.

3. To study the availability of the Government participating with private corporations in the manufacture of certain products, endeavouring to adjust the interests of the Government and those of the private sector.

4. To supervise that the permit which is granted as a consequence of the study of the application is granted to a corporation formed in accordance with the laws and regulations applicable for Mexicans and foreigners.

PETROCHEMICAL PERMIT

Based on the ruling of the Petrochemical Commission, the Federal Government grants the permit requested, mentioning the merits and characteristics of the industrial installation and establishing the conditions that the corporation must fulfil in order to make use of the permit. It is an established practice to demand a bond from the corporation requesting the permit. This bond is requested so that the corporations might proceed to the construction and operation of the plant once the permit is received, and also in order to avoid the possibility of the permit being passed to other companies.

The following is an example of one of the permits that has been granted:

"*Decree granting to Celanese Mexicana, S.A., permit not transferable, to install and operate a plant for the manufacture of polyester fibres and their polymer, starting from dimethyl terephthalate and ethylene glycol*.

"Decree to the Secretarías del Patrimonio Nacional and Industria y Comercio,

"Taking as a basis sections I and 3 of the Regulations of article 27 of the Constitution, regarding petroleum, sections 1, 26, 28 and 30 of the Regulations of the above-mentioned Law, dated August 24, 1959, and published in the "Diario Oficial" of the Federation of August 25, 1959,

"*Considering* that before the Secretarías del Patrimonio Nacional and Industria y Comercio, Celanese Mexicana, S.A., presented an application to install and operate plants for the extrusion and stranding of polyester fibres and the processing of their polymer, utilizing as petrochemical raw materials, dimethyl terephthalate and ethylene glycol,

"*Considering* that said application was turned over to the Commission for the study of the Petrochemical Industry, integrated by representatives of the Secretarías del Patrimonio Nacional and Industria y Comercio and of Petróleos Mexicanos, and that said Commission was of the opinion that it is convenient to grant this permit to elaborate the mentioned products, due to the fact that (*a*) the elaboration of the mentioned products corresponds to the field in which private investors can participate, according to the stipulations of section 28 of the regulations of article 27 of the Constitution, in the section on petroleum, (*b*) it is economically feasible to make the installation of another plant for the elaboration of the solicited products; (*c*) this will supply the textile industry with polyester fibres which are imported at the present time; (*d*) it will substitute annual imports of approximately 16 million pesos for each 1,000 metric tons of fibre extruded and consumed in the country, and 6 million pesos for each 1,000 tons of polymer manufactured in the country; (*e*) it will partially substitute wool in the manufacture of textiles, thus avoiding more increases in the importation of this fibre; (*f*) it will enlarge the possibility of exporting polyester fibre to the countries in the Latin American zone of free commerce and to other nations,

"*Considering* that the project will be developed in two stages; in the first one, 2,000 metric tons per year of short fibre will be produced and approximately 20.5 million pesos will be invested. In the second stage, up to 2,750 tons of polymer and 500 metric tons of continuous filament will be processed, with an investment of 16.5 million pesos. This plant will be located in Toluca, state of Mexico.

"*Considering* that Petróleos Mexicanos, in letter of 11 February of 1964, judged it convenient that Celanese Mexicana, S.A., be granted the permit to process polyester fibres and their polymer.

"*Considering* that it is convenient for the national economy to have the installation of another plant for the manufacture of the polyester fibres and their polymer, and that this activity is not reserved exclusively to the Government, but that it may be carried out by the private sector, I have ordered the issuance of the following:

"*Decree*

"*First*. Celanese Mexicana, S.A., is granted permit, not transferable, to install and operate a plant for the manufacture of polyester fibres and their polymer, starting from dimethyl terephthalate and ethylene glycol.

"*Second*. Celanese Mexicana, S.A., will produce in its first stage two thousand tons per year of short fibre of polyester with an approximate investment of 20.5 million pesos and in the second stage up to 2,750 metric tons per year of polymer and five hundred tons per year of continuous filament, with an approximate investment of 16.5 million pesos. The plant will be located in Toluca, state of Mexico.

"*Third*. Celanese Mexicana, S.A., will be obliged to maintain in a permanent manner a minimum of 51 per cent of the corporate capital in the possession of Mexican investors and to prove this circumstance at any time to the satisfaction of the Federal Government. The foreign investors that have or acquire a certain interest in Celanese Mexicana, S.A., will be subject in any case to the laws in force as regarding foreign investments.

"*Fourth*. Celanese Mexicana, S.A., will sell wholesale the material products of this permit at prices that will not exceed 15 per cent of the normal internal prices of the North American market, provided that the raw materials can be acquired in the country at conditions and prices similar to the normal internal ones of said market. If, due to the magnitude of the national market and other factors of the cost of manufacture, the wholesale prices should be above the marked percentage, the company shall submit the case to the Secretaría de Industria y Commercio so that, after a careful study, the corresponding prices be authorized.

"*Fifth*. Celanese Mexicana, S.A., is obliged to initiate and finish the installation of the first unit of 1,000 tons per year of short fibre, within the terms of six to eighteen months, starting on the date of publication of the present decree in the 'Diario Oficial'.

"*Sixth*. Celanese Mexicana, S.A., within a term of two months, starting on the date of publication of the present decree in the 'Diario Oficial' of the Federation, shall present before the Secretarías del Patrimonio Nacional and Industria y Comercio bond in favour of the Treasury of the Federation in the amount of one million pesos to guarantee the carrying out of the construction works and installations within the respective appointed terms.

"*Seventh.* This permit will be cancelled, except for motives of proven superior force in the opinion of the competent Secretarías, for the following reasons: I. the lack of presentation of the bond within the respective term; II. if the construction works and installations are not begun within the term marked to the effect, circumstance in which the bond will be cashed; III. if in the fixed-term for the termination of the plant at least 60 per cent of the equipment should not be installed, the bond also will be cashed.

"*Eighth.* The Secretarías del Patrimonio Nacional and Industria y Comercio shall proceed, within their sphere of competence, to fulfill the present decree.

"Given in the residence of the Executive Federal Power, in Mexico City, Federal District, on the twentieth day of May of nineteen hundred and sixty-four. The Constitutional President of the United States of Mexico, Adolfo López Mateos. *Signature.* The Secretario del Patrimonio Nacional, Eduardo Bustamante. *Signature.* The Secretario de Industria y Comercio, Raúl Salinas Lozano. *Signature.*"

PERMITS GRANTED

During five years of activity, the Petrochemical Comission has given thirty permits covering plants with an estimated cost of 3,543.9 million pesos and with a production value of 3,675.219 million pesos. A complete list is attached.

PETROCHEMICAL INDUSTRY, AUGUST 31, 1964

Private enterprises

Number	*Concessionary enterprise*	*Products*	*Production (tons/year)*	*Investment (million pesos)*	*Maximum estimated production value/year (in million ps.)*
1	Fertilizantes del Bajío, S.A.	Urea	57,250	81.5	83.000
2	Negro-Mex, S.A.	Carbon black	15,000	31.0	33.045
3	Canamex, S.A.	Detergent emulsifiers, not ionic	1,200	2.4	2.060
4	Fenoquimia, S.A.	Phenol	5,400	25.0	25.245
5	Adhesivos Resistol, S.A.	Butadienne-styrene emulsions	2,160	2.0	10.709
6	Fertilizantes de Occidente S.A.	Granulated fertilizers	7,500	15.0	12.878
7	Fertilizantes Delta, S.A.	Granulated fertilizers	3,200	1.0	5.904
8	Química General, S.A.	Acetone, methyl isobutyl carbinol, methyl isobutyl ketone, alcohol diacetone, mesityl oxide	10,000	45.0	37.170
9	Química General, S.A.	Acetic acid, acetic anhydride, vinyl acetates, ethyl alcohol, butanol, croton aldehyde	17,000	125.0	160.562
10	Química General, S.A.	Methyl ethyl ketone	1,200	4.0	2.000
11	Industria Nacional Químico-Farm., S.A. de C.V.	Methanol	15,000	40.0	23.500
12	Polímeros de México, S.A.	Polyester fibres	5,000	54.0	150.000
13	Derivados Macroquímicos S.A.	Mono-chloracetic acid	1,300	3.8	6.806
14	Salicilatos de México, S.A.	Benzoic acid, benzoates derivatives	1,100	2.5	1.809
15	Industria Acrílica de México, S.A.	Methyl metacrylate	1,200	9.5	8.265
16	Química Orgánica, S.A.	Epoxy resins	1,000	4.0	21.500
17	[illegible], S.A.	Caprolactam	10,000	120.0	92.500
18	Polaquimia, S.A.	Tenso active agents	10,000	1.0	1.717

Private enterprises (continued)

Number	*Concessionary enterprise*	*Products*	*Production (tons/year)*	*Investment (million pesos)*	*Maximum estimated production value/year (in million ps.)*
19	Polioles, S.A. de C.V.	Mono and dipropylene glycols, polyols	2,000	13.1	7.990
			1,800	13.0	3.090
20	Industrias Derivadas del Etileno, S.A.	Ethanolamines, ethylene glycols	2,000		
			8,500	20.9	55.137
21	Síntesis Orgánica, S.A.	Phthalic anhydride	5,000	34.0	30.000
22	Ingsam, S.A.	Surfactants (non ionic)	800	1.0	9.600
23	Polaquimia, S.A.	Dichlorophenox acetic acid, pentachlorophenol	800		8.156
			800	2.0	4.456
24	General Mills de México, S.A.	Polyamides	400		0.686
		Fatty amides	400	4.0	0.686
25	Acetato Interamericano, S.A.	Cellulose acetate	20,000	216.0	320.500
26	Industrias Atlas, S.A.	Acrylic resins	1,000	3.0	16.400
27	Adhesivos Resistol, S.A.	Formaldehyde	3,600	2.0	6.400
28	Onyx-Mex, S.A.	Polyvinyl chloride	2,000	12.0	11.700
29	Química Orgánica Mexicana, S.A. de C.V.	Nitrobenzene, pentachloronitrobenzene	600		1.567
			600	5.0	1.567
30	Celanese Mexicana, S.A.	Polyester fibres, polymer short fibres	2,750		
			500	37.0	96.258
		SUB-TOTAL		929.7	1,253.083

Mixed enterprises

Number	*Concessionary enterprise*	*Products*	*Production (tons/year)*	*Investment (million pesos)*	*Maximum estimated production value/year (in million ps.)*
1	Fertilizantes del Istmo, S.A.	Urea, nitric acid, ammonia nitrate, sulphuric acid, phosphoric acid, complex fertilizers	36,500		59.925
			55,000		53.350
			73,000		91.250
			55,000		27.156
			18,250		24.126
			128,000	330.0	172.800
2	Tetraetilo de México, S.A.	Tetraethyl lead (ethylic fluid)	24,000	113.0	225.500
3	Derivados Etílicos, S.A.[a]	Ethylene oxide	12,000	53.3	51.120
4	Hules Mexicanos, S.A.[a]	Synthetic rubber (SBR)	44,500	175.0	279.994
5	Acetaldehído de México, S.A.[a]	Acetaldehyde	24,000	61.0	57.600
6	Poliray, S.A.[a]	Polyethylene	18,000	109.0	114.102
7	Derivados Clorados, S.A.[a]	Ethylene chloride, ethylene dichloride, ethylene dibromide, vinyl chloride	13,000	26.0	35.750
			30,000	28.5	55.100
			5,000	4.5	42.025
			18,000	23.5	53.400
		SUB-TOTAL		923.3	1,346.088

Productions of Petróleos Mexicanos

Number	Plant location	Products	Production (tons/year)	Investment (million pesos)	Maximum estimated production value/year (in million ps)
1	Minatitlán	Benzene, toluene, O-xylene, m- and p-xylenes	104,900		133.957
			21,800		21.167
			12,500		16.100
			42,000	630.0	45.696
		Ethylbenzene	20,500	29.7	45.100
		Cyclohexane [a]	20,410	37.5	39.023
		Ammonia	66,000	125.0	66.579
		Carbonic gas	79,300	20.0	2.274
2	Pajaritos	Ethylene [b]	36,000	110.0	50.400
3	Atzcapotzalco	Dodecylbenzene	23,100	25.0	86.625
4	Salamanca	Ammonia	66,000	125.0	66.579
		Carbonic gas	79,300	20.0	2.274
		Oil Carbon black, ammonium sulphide	30,000		
			2,000	15.0	16.060
5	Madero	Ethylbenzene [b]	20,500	29.7	45.100
		Dodecylbenzene	23,100	28.0	86.625
		Butadiene [b]	30,000	116.0	91.500
		Styrene [b]	30,000	60.0	90.750
6	Reynosa	Ethylene [b]	36,000	110.0	50.400
7	Chihuahua	Ammonia [b]	132,000	175.0	115.896
		Carbon dioxide	158,500	35.0	5.943
		SUB-TOTAL		1,690.9	1,078.048

	Investment (million pesos)	Maximum estimated production value/year (million pesos)
Private enterprises	929.7	1,253.083
Mixed enterprises	923.3	1,344.088
Petróleos Mexicanos	1,690.9	1,078.048
TOTAL	3,543.9	3,675.219

[a] Under construction.

[b] Plant under construction.

16. THE PETROCHEMICAL INDUSTRY AND ITS FUTURE IN PAKISTAN

A. Rahman, Investment Advisory Centre of Pakistan

Pakistan has substantial deposits of natural gas, both in East and West Pakistan, and the Government of Pakistan has given permission to several companies to produce petrochemical intermediate and end-products based on natural gas. The country has already made considerable headway in the manufacture of fertilizer from natural gas in both areas of the country.

The internal oil resources of Pakistan meet only 20 per cent of the country's demand for petroleum products, the remainder being met by imported crude which is processed in the country. Currently, Pakistan has two oil refineries, one at Karachi and the other at Rawalpindi, whose total refining capacity is 3 million tons *per annum*. Two more refineries are scheduled to be constructed by the end of 1965 — one at Karachi based on heavy crude with a capacity of a little over half a million tons *per annum*, and the other at Chittagong with a capacity of one million tons *per annum*.

As a result of substantial surplus naphtha, off-gases and mixed aromatics from these four refineries the Pakistan Government is actively considering the intallation of an integrated petrochemical complex in both areas of the country. This complex is to be based on natural gas and surplus refinery products. In the Third Five-Year Plan, which starts in the year 1965, the development of the petrochemical industry has been given special importance. Pakistan has already engaged consultants on the planning of the petrochemical industry and their report is complete and under active consideration. United Nations experts are also helping Pakistan in the planning of her petrochemical development programme in the Third Five-Year Plan.

Because of her large deposits of natural gas in both areas it is natural that Pakistan is placing more emphasis on the use of natural gas and less on petroleum products in the development of petrochemical industry.

To meet the demand of various end-products, Pakistan is seriously considering the installation of two naphtha crackers, one in each area of the country. The requirement of feed material for various end-products is such that it suggests maximum recovery of ethylene and minimum recovery of propylene from the naphtha cracker. Since Pakistan does not have any coke-oven plants, there is also a strong possibility of installing one aromatics production unit independently to meet the requirements of aromatic hydrocarbons in the proposed petrochemical complex.

APPROVED PETROCHEMICALS PLANT

Pakistan has already approved a sufficient number of projects based on natural gas. Some of these projects have already gone into production and the rest are in the construction and planning stages.

The following are the approved projects:

Urea fertilizer	3,460,000 t/yr
Ammonium nitrate	99,000 t/yr
Acetate rayon	3,000 t/yr (present raw material is molasses)
Acetylene	5,800 t/yr
Methylacrylate	700 t/yr
Polyacrylonitrile	5,000 t/yr
Polyvinylchloride	5,000 t/yr
Polyethylene	5,000 t/yr (present raw material is molasses)
Polyester fibre	3,500 t/yr
BHC (50 per cent w.p.)	4,500 t/yr
DDT (50 per cent w.p.)	2,500 t/yr
Methanol	3,000 t/yr
Formaldehyde (37 per cent)	5,100 t/yr
Urea formaldehyde resin	2,150 t/yr

PETROCHEMICAL PROJECTS UNDER CONSIDERATION

A major step has already been taken by the Government of Pakistan in providing a substantial allocation of funds for establishment of the petrochemical complex industry in the Third Five-Year Plan starting in the year 1965.

As mentioned previously, foreign consultants have submitted their reports on the basis of long-term planning for the integrated petrochemical complex industry in both areas of the country based on natural gas and surplus refinery products. The recommended projects include production of more than one million tons of nitrogenous fertilizer and about thirty-five other petrochemical products such as plastics, fibres, resins, rubber, insecticide and organic chemicals.

The major portion of the petrochemical complex industry in Pakistan will be in the private sector. The Government of Pakistan is encouraging private foreign investors to collaborate with Pakistani patrons particularly in the form of foreign capital investment and technical know-how. Favourable policies have already been formulated to attract foreign capital to Pakistan and any foreign investment in the proposed petrochemical industry would be treated favourably.

17. THE PETROCHEMICAL INDUSTRY IN EAST PAKISTAN

S. A. Momen, Director, East Pakistan Industrial Development Corporation

When analysing the most outstanding differences between western industrialized areas and under-developed areas like Pakistan, it is found that the high *per capita* gross domestic product in the former originates mainly from industry or related activities. The share of agriculture does not as a rule exceed 20 per cent. The share in value added by industrial productivity in these areas accounts for roughly 88 per cent of the world figure. Their high share in world export originates mainly from commodities supplied by industry, whilst the share of agricultural products amounts roughly to 20 per cent. The high agricultural productivity is mainly based on fertilization with domestically produced fertilizers. A high state of nutrition results either from high agricultural productivity or from food imports paid with foreign exchange earned through the export of manufactured goods.

In consequence, the first task of a country which aims at a bigger gross domestic product and thus a higher standard of living, will be industrialization and an increase in agricultural productivity. Industrialization depends on raw materials, capital and skilled labour. Higher agricultural productivity is mainly achieved by intensive use of fertilizers.

As the experience of industrialized countries has taught, fertilizer and scarce raw materials can best be supplied by chemical industry. In the last decade, this task has been increasingly fulfilled in the United States, Canada, the United Kingdom, Western Europe and Oceanic countries by a special branch of the chemical industry, namely, the petrochemical industry.

Petrochemistry produces organic chemicals and fertilizers by changing the molecular structure of hydrocarbon. It supplies a very large number of petrochemical derivatives.

According to their end-uses, petrochemicals can be roughly divided into the following groups:

A. Nitrogenous fertilizers;
B. Synthetic rubbers;
C. Synthetic fibres;
D. Plastics and resins;
E. Pesticides;
F. Dyestuffs;
G. Others.

Petrochemical products can also be classified according to their sources. They are derivatives of one or more of the following: (i) acetylene; (ii) ethylene; (iii) propylene; (iv) C_4 hydrocarbons; (v) higher olefins; (vi) higher paraffins; and (vii) aromatics.

Petrochemical industry is growing rapidly. Factors responsible for this rapid growth are:

(*a*) Increased demand for petrochemical products.

(*b*) Abundant reserve of cheap raw materials.

(*c*) Motor car boom in industrialized countries.

(*d*) Chemical processing of crude oil and natural gas is cheaper than processing of coal and organic matters.

It is, therefore, imperative that Pakistan, aiming at economic development and higher living standards, should extend her resources and energy in order to develop a petrochemical industry.

Crude oil and natural gas can be used as feedstocks for petrochemicals. The discovery of a substantial quantity of recoverable reserves of natural gas has thus opened up fresh avenues for further industrialization, particularly in the field of petrochemicals.

The Government of Pakistan realized that industrialization, especially in the field of chemicals, was an important means of increasing agricultural and industrial productivity and consequently, also, the gross domestic product and standard of living. Accordingly, a firm highly knowledgeable in this line was appointed as consultants by the Government of Pakistan to look into the possibilities of developing petrochemical industries in Pakistan.

Summing up their findings, these consultants observed that agricultural productivity was low, mainly owing to insufficient use of fertilizers. It could be improved by increased application of locally manufactured fertilizers and pesticides.

Pakistan's foreign trade has been unbalanced. Exports consist mainly of unprocessed raw materials, whilst imports are characterized by a large volume of processed goods, including chemicals. It appears desirable, therefore, to process indigenous raw materials before they are exported and to substitute for imports locally processed goods as far as possible.

Pakistan's contribution to the value added by industry is extremely low and out of proportion for a country with the sixth largest population of the world. Further industrialization is, therefore, most essential.

The structure of the various industries in Pakistan is also unbalanced. Apart from a large cotton and jute industry, there are only a few other important industries.

Availability of indigenous raw materials in Pakistan is rather narrow. Apart from jute and cotton, only natural gas is available in quantities sufficient for further industrialization.

It has, therefore, been strongly recommended that the industrialization of Pakistan be undertaken in the field of petrochemicals, on the basis of natural gas and petroleum refinery by-products. This would contribute considerably towards an increase in Pakistan's agricultural and industrial production. At the same time, it would lead to a most desirable increase in the *per capita* national income, which is, at present, extremely low. This is more so in the case of East Pakistan, where density of population is extremely high.

The first refinery in East Pakistan, which is now under construction, is scheduled to begin operations in 1966 and will be located in Chittagong. This refinery is designed for a capacity of 1 million tons/year of crude oil. The refinery is expected to work with an initial capacity of 60 per cent and by 1970 it is likely to work at full capacity.

In these circumstances, roughly 75,000 tons/year of light naptha and refinery off-gas will be available from the refinery in the initial years in a ratio of about 3:1. These products are suitable feedstocks for petrochemical plants.

The demand for petroleum products will gradually increase considerably. The refinery will consequently increase its crude distillation. By 1970, it is expected that its capacity will increase by 10 to 20 per cent which will be sufficient to meet the requirement for the feedstocks. Furthermore, all low-boiling products will also be available from the proposed increase in capacity. In that case, it will be possible to make available 165,000 tons of light and full range naptha by 1970. The requirements of the complex in 1980 will be 250,000 tons of full range naphtha and 50,000 tons of platformate.

It is to be expected that the capacity of the refinery in East Pakistan will be expanded in the course of the next fifteen to twenty years. If these extensions are made in the light of the requirement of the petrochemical complex, it is likely that the whole feedstock requirements can be covered. Based on the average rate of the refinery products, it can be expected that the refinery capacity will be extended, up to 1980, to a capacity of 2.5-3 million tons per year of crude oil. Accordingly, it is assumed that 250,000-300,000 tons per year of light and full range naphtha will be available, by 1980, for the complex. As regards the 50,000 tons of platformate requirement for the production of aromatics, it would be necessary to install a platforming unit with a corresponding excess capacity.

East Pakistan possesses large deposits of natural gas, which represent a sound basis for the further industrialization of the country. It has been estimated that the natural gas resources discovered in East Pakistan amount to approximately 2.78 × 10^{12} cu. ft. These resources are distributed as follows:

	Cu. ft.
Sylhet	0.28×10^{12}
Chattack	0.02×10^{12}
Kailashtila	0.38×10^{12}
Rashidpur	0.74×10^{12}
Titas I	0.56×10^{12}
Titas II	0.80×10^{12}
	2.78×10^{12}

Current consumption of natural gas in East Pakistan is limited to the uses in a fertilizer factory and a cement factory. It is planned to construct a pipeline from Brahmanbaria (Titas II) to Dacca by 1967 for industrial utilization.

Quantities of natural gas required for the petrochemical complex are:

	Cu. ft./day
1970	Approx. 41.6 million
1980	Approx. 77.0 million

The proposed petrochemical complex for the utilization of naphtha feedstock, refinery gas and natural gas is designed as an integrated complex with a common power station and auxiliary plants.

The capacities of the plants have been determined according to the market survey carried out to evaluate the consumption in 1970 and 1980 and also on the export possibilities which exist for the various products. The selected products comprise about ten types of plastics, resins and synthetic rubber for processing the plastic films, pipes and various other products of everyday use. Preference has been given to products the consumption of which shows an upward trend. Furthermore, the production of four types of artificial fibres of increasing importance has been suggested.

The proposed capacities are in line with the estimated consumption in 1980 and also with the aim of exporting 30-35 per cent of the production and retaining a reasonable overcapacity.

Assuming an average consumption of 1-2 kg of plastic *per capita* and normal rate of increase of population, the consumption of all plastics, including reasonable export quota, is expected to be between 70,000 tons and 140,000 tons per year in 1980 based on a population of 60 million. The proposed production capacity of the petrochemical combined plant, as far as plastics, resins and synthetic rubber are concerned, is 100,000-120,000 tons per year, including a reserve capacity of 10-15 per cent. This production capacity is in line with the calculated requirements for 1980.

The consumption of synthetic fibre is equally increasing owing to a higher standard of living and a resulting higher demand for textile products. Consumption has also been favoured by the fact that textile consisting of a mixture of natural fibres and synthetic fibres is being used increasingly. Some types of artificial fibres, especially in technical application, possess superior qualities to natural fibres. Assuming *per capita* consumption of 0.5 kg in 1980, consumption of synthetic fibres in East Pakistan will be 30,000 to 40,000 tons and plant capacity has been recommended to that extent.

Apart from the production of plastics and synthetic fibres, the petrochemical complex plant is designed for the production of the majority of the auxiliary products which are required for the establishment of a local plastic and fibre industry. These auxiliary products include plasticizers and auxiliary products for textile industry detergents and are made on the basis of the intermediate products obtained in the combined plant.

RECOMMENDATION FOR PRODUCTION CAPACITIES OF PETROCHEMICAL COMPLEX, EAST PAKISTAN
(In metric tons)

Item	*Production*		*Export*
	1970	*1980*	
A. *Plastics and resins*			
(*a*) Polyvinyl chloride	10,000	21,000	7,000
(*b*) Polyethylene	10,000	20,000	7,000
(*c*) Polystyrene	12,000	12,000	5,000
(*d*) Polyvinylacetate	—	14,000	—
(*e*) Polypropylene	10,000	21,000	7,000
(*f*) Polymethylmetha crylate	—	3,000	1,000
(*g*) Styrenebutadiene copolynurisates	—	10,000	4,000
(*h*) Phenolformaldehyde resin	—	5,000	2,000
(*i*) Urea formaldehyde resins	5,000	10,000	4,000
B. *Synthetic rubber*			
(*a*) Cis-polybutadiene	10,000	12,000	4,500
C. *Synthetic fibres*			
(*a*) Polyacrylonitrile fibres	5,000	10,000	5,000
(*b*) Polypropylene fibres	3,000	5,000	2,000
(*c*) Polyvinyl alcohol	—	4,000	2,000
(*d*) Polyester fibres	—	10,000	4,000
D. *Fertilizers*			
(*a*) *Urea*	160,000	500,000	160,000
E. *Insecticides*			
(*a*) BHC (50 per cent wettable)	4,000	8,000	3,000
F. *Others*			
(*a*) Dioctylphthalate	10,000	10,000	4,000
(*b*) Dioctyladipate	—	12.000	8,000
(*c*) Diodecylbenzene sulphonate	8,500	8,500	—
(*d*) Methanol	20,000	35,000	5,000
(*e*) Formaldehyde	20,000	35,000	7,000
(*f*) Carbon black	—	10,000	4,000
(*g*) Caustic soda	21,400	26,725	—
(*h*) Hexamethylene tetramine	—	1,500	—
(*i*) Pentaerythritol	—	2,000	—

The capacities of the insecticide and fertilizer manufacturing plants have been determined in accordance with the requirements ascertained in the local market survey.

Above, in a nutshell, is shown the projected plant capacities in East Pakistan in 1970 and 1980.

The steam cracking and gas recovery units are to constitute the hub of activities for the recommended complex. The units for individual petrochemical items which have to depend on steam cracking and gas recovery units can be fed directly from such units. Consequently, the logical location for the East Pakistan petrochemical complex is in the Chittagong area where an oil refinery with a capacity of 1 million tons will be constructed by 1966 and a gas pipeline network is envisaged by 1970.

The interdependence of various individual units for their raw materials is such that the Government has decided to participate effectively and the East Pakistan Industrial Development Corporation (EPIDC), an autonomous body of the East Pakistan Government, has been entrusted with the job of setting up a complex at Chittagong. It has already prepared a proposal for such a complex whose total capital cost is estimated to be Rs. 2,911[1] million including a foreign exchange component of Rs. 1,962 million. Divided into two phases, the first, by 1970, involves a total cost of Rs. 1,549 million, with a foreign exchange component of Rs. 1,024 million, having a production cost of Rs. 765 million and gross market value of products at Rs. 1,131 million.

PETROCHEMICAL FROM NATURAL GAS ONLY

One factory with an annual capacity of 110,000 tons of urea has already been in production since 1962. The natural gas requirement of this urea factory is about 19 million cu.ft. per day — 6 to 7 million cu.ft. per day for process, 12 to 13 million cu.ft. for generation of

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[1] One Pakistani rupee = 21 US cents.

20,000 kilowatts of electricity. Another urea factory, based on natural gas, with a capacity of 170,000 tons of urea is in the advanced stage of planning and is expected to go into production by 1968. The immense benefit accruing from the urea factory at Fenchuganj based on natural gas may be gauged from the fact that increase in national agricultural income due to additional yield of crops is valued at Rs. 200 million annually through the use of 100,000 tons of urea from this factory. With the construction of the second fertilizer factory, the additional agricultural income will rise by another 300 million rupees. Another urea factory with a capacity of 500,000 tons will form a part of the petrochemical complex, Chittagong. This urea plant alone will contribute Rs. 10,000 million towards additional agricultural income. We have also thoroughly examined alternative uses of gas other than for making urea, such as the manufacturing of a host of petrochemicals which constitute raw materials for commercial plastics, synthetic resin, synthetic fibre, synthetic rubber solvent and detergent. The production of acetylene, which is the common raw material for all these marketable commodities, is only feasible alongside a huge production capacity of ammonia and/or methanol because about 90 per cent of the cracked gases of the acetylene plant and 80 per cent of the acetylene-ethylene cracking plant is to be used for the production of Ammonia and/or methanol. Consequently such a petrochemical complex from natural gas will need a total capital investment of about Rs. 700 million for a smallest economic unit of integrated projects consisting of either of the following two groups:

GROUP (A)

Plant	*Capacity (tons)*
(1) Acetylene	25,000
(2) Styrene rubber	30,000
(3) Acrylonitrile	25,000
(4) Urea	100,000
(5) Methanol	45,000
(6) Formal 37 per cent. . .	95,000

GROUP (B)

Plant	*Capacity (tons)*
(1) Acetylene	25,000
(2) PVC	16,000
(3) Chloreprene rubber . .	25,000
(4) Urea	100,000
(5) Methanol	45,000
(6) Formal 37 per cent. . .	95,000

The possibility of setting up such a petrochemical complex based on natural gas available in East Pakistan is being examined.

Annex I

EPIDC PETROCHEMICAL COMPLEX

Sl. No.	*Plant*	*Annual capacity*	*Cost per ton of production in rupees*
		Tons of ethylene	
1	Steam cracking and gas recovery . .	70,000	255
		Tons	
2	Aromatics recovery	66,000	487
3	Butadiene recovery	15,000	1,880
4	Acetylene production	10,000	1,810
5	Carbon black production	10,000	950
6	Vinyl chloride production	23,000	805
7	Polyvinyl chloride	21,000	1,490
8	Hp-Polyethylene production . . .	20,000	1,435
9	Vinyl acetate production	15,000	1,320
10	Polyvinylacetate production	14,000	2,210
11	Polyvinylalcohol production . . .	5,500	7,440
12	Polyvinylalcohol fibre production .	4,000	10,250
13	Acetaldehyde production	40,000	625
14	Acetic acid production	11,000	715
15	Ethylene glycol production, including ethylene oxide	5,000	1,530
16	Phthalic anhydride production . .	15,000	1,050
17	2-ethylhexanol production	16,000	1,919
18	Dioctylphthalate production . . .	10,000	2,073
19	Dioctyladipate production	12,000	2,680
20	Styrene production	20,000	1,138
21	Polystyrene production.	12,000	1,710
22	Polypropylene production	21,000	1,480
23	Polypropylene fibre production . .	5,000	9,850
24	Acrylonitrile production	10,000	1,965
25	Polyacrylonitrile fibre production .	10,000	6,570
26	Propylene tetramer production . .	3,500	1,120
27	Dodecyl benzene sulfonate production	8,300	1,440
28	Cis-polybutadiene production . .	12,000	2,770
29	Styrene butadiene copolymers production	10,000	1,699
30	Terephthalic acid production . . .	10,000	2,457
31	Polyester fibre production	10,000	7,155
32	Polymethylmethacrylate including methylmethacrylate production .	3,000	3,500
33	BHC production (50 per cent wettable powder)	8,000	860
34	Methanol production	35,000	482
35	Formaldehyde production	35,000	290
36	Urea formaldehyde resin production	10,000	1,153
37	Phenol formaldehyde resin production	5,000	2,100
38	Chloralkali electrolysis	25,000	288
39	Hexamethylene tetramine production	1,500	2,350
40	Pentaerythritol production	2,000	2,700
41	Urea	500,000	300

Annex II

EPIDC PETROCHEMICAL COMPLEX

Sl. No.	*Sales product*	*Metric quantity (tons per year)*	*Total turnover (million of rupees)*	*Sl. No.*	*Sales Product*	*Metric quantity (tons per year)*	*Total turnover (million of rupees)*
1	Polyvinylchloride	21,000	38.1	24	Hexamethylenetetramine	1,370	3.4
2	Polyethylene	20,000	43.5	25	Pentacrythritol	2,000	6.0
3	Polyvinylacetate	3,000	9.4	26	Touence	23,000	11.1
4	Polyvinylalcohol fibre	4,000	48.4	27	Aromatics	26,000	4.7
5	Polystyrene	12,000	23.2	28	i-Butylene	9,000	1.7
6	Dodecylbenzene sulfonate	8,500	20 5	29	Vinylacetate	700	1.0
7	Polypropylene	15,000	68.9	30	Polyvinylalcohol	1,000	5.5
8	Polypropylene fibre	5,000	66.5	31	Sodium acetate	1,260	1.5
9	Polyacrylonitrile fibre	10,000	145.2	32	Sodium sulphate	1,060	0.2
10	Cis-Polybutadiene	12,000	37.7	33	Acetaldehyde	1,600	1.0
11	Styrene butadiene copolymers	10,000	25.4	34	Ethylene glycol	1,150	1.6
12	Dioctylphthalate	10,000	25.4	35	Polyglycols	730	0.9
13	Dioctyladipate production	12,000	36.3	36	Phthalic anhydride	1,100	1.1
14	Polyester fibre	10,000	151.2	37	2-ethylhexanol	800	2.1
15	Polymethylmethacrylate	3,000	34.4	38	Isotactic polymer	2,000	3.8
16	Carbon black	10,000	9.6	39	Ammonium sulphate	10,360	1.9
17	Urea	495,800	209.9	40	Light polymer	800	0,1
18	Methanol	14,390	6.9	41	Light akylate	1,050	0.1
19	Formaldehyde	11,070	4.6	42	Terephthalic acid	1,000	2.6
20	Urea formaldehyde resins	10.000	31.4	43	Chlorine	6,350	1.9
21	Phenol formaldehyde resins	5,000	16.9	44	Solvents	11,530	5.5
22	Caustic Soda	21,812	7.1				1,131.1
23	BHC (50 per cent wettable powder)	8,000	11.6				

Annex III

REQUIREMENT OF MATERIALS FOR EPIDC PETROCHEMICAL COMPLEX, CHITTAGONG

		Tons/year
1. *Raw materials*		
Light naptha		250,000
Platformate		50,000
Natural gas		550,000
Heavy aromatics		25,000
Benzene		10.300
O-xylene		8,750
2. *Auxiliary materials*		
Acetone	From West Pakistan petrochemicals combined plant	3,270
Adipic acid		5,000

	Tons/year
2. *Auxiliary materials* (continued)	
Filler	3,770
Kaolin or talc	3,700
Sulphuric acid	11,300
Salt	45,000
3. *Catalysts*	Imported
4. *Miscellaneous chemicals*	Local/imported

18. THE PETROCHEMICAL INDUSTRY — PERU

Héctor de Souza Reategui, Empresa Petrolera Fiscal del Peru, Peru

I. Introductory remarks

1. SHORT HISTORICAL SURVEY OF THE DEVELOPMENT OF PETROCHEMICAL INDUSTRY IN THE COUNTRY

Undoubtedly, for many years a great concern has existed in Peru regarding the function of private national and foreign capital in the development of the petrochemical industry, specially in the uses of oil products or natural gas for the manufacture of ammonium fertilizers and others that can be applied to Peruvian soil.

According to the studies made by the Government and, private and international organizations specialized in such matters, it was found that although Peru has a wide area, there are only 1,970,973 cultivated hectares, and, considering the number of inhabitants, 9,906,766, this represents only 0.20 cultivated hectares per man, showing that these lands have a low production capacity which needs to be improved; thus providing the Government with a great task.

On the other hand, it is important to stress that there is a considerable natural market for the petrochemical products, apart from ammonia products, such as urea, carbon black, polyethylene, benzene, and synthetic rubbers.

The Latin American countries in general, and in particular Peru, are potential consumers of fertilizers. These countries, essentially agricultural, export great quantities of their products, and find themselves facing an international competition which is growing stronger all the time. Internally, the extension of the cultivated areas does not keep pace with the demographic pressure and the crops are not sufficient for the inhabitants to survive.

One ploughed hectare that currently feeds, inadequately, 6.2 Peruvians, will have to feed 8 inhabitants in 1975, if the cultivated areas remain as they are. However, for the normal nourishing diet for the population, the ratio should not exceed 3.6 inhabitants per hectare; this is the reason for striving to achieve a growing productivity by the general employment of fertilizers. In this regard, as part of a gigantic plan to increase the cultivated areas, the Peruvian Government during the middle of 1964 approved the agricultural reform project, providing for measures in the coastal, sierra and jungle areas, in order to increase the cultivated areas by 1,000,000 of hectares by the end of its term of office.

2. THE ECONOMIC MOTIVES AND CONSIDERATIONS TO ASSIGN THE GIVEN PRIORITY TO PETROCHEMICAL INDUSTRY

Considering first the economic factor of the agrochemical production, the petrochemical industries contemplated for Peru will have to create a favourable climate for the quick increase of the use of fertilizers, a goal which the present Government wishes to achieve. On the other hand, since Peru is a country where 65 per cent of the population is engaged in agriculture, and since the cultivated areas do not increase in accordance with demographic pressure so as to maintain the necessary rate of 3.6 men per cultivated hectare, as expressed in the preceeding section, the introduction of inexpensive fertilizers would fulfil the immediate and future agricultural needs of Peru.

The consumption of fertilizers in Peru is, of course, dependent on the level of prices at which they could be made available to farmers. At the present level of prices the rate of increase of demand is 7 to 8 per cent annually. This could be compared with Mexico whose nitrogenous fertilizers are locally produced and made available to farmers at low prices; there consumption has grown recently at the rate of 37 per cent.

On the other hand, the fact that Peru has a variety of geographic formations, with the coastal, sierra and jungle regions situated at different levels, means that the fertilizers required for each zone differ in composition and in quantity. Also, the means of transportation between the regions have been developed in the first two zones — allowing regular intercommunication between the two — while the jungle can only be reached by air or water.

To give an idea of the Peruvian market for petrochemical products, its extent is shown in table 1, arranged according to the origin of the products and their principal use. Only those products for which there is an annual demand of S/. 100 have been included, except for some basic products which, even though they do not reach this amount, have been considered of sufficient importance.

The national deficit of ammonia products, used principally in agriculture as fertilizers and in mining as explosives (ammonia nitrate), is of the order of 35,000 metric tons of nitrogen per year.

The volume of sales of these ammonia products is considered as one of the most important indices in the national market. Consequently, availability of an adequate supply of residual oil as a source of raw material is of the greatest importance.

All the products and compounds indicated above can be used in the Peruvian industrial market. Of course, in some cases, it is necessary to promote the use or find the application of the product in industries that may disregard their special application.

TABLE 1. PETROCHEMICAL PRODUCTS — ESTIMATED CONSUMPTION, 1963, CLASSIFIED ACCORDING TO THEIR HYDROCARBON ORIGIN

	(Metric tons)	Value (1,000 soles)
A. METHANE BASED COMPOUNDS		
(a) *Ammonium and its products*:		
1. Ammonium nitrate (a)	37,300	111,000 (b)
2. Ammonium sulfate (a)	105,700	193,600 (b)
3. Urea	12,884	28,672
4. Nitroglycerine	455	4,900
(b) *Other*:		
5. Carbon black	1,822	10,770
6. Formaldehyde phenol	100	3,000
7. Formaldehyde urea	500	7,000
8. Cyanide sodium	904	8,633
9. Cyanide calcium	1,055	4,140
10. Polyacrylic fibres	705	74,000 (b)
B. ETHANE-ETHYLENE BASED COMPOUNDS		
1. Chloride	2,800	29,700
2. Polyethylene	1,800	23,300
3. Glycol	187	1,897
4. Tetraethyl lead	113	6,427
5. Ether	10	378
6. Acetate Cellulose	613	23,419
7. DDT	84	1,126
8. Butyl acetate (see D-2)		
C. PROPANE BASED COMPOUNDS		
1. Acetone	282	1,206
2. Benzene (propyl tetracid)	2,600	14,600
D. BUTANE-BUTENE BASED COMPOUNDS		
1. Synthetic rubber — SBR	2,400	38,400
Synthetic rubber — IIR (butylic)	240	3,800
2. Butylic acetate	422	3,186
E. AROMATIC HYDROCARBON BASED COMPOUNDS		
1. Polyethylene	2,400	28,500
2. Benzene (see C-2)		
3. Nylon	570	77,000
4. Xylol	434	1,207
5. Plastic materials	520	6,240

SOURCE: Official Statistics; W. R. Grace & Co., Fertisa; and International Petroleum Company.

a National production — 1963:
Ammonium nitrate . . . . 34,000 metric tons
Ammonium sulfate . . . . 12,000 metric tons

b Estimated, based on market prices

TABLE 2. ESTIMATED CONSUMPTION OF PETROCHEMICAL PRODUCTS CLASSIFIED ACCORDING TO THEIR INDUSTRIAL USES

	Metric tons	Value (1,000 soles)
A. SOLVENTS		
1. Ether	10	378
2. Acetone	282	1,206
3. Butyl acetate	422	3,186
4. Xylol	432	1,207
B. FERTILIZERS		
1. Ammonium nitrate	34,000	101,000
2. Ammonium sulfate	105,700	193,600
3. Urea	12,884	28,672
C. RESINS AND PLASTICS		
1. Chloride	2,800	29,700
2. Polyethylene	7,200	51,800
3. Formaldehyde urea	500	7,000
4. Formaldehyde phenol	100	3,000
5. Di-octyl phthalate	520	6,240
D. SYNTHETIC FIBRES		
1. Polyacrylic	705	74,000
2. Celulose acetate	613	23,419
3. Polyester	133	14,000
4. Nylon	570	77,000
E. RUBBER PRODUCTS		
1. Synthetic rubber (IIR)	240	3,800
2. Synthetic rubber (SBR)	2,400	38,400
3. Carbon Black	1,822	10,770
F. AUTOMOTIVE PRODUCTS		
1. Glycol	187	1,897
2. Tetra ethylic lead	113	6,427
G. EXPLOSIVES		
1. Ammonium nitrate	3,300	10,000
2. Nitroglycerine	455	4,900
H. DETERGENTS		
1. Benzene	2,600	14,600
I. DISINFECTANTS		
1. DDT	84	1,126

Undoubtedly the Government has the best disposition to help in the development of the petrochemical industry. In the case of the only petrochemical plant, Synthetic Fertilizers S.A., operating in Peru, the Government has annulled almost all import restrictions, until 1971, on oil and jute containers. Also, it is exempted from taxes on utilities until 1969.

Thus, we can say that, in order to attract the investment of foreign capital, the Government in power will take the necessary measures to make those investments possible. We can consider, in that sense, the maintenance on a sound basis of our currency, which is an important point for any investor. Besides, Peru has been and will always be known as a traditional good payer of its debts.

4. SUPPORTING ACTIVITIES FOR PETROCHEMICAL INDUSTRIES

No institution specialized in research exists in Peru, and we can only indicate, for instance, some private companies such as International Petroleum Company and Petrolera Lobitos, and State enterprises such as Empresa Petrolera Fiscal, which are studying the project of installing a petrochemical plant in the northern part of Peru.

Among engineering organizations, we can indicate, for instance, the Agricultural University and Engineering University, where some research is being undertaken into the application of fertilizers produced from animal and vegetable matter. However, their activities are limited.

5. EXPECTED LINES AND RATE OF DEVELOPMENT IN THE FUTURE UNTIL 1970

Table 3 shows the tons of fertilizer to be consumed per year in the different zones, according to programmes which have been developed.

TABLE 3

Region		1965-1970			1970-1975		
		N	P	K	N	P	K
Coast							
North		31,500	17,000	11,400	51,000	34,000	27,000
Centre		20,000	12,200	8,000	22,500	15,000	13,000
South		4,000	3,100	500	12,000	9,000	4,000
	TOTAL	55,500	32,300	19,900	85,500	58,000	44,000
Sierra							
North		12,700	10,000	9,500	21,500	17,000	14,000
Centre		13,200	10,500	8,500	27,000	21,000	18,000
South		13,000	10,000	8,300	32,000	24,200	19,000
	TOTAL	38,900	30,500	26,300	80,500	62,400	52,200
Jungle		5,500	3,000	3,300	20,000	13,200	12,300

The distribution of plants per zone: north, Central and south, is in accordance with the industrial plan proposed in the map (see figure 1); each zone has one or more natural resources which will facilitate the installation of plants to produce fertilizers basically. The north and central part of Peru are better suited because they contain hydrocarbons. Table 4 gives an analysis of some natural gases of the northern part of Peru, and those in the United States, France, and Italy.

In the northern part of Peru, we have gas reserves estimated to suffice for almost thirty years, besides the reserves to be explored in the future.

TABLE 4. ANALYSIS OF SOME NATURAL GASES

	Coyonitas	*Organos*	*Alvarez*	*Portillo*	*Pozo*	*Sheridan*	*(France) Lacq*	*Cortemaggiore*
Methane	97.14	86.25	83.30	90.36	84.80	77.75	69.22	88.9
Ethane	1.83	3.33	5.25	4.61	8.12	6.41	3.26	4.4
Propane	0.21	2.43	3.44	2.46	4.39	5.00	0.97	1.6
i-Butane	0.21	1.37	1.50	0.40	0.40	—	—	—
n-Butane	0.10	1.37	1.95	0.91	0.28	2.00	0.68	0.8
i-Pentane	0.12	3.48	3.13	0.12	0.14	—	—	—
n-Pentane	0.21	—	—	—	—	—	0.20	1.0
CO_2	—	0.40	0.40	0.40	0.40	2.6	9.6	—
O_2	—	0.30	0.20	0.20	0.20	—	—	—
N_2	—	1.13	0.75	0.75	0.75	—	—	—
H_2S	—	—	—	—	—	—	—	—
Sp. Gr.	0.595	0.780	0.760	0.686	0.670	—	—	—
Condensed								
gal/m³	31	—	—	—	—	—	20	—
gal/1000 feet³	1.13	—	—	—	—	—	—	—

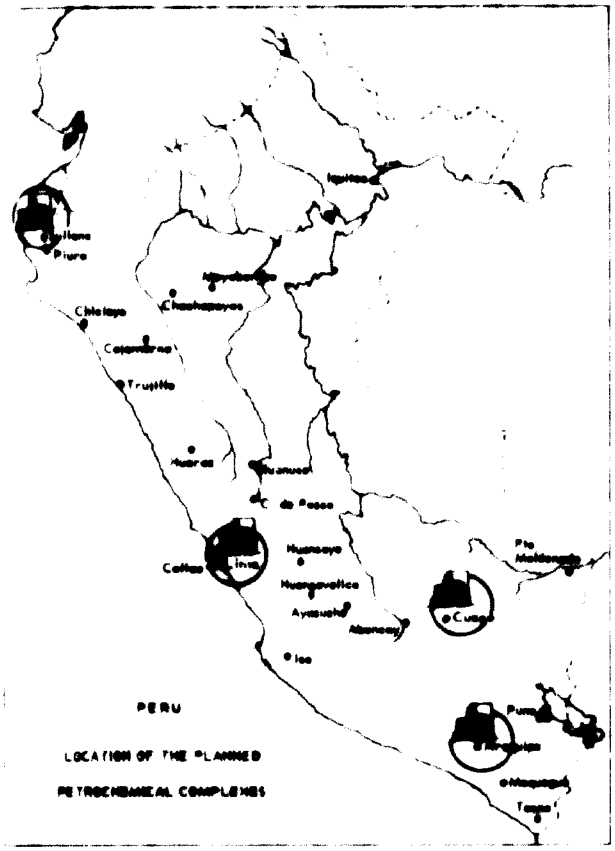

Figure 1. Location of the planned petrochemical complexes

On the other side, we have Aguaytia in the department of Loreto a reservoir of gas of the Mobil Oil Co., which it is estimated will produce 70 million cubic feet per day in 1970, and this production will double by the year 1975. This reservoir can be used to supply the demand for fertilizers in the central part of the country.

In the southern part of the country, a plant for fertilizers is being installed in Cuzco, and it will employ calcareous loams as raw material for the production of calcium-ammonium.

All these complexes of plants have the immediate purpose of producing fertilizers for agricultural needs; however, there is a demand, increasing day by day for their products other than fertilizers.

II. Description and characterization of petrochemical plants

SYNTHETIC FERTILIZERS A.S.

Up to the present moment, we have only one petrochemical plant in the country, Synthetic Fertilizers A.S., located in the province of Callao. Fertiza, as it is called, has installed a plant for the production of 16,500 metric tons of nitrogen in 330 days per year and 24 hours per day. A plan for foreign financing has been arranged to increase by 20 per cent the productive capacity of the plant.

The Fertiza plant operates with hydrogen produced by catalytic cracking of residual oil employing the process developed by Montecatini.

Part of the production is expended as ammonia nitrate of 33 per cent and part as ammonium sulfate of 21 per cent. The plant also produces ammonium nitrate of 33 per cent for explosives, concentrated nitric acid of 98 per cent and dilute of 53 per cent.

Since Fertiza started to operate in the year 1962, it has reached an average production as follows:

PRODUCTS	1962 metric tons
Ammonia	18,173
Concentrated nitric acid (98 per cent)	431
Dilute nitric acid (53 per cent)	51,214
Agricultural ammonia nitrate	33,845
Ammonium nitrate	177
Ammonium sulfate	11,833

The annual sales of Fertiza represent 3 per cent of the total value of consumption of chemical products, estimated around S/. 3,000 million per year. This project was undertaken in 1955 by private national initiative, assisted by the Montecatini Society of Italy. The total capital outlay for the plant was more than S/. 300 million, of which almost S/. 100 million was financed by the World Bank.

Other plants are mentioned in the following paragraph, in order to give an idea of the increasing interest of private enterprises in this field.

COMPLETE FERTILIZERS A.S.

In the last few years the manufacturing of complete fertilizers, also called balanced fertilizers, containing the fundamental elements, nitrogen, phosphorus, and potassium in adequate amounts for each crop and for each soil, has started.

Owing to the lack of information, we can only say that this plant was installed by a private company in the year 1961. The plant is located on the 24th km of the Central Road in Lima. It will produce 96 metric tons of granular complex fertilizers per day, that is, around 2[illegible] metric tons per year of 275 days.

BASIC CHEMICAL INDUSTRIES A.S.

Like the above-mentioned company there is no information concerning this enterprise; only a financing plan is known for the establishment, together with Fertiza, of a superphosphate calcium plant and another plant for balanced fertilizer.

FERTILIZER PLANT, CUZCO

This plant is at present being built by the German Company, Uhde Ferrostaal *Hochtief*, and will be handed over to the Corporation of Improvement and Reconstruction of Cusco.

The plant will be located in Chacamayo, 18 km from the city of Cusco. There are plans to manufacture calcium ammonium, using as raw material calcareous loams, which are abundant in that zone, with the possibility of manufacturing, in the future, ammonium nitrate and agricultural chemicals. The necessary hydrogen for the synthesis will be obtained from water electrolysis. The capacity of production will be 190 metric tons daily — 6,200 metric tons of ammonium nitrate per year with 20.5 per cent of nitrogen. The total investment cost will be 70,622,950 D.M. or $17,833,000. or S/ 478,824,000.

19. PETROCHEMICAL AND CARBOCHEMICAL PROCESSES IN POLAND WITHIN THE PERIOD 1955-1967

Konstanty Laidler, Director of the Technical Department, Ministry of Chemical Industry of Poland

Some of the developments which have taken place in the Polish chemical industry from 1955 till 1964 and are planned for the period 1965-1967 merely demonstrate how within a framework of a national economy in a period of fairly intensive growth, demands of the internal and export markets are being met. Representatives of countries entering a period of intensive industrial growth will probably find our experience interesting enough to justify such information.

I. THE PART PLAYED BY THE CHEMICAL INDUSTRY IN POLAND DEPENDS ON MANUFACTURING COSTS. RECENT SHIFT FROM COKE TOWARDS NATURAL GAS AND PETROLEUM HYDROCARBONS LOWERS MANUFACTURING COSTS

The value of the chemical industry in Poland can be attributed directly to the part played by this industry in reducing the dependence of economy on imports of products such as grain, cellulose, cotton, wool, timber, oils and fats, natural waxes, natural rubber, and coloured metals which are not easy to obtain. In some cases they might be substituted by chemicals which are more expensive than products chemically synthesized. However, synthetic chemicals not only help to close the gap for products derived from vegetable and animal sources which do not expand as quickly as human requirements, but represent also new unknown qualities and new end-uses.

The impact of the chemical industry in Poland has been decisive for the achievements of the following sectors of the economy:

Mineral fertilizers in agricultural production and food supply are responsible for about 6.5 million tons of grain yearly and have to add another 7-million tons till 1970 in order to eliminate substantial imports of wheat;

In the textile industry, 3.5 kg of man-made fibres *per capita* are added to 4 kg of natural fibres yearly. Projects are well under way to increase the share of man-made fibres to 5 kg in 1969;

In transportation and packaging — plastics, man-made fibres and synthetic rubber, paint and varnish are not only being used for protection of surfaces but also as construction materials;

In construction, where 25,000 tons of plastic materials are being used, 100,000 tons are being planned for 1970;

In health service, pharmaceuticals and syndets.

Listed above are industries where chemicals are playing a decisive role in one country, but a similar pattern might be representative of several other countries with the exception of those few highly industrialized ones which, owing to their development, have achieved a substantial agricultural production in the past and do not concentrate their efforts on mineral fertilizers any more.

The capital investment in the chemical industry reached in Poland in recent years eight dollars annually per head of population, which accounts for 2.5 per cent of the annual national income. This high expenditure will rise to about thirteen dollars annually from 1966 through 1968. It has also been recognized that the value added by manufacture calculated per one employee in the chemical industry is one of the highest, this being because manufacturing costs of organic chemicals are moderate when compared with prices of traditional products derived from animal and vegetable sources. It is obvious to anyone familiar with the actual trend in the chemical industry that manufacturing costs vary within certain limits whereby the factor which has the strongest direct and indirect effect on hydrogen and monomers are prices and chemical characteristics of fuels used as feed for processing into chemicals. Physico-chemical characteristics of fuels determine technological routes, capital-costs and labour requirements. That is the reason why in the postwar period a shift from coal and coke towards natural gas and liquid hydrocarbons has taken place practically everywhere.

Assuming cost of 1 million kcal in coke in Poland to be 100 units, cost in coke oven gas is 150, in natural gas 55, in virgin gasolene of a low octane rating 100.

Thermodynamic efficiencies of the synthesis gas and ammonia manufacturing processes as used in Poland: 37 per cent for coke oven gas, 32 per cent for methane reforming with steam under atmospheric pressure, 27.5 per cent for coke gasification in conventional producers, and lower capital expenditure per 1 ton of ammonia from coke oven gas and methane than in the case of coke, have had their part in the manufacturing costs of this very important chemical together with the price difference of kcalories. With other factors such as the increase of size and capacity of plants, and their automation, production costs of ammonia manufactured in Poland have been substantially reduced and will be further reduced.

The high price of coke and the lowest thermodynamic efficiency of coke gasification coupled with the lowest

TABLE 1

Year	Capacity of a single ammonia converter (t/day)	Raw material for synthesis gas production	Works manufacturing costs per 1 ton NH_3	
			zl	$
1955	40	Coke	2,700	72
1962	40	CH_4 reformed with steam under atm. pressure	1,700	46
1963	70	Coke oven gas low temp. fractionation	2,200	59
1965	190	CH_4 partially oxidized to C_2H_2 and synthesis gas	1,800	48
		C_2H_2 calculated for captive use	5,000	130
1967	300	CH_4 oxidized under pressure to $CO + H_2$	1,600	43
1969	600 (planned)	CH_4 reformed with steam in tube ovens under pressure	1,400	37

ratio of hydrogen to carbon (coke oven gas has the highest ratio) with surface of coke particles restricting contact with gasifying medium and diffusion, and consequently influencing unfavourable kinetics of gasification, cause coke to be discarded as a raw material for hydrogen. Moreover, processes for treating coke involve a great deal of equipment and result in large volumes of carbon oxide gases. The price structure of fuels in Poland does not encourage coke oven gas for chemicals despite its high content of H_2 to be separated from other constituents by simple cryogenic processes and despite the close proximity of chemical works and coke ovens in southern Poland. Polish ammonia synthesis units have been erected in three large factories with daily capacities of 460 tons to 1.500 tons. However, a recent development demonstrates that it is possible to run ammonia synthesis plants with daily capacities as low as 60 tons of ammonia, which will produce ammonia for about $30-$40/t and which, skilfully designed, will cost only about 20-30 per cent more to erect than large plants (130 dollars per yearly ton).

Such plants integrated with urea plants might be of special interest for regions where agriculture is not too intensive yet and where the actual demand for fertilizers is not yet too heavy. Ammonia production is representative of a large number of chemicals obtained by processing methane in large units at manufacturing costs which are well established from the economic point of view.

These chemicals include ammonia, urea, hydroxylamine, nitrogenous fertilizers, methanol, formaldehyde, methylamines, hydrocyanic acid and others.

Under Polish conditions, acrylonitrile, vinyl chloride, monovinylacetylene and acetaldehyde could also be included in the category of methane derivatives.

The price structure of solid fuels and of crude hydrocarbon mixtures not only started the substitution of coke by natural gas in synthesis gas manufacture but is also strongly influencing costs of monomers and pure hydrocarbons. The present costs for captive use are:

	zl
Acetylene from carbide	7,000
Acetylene from natural gas	4,500
Ethylene from straight-run gasolene	3,500
Propylene 40-70 per cent concentration	2,850
Benzene chem. grade from crude benzene	3,000
Naphthalene from coke oven tar	3,500

The actual trend in utilization of the raw material base for the manufacture of chemicals in Poland can easily be judged from plants which will go into operation from 1964 to 1967.

2. PETROCHEMICAL AND CARBOCHEMICAL PLANTS BEING ERECTED WITH THE OBJECT OF SECURING LOWER COSTS OF PRODUCTION WITHIN EXISTING PRICE STRUCTURE OF FUELS PROCESSED INTO CHEMICALS

In sum, there are in Poland in 1964 in an advanced stage of construction the following *new plants based on natural gas* which is available for processing into chemicals at $12/1,000 cu.m.

	T/yr
Ammonia	600,000
Methanol	60,000
Acetylene	32,000
Vinyl chloride	80,000
Acrylonitrile	16,000
Chlorinated products of methane	5,000

The yearly consumption of natural gas in the chemical industry will in 1970 exceed 2 billion cu.m.

The following capacities for the production and processing of lower olefinic hydrocarbons, *ethylene and propylene* are in an advanced stage of design and construction and will go into operation from 1964 to 1967.

	T/yr
Ethylene	100,000
Propylene	60,000
Polyethylene H.P.	24,000
Ethylbenzene	40,000
Cumene (phenol and acetone)	20,000
Bis-phenol	5,000
Oxo-alcohols	10,000
Propylene glycol	3,000

Higher boiling *liquid fractions from the refining* of Polish and imported crudes will be or are being utilised for the following productions:

	Tons
Butadiene from normal C_4 hydrocarbons	40,000
p-xylene from mixture of xylenes (from catalytic reforming)	20,000
C_9-C_{16} straight chain aliphatic hydrocarbons separated by means of adsorbents from selected naphthas and used for alkylation of benzene to alkylbenzene for detergents	

	Tons
Higher olefinic hydrocarbons obtained through cracking of paraffin waxes	
C_{10}-C_{20} fatty acids from oxidation of paraffin waxes	1,500
C_{10}-C_{20} fatty alcohols	5,000

The utilization of liquid fractions and ethylene and propylene is at present limited by our small petroleum refining capacities which do not yet reach 4 million t/yr. By 1970 those capacities will increase to 10 million t/yr. Straight-run gasolene will be the main raw material for ethylene and propylene; C_4 hydrocarbons from catalytic cracking and reforming operations will be processed into butadiene. Whereas larger petrochemical plants apart from ammonia and methanol plants are in course of construction and will go into operation from 1964 onwards (this delay being caused by the encouraging results of crude oil exploration which, however, will give larger quantities of crude oil after 1970), there are several plants in operation and in course of expansion processing light oil and coke oven tar.

Also, there is a very large production of acetylene from carbide, and of acetylene derivatives and calcium cyanamide derivatives in the *carbochemical domain*. The following chemical intermediates are at present and will remain carbochemicals until 1968:

	Tons
Benzene	150,000
Toluene	21,000
Naphthalene	65,000
Pyridine, chinolines and picolines	
Anthracene	
Caprolactam	40,000
Benzoic and terephthalic acids	5,000
Phthalic anhydride	40,000
Maleic anhydride	10,000
Anthraquinone	500
Nicotinic and isonicotinic acids	300
Coumarone-indene resins	
Toluenediisocyanates for polyurethanes	5,000
Acetaldehyde	100,000
Acetic acid, acetic anhydride	30,000
2-ethylhexanol	20,000
Acetates	10,000

Derivatives of coke oven tars and crude benzene will not grow by more than 25 to 50 per cent up to 1970 because of technological developments in the iron-smelting industry, where less coke per ton of pig-iron is being presently used and even less planned for the immediate future.

To justify our position regarding acrylonitrile, acetaldehyde and vinyl chloride and aromatic hydrocarbons it is worth while giving some more details.

3. PETROCHEMICAL ACETYLENE FOR PRODUCTION OF ACRYLONITRILE, ACETALDEHYDE, VINYL CHLORIDE

3.1. *Acrylonitrile*

Of two most important processes for the manufacture of acrylonitrile, one is the use of ammonolysis of methane catalyzed by a potent platinum catalyst at a temperature higher than 850°C with HCN produced at a cost of about $147. The subsequent reaction of HCN with acetylene is however much slower (in aqueous solution).

The cost of manufacturing acrylonitrile from acetylene for $120/t will not exceed $250/t in 1964. However, new processes for production of HCN for probably less than $130/t are being offered; these are characterized by higher yields and lower manufacturing costs.

One is utilizing partial oxidation of methane mixed with ammonia in a flame reactor; the second process is making use of an electric arc. Very interesting results have also been published regarding production of hydrocyanic acid with acetylene as a by-product in plasma torch reactors.

The newest process is making use of ammonolysis of propylene at about 500°C. The manufacturing costs of acrylonitrile from propylene depend mainly upon the price of propylene and the by-product acetonitrile. Propylene with purity of 40-70 per cent obtained from refinery operation, from pyrolysis of gasolene or catalytic dehydrogenation of propane, cannot be much cheaper than $35-$40/t (methane -- $17/t). The manufacturing cost of acrylonitrile from such propylene has been calculated to be about $210.

The first plant using the acetylene route in Poland with a capacity of 8,000 t/yr will go into operation by the end of 1964, the first plant based on propylene (if the acetylene route could not be improved) will be built in 1970.

Other processes starting with ethylene oxide or acetaldehyde or acrolein are not being taken into account as they are not justified economically.

3.2. *Acetaldehyde*

Acetaldehyde is being manufactured in Poland in large quantities from acetylene (from carbide) at a cost of about $160/t. With acetylene from partial oxidation of natural gas fed to the existing plant, expanded to a capacity of 120,000 t/yr, the cost of acetaldehyde will drop to about $130.

A new process starting with ethylene is characterized by about the same consumption of ethylene *by weight* as *acetylene* in the classical mercury process, by the same cost for energy and not very different labour consumption.

The comparison of manufacturing costs has convinced us that the advantage of the ethylene route lies in lower costs of ethylene versus acetylene costs.

3.3. *Derivatives of acetaldehyde*

Classical routes starting with acetaldehyde from acetylene will remain competitive in Poland till 1970 for acetic acid and anhydride, ethyl acetate, 2-ethylhexanol, vinyl acetate, polyvinyl acetate, polyvinyl alcohol, cellulose acetate, pentaerythritol.

3.4. *Vinyl chloride*

The choice between the two principal processes for the production of vinyl chloride was until recently governed by the price difference between acetylene and ethylene. The cost of production of ethylene varies widely depending on the price of hydrocarbons, the size of the plant and the purity of the product. It may be safely assumed that ethylene of about 90 per cent purity from ethane costs \$50-\$70 and, from a steam pyrolysis of gasolene \$70-\$100. In Poland, where pyrolysis and pyrolysis gas separation plant capacities are not yet large enough, C_2H_4 is being produced at about \$100/t from gasolene for \$32/t. Also, as previously, stated, concentrated acetylene is being produced at \$120/t.

Now, the classical acethylene route demands 0.450 tons of C_2H_2 and 0.68 tons of Cl_2 plus 210 Nm^3 of H_2 whereas the ethylene route requires about 0.565 tons of C_2H_4 and 1.26 tons of Cl_2 with 0.59 tons of HCl as a by-product. Those consumption figures only account for about \$110 as against \$92 and where ethylene is being produced from ethane the ethylene route will also require lower capital expenditure only partly counterbalanced by higher capital expenditure for a larger chlorine plant. The comparison leads to about \$140/t of vinyl chloride derived from ethylene and \$150/t from acetylene.

As in the case of acetaldehyde the reduction of the cost of production of C_2H_2 will reduce the cost of the acetylene derived vinyl chloride.

Some developments recently announced will introduce new factors which could lower the present costs of production of vinyl chloride.

These are:

Simultaneous production of C_2H_2 and C_2H_4 by partial oxidation of gasolene hydrocarbons.

Production of vinyl chloride from dilute acetylene or ethylene or dilute mixtures of both.

From what has been said on the very disputed subject of production which might be economically organized on the basis of different raw materials it should be clear enough that:

Where low-priced ethane, and consequently cheap ethylene could be made available in large quantities, ethylene routes are preferable.

Where ethane, or even low-octane straight-run low-priced gasolene, is not available, acetylene from natural gas should be used.

In Poland where the increase of reserves of natural gas proceeds at a faster rate than additions to oil reserves and where the cost of acetylene is being lowered from zł 7,000 = \$190 (made from carbide) to zł 4,500 = \$120 (from partial oxidation of methane) and where expansion of existing capacities for acetylene derivatives requires lower capital expenditure than erection of new plants, acetylene will remain one of the most important intermediates. There are good prospects that in a few years' time the price difference between acetylene and ethylene will narrow to less than \$30/t which might not be an excessive price for the high activity of the triple bond.

3.5. *Acetylene derivatives with interesting possibilities*

When the cost of acetylene falls below \$100-\$120/t several of the Reppe syntheses will probably gain industrial importance. Already some routes leading to acrylic acid and acrylates start from acetylene such as the synthesis utilizing nickel carbonyl for the reaction of acetylene with carbon monoxide under pressure and the synthesis *via* acrylonitrile are competitive with the acrolein route starting with propylene. The author has not sufficient information to compare those processes with ethylene and ethylene oxide methods.

Interest in tetrahydrofuran, vinyl pyrrolidone, etc. is hampered by present cost of production of acetylene.

4. PETROCHEMICALS BASED ON OLEFINS AND ON DIENES

Ethylene and propylene oxides, glycols, acrolein and glycerol, ethanol and higher alcohols, oxo-alcohols, chlorinated derivatives of ethylene and propylene, polyolefins, butadiene rubbers will be derived from petroleum. Substantial reductions of manufacturing costs in a few years' time are foreseen owing to a quick expansion of existing capacities and because of the necessity of finding new end-uses.

Conventional polyethylene will have to be manufactured for \$230-\$300/t, polypropylene for \$280-\$400/t, high density polyethylene for \$300-\$450/t, polystyrene and copolymers for \$260-\$300/t, styrene-butadiene cold rubber and cis-polybutadiene rubber for \$350-\$450/t.

This will be possible only when costs of ethylene and propylene are reduced by some 30 per cent and manufacturing costs of styrene and butadiene and higher olefinic hydrocarbons are lowered to \$150-\$250/t.

5. *Aromatic hydrocarbons from carbo and petrochemical sources*

Where coking operations of bituminous coal are conducted on a large scale, aromatic hydrocarbons constitute valuable by-products. Technological operations which are used for recovery of benzene, toluene, xylenes, phenol and other tar acids, of pyridine bases, of naphthalene, methylnaphthalenes, anthracene and higher boiling tar constituents are well known. Some modifications of classical processes for treatment of those very complex azeotropic mixtures which give better results than classical procedures have been developed in Poland. The most important ones are:

Distillation for a higher yield of naphthalene;

Extraction of higher pyridine bases;

Continuous process for production of indene-coumarone resins;

Process for dealkylation of toluene to benzene;

Dealkylation of methylnaphthalene to naphthalene;

Oxidation of methylbenzenes to aromatic polycarbonylic acids;

Oxidation of pyridine bases to nicotinic and isonicotinic acids;

Oxidation of toluene to benzoic acid, etc.

As stated previously, costs of benzene and naphthalene from coke oven operations are competitive; however, processing of coal to coke will not cover requirements for benzene and naphthalene. Before 1970, benzene will also be obtained from petrochemical toluene by dealkyla-

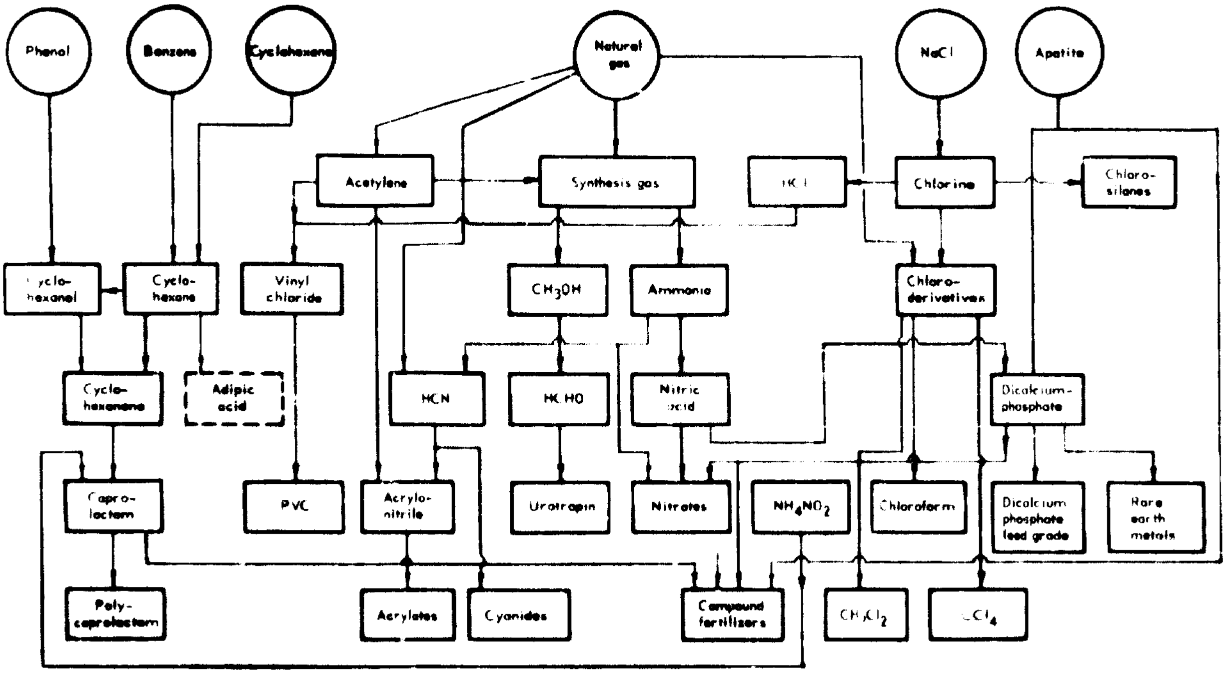

Figure I. *Chemical works, Tarnów*

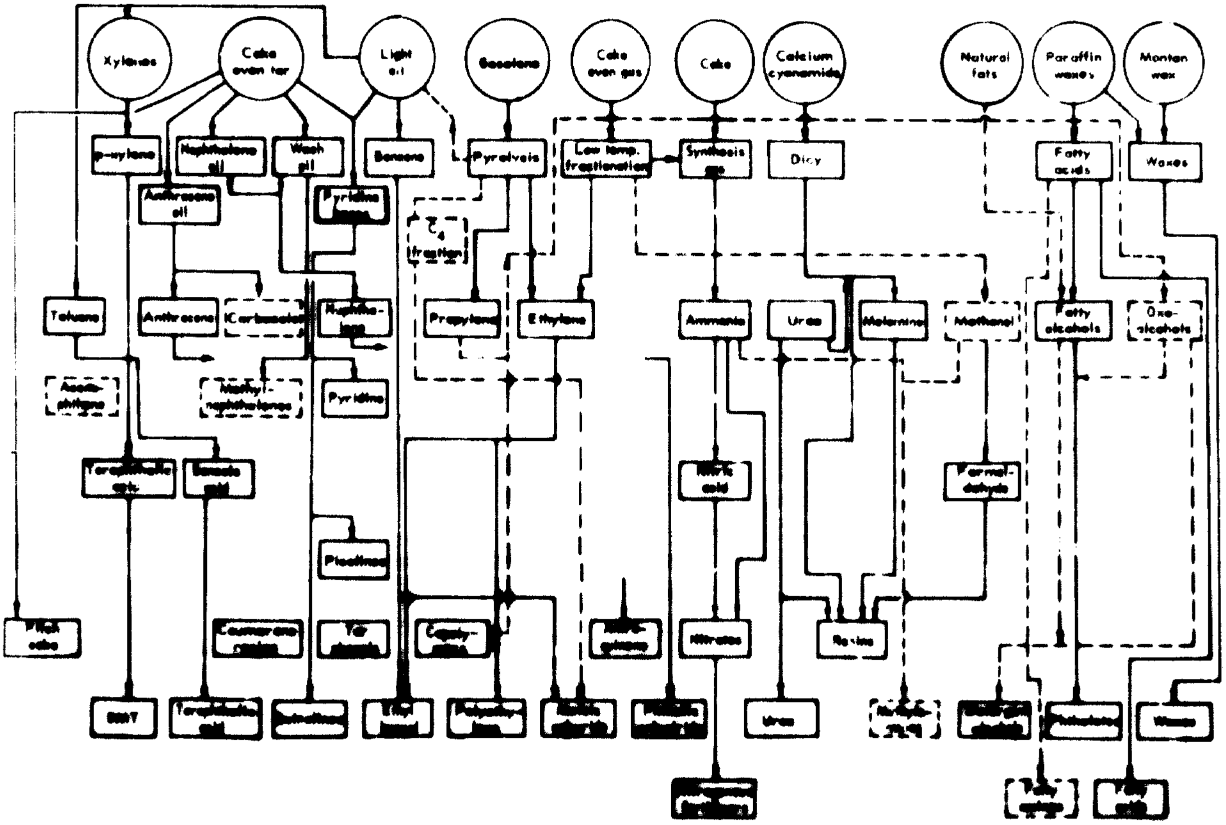

Figure II. Kędzierzyn and Blachownia Chemical Works

tion. This benzene will however not be appreciably cheaper than the carbochemical benzene. For xylenes the chemical industry will rely on separation operations of reformed and aromatized gasolene fractions which underwent pyrolysis.

6. Examples of organization of petro and carbochemical productions

Organization of the petro and carbochemical productions is shown in the diagrams which represent Chemical Works in Tarnów, Kędzierzyn and Blachownia Combined Works and Płock Refinery and Petrochemical Works (see figures I, II and III). Kedzierzyn and Blachownia Works in Upper Silesia were rebuilt in 1947 to 1953 to process coke and coke oven gas, crude benzene and tar to nitrogenous fertilizers, aromatic hydrocarbons and aromatic intermediates. In 1964 a pyrolysis plant was added and virgin gasolene from a neighbouring refinery is processed to ethylbenzene and polyethylene.

The works in Tarnów which have been using natural gas as a source of ammonia and methanol synthesis gas since 1939, will by the end of 1964 process acetylene from partial oxidation of methane into acrylonitrile and PVC. The diagram of Płock presents still another scheme of organization of petrochemical production. Only refining of crude oil will be undertaken untill 1965, but substantial production facilities for butadiene, cumene, phenol and acetone are in course of construction.

Those examples demonstrate the trend to concentrate production of inorganic and organic petro- and carbochemicals in a few large factories. The majority of plants have been designed by polish design organizations and the bulk of the equipment has been made in Poland. The manufacture of such items of plants as had to be imported in the past from other countries, such as large compressors, H.P. vessels and measuring and regulating instruments, has recently been undertaken by the local machine-building industry.

7. Evaluation of future demand

Abundant raw material supply and available reserves of manpower are being considered as sufficient justification for the decision to start petrochemical production. It is assumed that licences, know-how and equipment could be made available to a prospective manufacturing company for purchase and that necessary financial assistance could also be arranged, with international help if necessary.

It is however necessary to keep in mind that creation of new markets or expansion of existing ones through lowering prices of established chemicals (which means the necessity of lowering costs of production below the level of other large manufacturers) fulfils not only economic conditions but represents the main purpose of new production facilities. It is also useful to acknowledge the most important differences between the home market

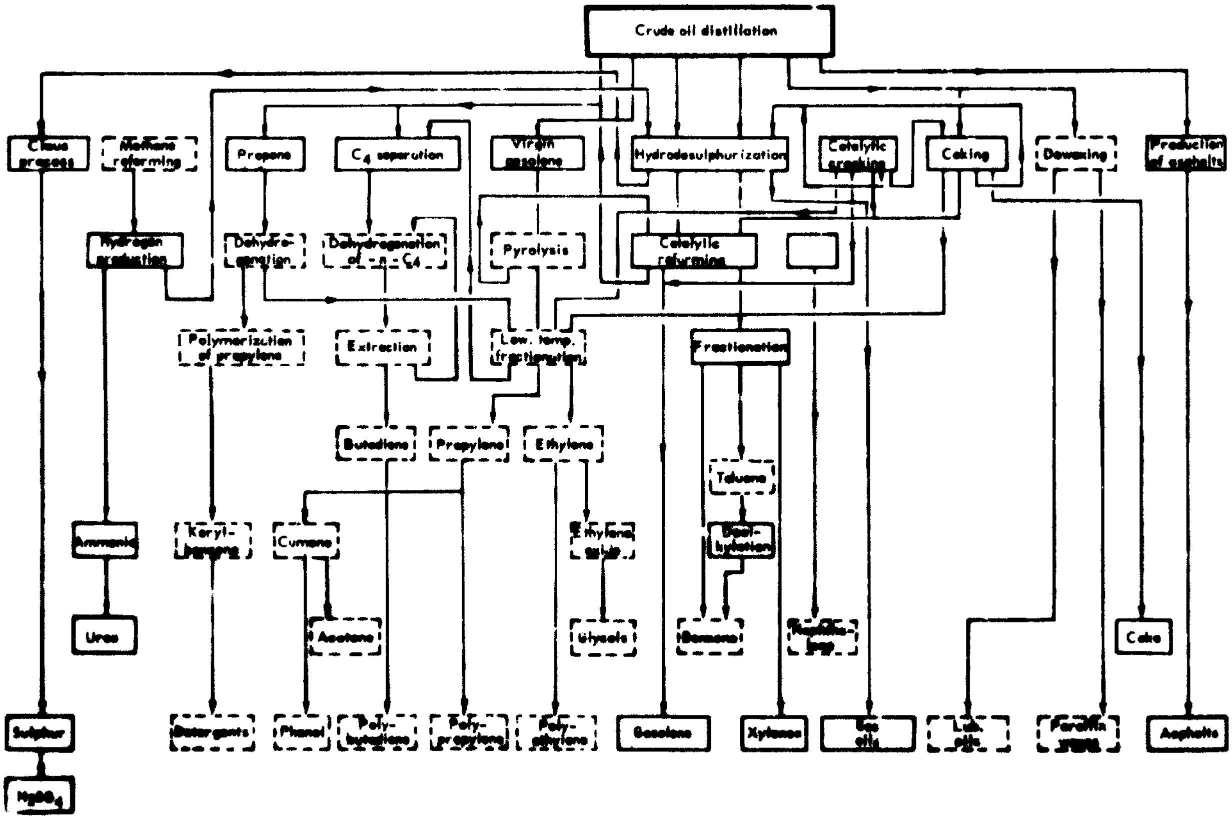

Figure III. Płock — Petroleum Refinery and Petrochemical Works

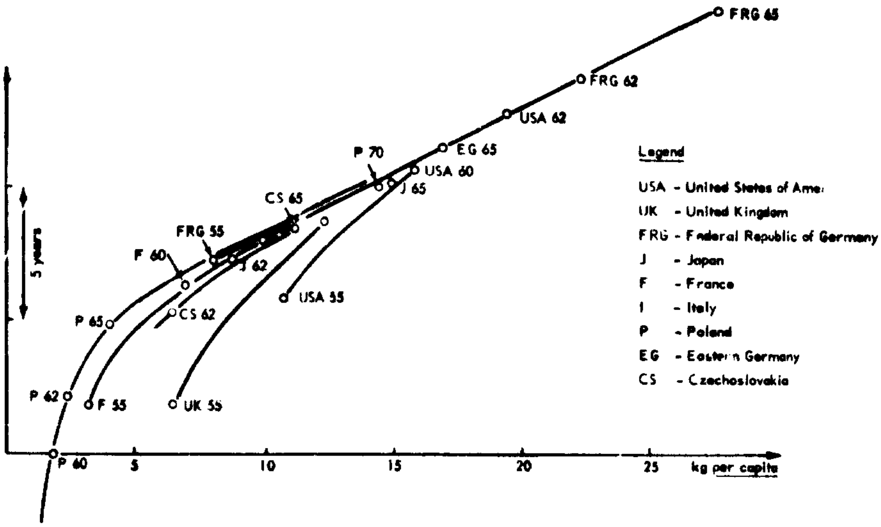

Figure IV. *Plastics and resins consumption*

and especially more distant export markets. Projects for the production for the internal markets are probably the safest despite the fact that the evaluation of growth of consumption even for the home market is by no means simple and will not be possible without the help of governmental agencies shaping or controlling the industrial policy and economic growth of the State.

In Poland, where there already was a sort of governmental economic planning before the war and where after the war the whole course of the development of national economy is being centrally planned, difficulties are still being encountered in forecasting future demands. In planning the consumption of some chemical commodities the country is helped by curves of growth in other countries (see figures IV and V). The shape of those curves follows, as a rule the growth of national income in about the same manner everywhere. Additional studies are, however, necessary to find out whether in a particular country some special conditions would not cause deviations from the universal curve.

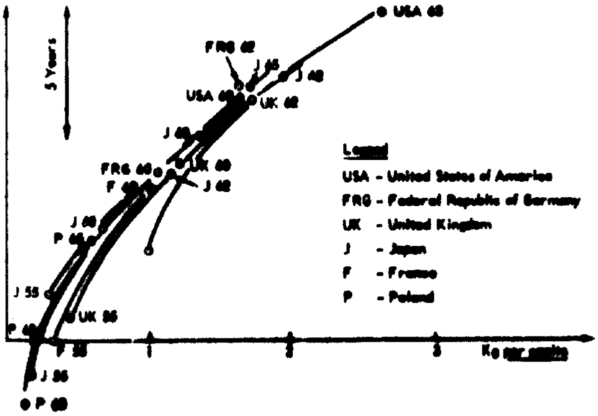

Figure V. *Synthetic fibres consumption*

In the development of chemical industry no difficulties were encountered with commodities where the level of domestic production was rather low and where even large plants put into operation were only in a position to bring some temporary relief. Such was the position with:

Nitrogenous and phosphoric fertilizers,

Plastics and resins for use in construction:

- Of new housing;
- Of transport equipment;
- Of electrotechnical and electronic equipment and machinery;

Synthetic fibres;

Synthetic rubber for tyres, footwear etc.;

Synthetic detergents.

Production facilities in these sectors are expensive, and high capital expenditure was hampering their speedy expansion. Yet even a project for the manufacture of fertilizers which seems to represent commercially the safest straight-forward proposition will have to fit into a definite agrarian policy. Such a policy will suggest the selection of agricultural targets, and the allocation of funds for irrigation, agricultural machinery, new farms, and transport facilities etc., and will assume a certain relation of fertilizers prices to prices of agricultural products etc.

There are many fields where the proper end-uses of chemical products will demand hard thinking.

Whereas, in a moderate climate synthetic wool-like fibres are in great demand, in a subtropical climate substitutes for cotton and silk (nylon and polyester filament yarn, cellulosics) will probably demand attention.

It is easier to start production of fine chemicals which are usually manufactured in medium-size batch operations. To this category belong: thermosetting resins, paints and varnishes, soaps and detergents, dyestuffs and pesticides and pharmaceuticals. To the same type of plants limited in size and capacities, belong also plants processing plastic resins.

Capital expenditure is not too high; site, energy, cooling water requirements are moderate; several operations might be made automatic or, if local conditions require, partly manual. It is essential to study carefully in all cases the production programme and to diversify it only gradually. It is rather difficult when planning a chemical production to resist the temptation to include too many targets in the production programme.

Yet, with our more than 40 years' experience in the manufacture of chemicals and with a chemical industry which has grown from 1949 to 1964 by more than 100 per cent, the country found a limit to the capacity of plant management for starting up new plants and for introducing new products. Two new processes per year are probably the utmost which one might expect from works under supervision of an able and energetic management.

8. THE NECESSITY OF RECONCILING MARKET REQUIREMENTS WITH OPTIMUM MANUFACTURING CAPACITIES

It is useful to acknowledge the fact that a vast majority of chemical plants have been expanding their production facilities for a number of years but are starting production of new chemicals on a scale which will from the very beginning secure competitive costs of production. The general trend is towards larger capacities.

In Eastern Europe we consider the following capacities as representing already lower limits of the optimum capacities. In countries with abundant and cheap raw materials supply these limits might probably be lowered, although only when the design of those smaller units is simplified.

Where the cost of a plant is given it has to be taken as approximate only for a plant within battery limits inclusive of construction cost, but excluding cost of licence and know-how:

Sulphuric acid from sulphur with a single unit of 100,000 t/yr, zł 50 million = $1.7 million.

Ammonia 100-300 t/day single train with a synthesis gas facility zł 150-300 million = $4.3-8.6 million.

Urea 250 t/day, single train, zł 150 million = $4.25 million.

Methanol 100 t/day unit with a synthesis gas plant, zł 120 million = $3.4 million.

Formaldehyde 9,000 t/yr, zł 30 million = $1 million.

Methanol 30 t/day, zł 65 million = $1.85 million.

Chloromethanes 3,000 t/yr, zł 20 million = $0.6 million.

Acetylene by partial oxidation of methane, three burners, each 25 t/day, a single concentration train 22,000 t/yr of concentrated C_2H_2, zł 300 million = $8.6 million.

Ethylene-propylene and butadiene by steam pyrolysis of straight-run low octane gasoline with low temperature fractionation of pyrolysis gas 100,000 t/yr of C_2H_4, C_3H_6, C_4H_6, zł 750 million = $21.5 million.

Vinyl chloride and PVC from C_2H_2 20,000 t/yr, zł 200 million = $6.5 million.

Vinyl chloride and PVA from C_2H_2 and acetic acid, 5,000 t/yr., zł 120 million = $3.5 million.

Acetaldehyde from C_2H_2, two units 40,000 t/yr.

Acetic acid 30,000 t/yr zł 200 million = $5.7 million.

Ethylbenzene from benzene 7,000-15,000 t/yr.

Cumene 20,000 t/yr.

Polystyrene 5,000 t/yr, zł 50 million = $1.65 million.

Butadiene-styrene cold rubber 30,000 t/yr, zł 650 million = $18.5 million.

Maleic anhydride, two units, each 1,000 t/yr, zł 175 million = $2.2 million.

Phthalic anhydride, two units, each 2,000 t/yr, zł 80 million = $2.3 million.

Cyclohexanone from cyclohexane, one train 10,000 t/yr, zł 130 million = $4.3 million.

Caprolactam monomer 8,000 t/yr, zł 250 million = $7 million.

The country has designed, built and operated plants of smaller capacities, such as methanol plants 30 t/day, urea plant 100 t/day which constitute a part of a larger industrial complex where their residue gases are being fed to other sections of the factory. Such special design gives under favourable conditions economically satisfactory results.

9. THE DECISIVE ROLE OF THE TECHNICAL STAFF IN THE SUCCESSFUL OPERATION AND EXPANSION OF A PLANT

The importance of technically efficient supervisory and scientific staff cannot be overrated. This single factor is of primary importance for the efficient operation of newly erected production facilities. A modern plant calls for a vast array of highly qualified specialists. Education of such a staff definitively takes more time than the construction of a new plant. Without such a staff it would be difficult to keep up with market requirements regarding the quality of products and the necessity of supplying more sophisticated products.

Especially pharmaceutical plants call for a sustained scientific and technological effort of a large research staff with a large proportion of qualified chemists, pharmacists, physicians, pharmacologists etc. If a newly established plant cannot be supported by its own research laboratory, the co-operation and assistance of some existing research organization has to be secured.

Large plants for continuous catalytic manufacture of chemical intermediates as well as plants making use of high pressures and temperatures even if they represent, when purchased, most advanced processes call for a great effort in developing even more efficient and robust catalysts, higher yields and consequently lower costs which determine the success of the plant. A scientifically trained chemical engineer is the most important person for this job.

Another branch of chemical production which equally depends on research and development for the best results are polymers. Research in this field is probably the most rewarding one but has to be supported and conducted by a large and skilled manpower. The shortest way to acquire the necessary intimate knowledge of purchased process, licence and know-how, apart from the assistance and training received from the engineering and contracting firm, is through buying, constructing and running a pilot plant along with the full scale unit.

10. CLOSING REMARKS

One fact could not have escaped attention of careful readers, namely, that Poland has rather delayed erection of petrochemical plants. To explain this it should be mentioned that about 70 per cent of the capacities have been based on local research and development work and designed by Polish designers. When Poland started in 1945 to rebuild its chemical industry, there were available for this task only about 600 chemists and chemical engineers with a university education. Poland is currently employing more than 9,300 technicians with university degrees, out of whom 2,200 are conducting research and development and 2,000 are plant and process design staff.

ANNEX 1

Capacities, production and demand for plastics and resins, synthetic rubber, and synthetic fibres in Poland from 1960-1970

The development of production from 1960 till 1963, the planned production figures for 1965 and 1970, as well as data on production capacities at the end of 1965 are given below in thousand metric tons.

	Production		*Planned production 1965*	*Planned capacity 1965*	*Planned production 1970*
	1960	*1963*			
Plastics and resins					
Phenolic resins	15.4	24.7	27	30	48
Urea and melamine resins	10.3	22	30	32	55
Alkyd resins	4.1	6.4	12.5	13	36
Polyesters, unsaturated	0.01	0.75	1.3	1.5	15
Epoxy resins	0.15	0.4	0.8	1.5	8
Isocyanates for polyurethanes	—	—	0.07	0.15	10
Acrylics- metacrylates	0.07	0.4	1.0	1.0	3.5
Polyamides	—	0.2	1.0	1.0	3
PVC	13.4	16.4	28	30	190
PVA and vinyl copolymers	—	—	—	—	30
Polyethylene	—	—	3	10	50
Polypropylene and copolymers	—	—	—	—	28
Styrene resins	3.2	8.1	10	10	30
TOTAL	46.63	80.1	114.67	130.15	400.5
Synthetic rubbers					
Styrene-butadiene rubber	20	36	40	42	70
Cis-polybutadiene	—	—	—	—	30
TOTAL	20	36	40	42	100
Synthetic fibres					
Nylon 6 filament yarn	1.9	2.8	4.7	5	7.5
Nylon 6 filament cord yarn	0.6	2.0	3.2	3.5	12.5
Nylon 6 filament staple	1.8	2.2	4.0	4.0	4.0
Polyester staple	0.1	0.1	6.5	7.0	17.0
Polyester filament yarn	—	—	—	—	5.0
Polyacrylic staple	0.1	0.1	4.0	7.5	25.0
Polyvinylalcohol-casein fibre	—	—	—	1.5	4
TOTAL	4.5	7.2	22.4	28.5	75

	Production			*Planned production [illegible]*	*Planned capacity [illegible]*	*Planned production [illegible]*
	[illegible]	*[illegible]*	*[illegible]*			
Nitrogenous fertilizers						
Total nitrogen	104	270	[illegible]	[illegible]	400	[illegible]
Ammonia	[illegible]	345	440	500	600	1,700
Ammonium nitrate 30 per cent N	—	100	300	400	600	[illegible]
Urea total	[illegible]	12	[illegible]	170	200	[illegible]

CONSUMPTION OF PLASTIC AND RUBBER GOODS AND MATERIALS

Plastic and resins as well as rubber goods will meet the demand in the following branches of Polish economy. Data on the demand in thousand metric tons have to be treated with some caution because the growing volume of production and the price reduction will develop new end-uses and expand the market.

	1963		*1965*		*1970 planned production*
	Production	*Demand*	*Production*	*Demand*	
Plastics for the construction of transportation equipment and for the building industry					
Rigid sheet, profiles (PVC)	2	5	2.5	7.5	40
Flooring without adhesives	25.4	35	31.4	40	80
Adhesives for plywood etc.	20.2	22	27	28	45
Piping and plumbing, sanitary installations, baths, sinks, etc	0.8	2	3	5	12.5
Fibreglass reinforced sheets and panels for roofs, windows, lights, lamp housings	0.8	3	4	8	30
Rigid foams (styrene, urea-formaldehyde, polyurethane, PVC)	2.1	4	3.5	6	13
Flexible foam for bedding, upholstery, linings of garments (polyurethane, rubber etc.)	1.5	3	2.2	5	10
Artificial leather, textile and paper plates coated with resins, laminates, finishing resins	8	12	12.5	15	25
Tyres for replacement and new cars, trucks, motorbicycles etc.	63.8	75	70.8	80	124
Conveyor belts, made from rubber and PVC	13.2	15	17.1	18	48.7
Packaging and moisture protection film, bags (polyolefins, PVC, cellophane etc.)	4	6	6	10	35
Rubber and PCV footwear					
Million pairs	24	25	24.7	27	30
Rubber soles	10	12	15	15	16
Containers, bottles, storage vessels, gasoline tanks, enclosures, corks	0.1		0.3	1	4
Engineering plastics					
Machine-parts and instruments, domestic machinery, fans, bearings, gears, gaskets, handles, etc.			8	10	30
Wire and cable coating, electrical motors insulation, etc.			15	20	30

It has been estimated that in Poland in 1970 increased production of plastics will save 300,000 tons of lumber, 300,000 tons of coloured metals, 10 million m² of leather, 70,000 tons of paper, 30,000 tons of cork, etc., while increased production of synthetic rubbers will eliminate the acute deficit of tyres.

For 1975 production of 25-30 kg *per capita* of plastic and resin materials is foreseen — with 5 kg of synthetic rubbers.

Production of man-made fibres in 1975 will increase to about 8 kg *per capita* from the level of 5 kg in 1970. Polypropylene, polyvinyl-alcohol fibres and improved cellulosic fibres will participate in this growth. Production of nitrogenous fertilizers will allow 64.5 kg of nitrogen per hectare of arable land to be applied in 1970, whereas in 1960 only 20 kg will be used. In 1975, the corresponding amount will surpass 90 kg.

ANNEX II

Polish petrochemical industry — country study

POLISH PETROCHEMICAL INDUSTRY IN THE PAST

Research on utilization of crude oil and natural gas had already started in Poland before the First World War. It accompanied mining operations in Southern Poland (Galicia) which in 1909 had already produced some petroleum.

Research activities before and during the First World War were centred on the problem of refining and utilization of petroleum fractions. As early as in 1853 Mr. Lukasiewicz applied the naphtha fraction as lighting fuel and made in Lwów the first lamp using fuel of this type.

TABLE 1. CHANGING PATTERN OF THE CONSUMPTION OF PETROCHEMICAL AND CARBOCHEMICAL RAW MATERIALS IN POLAND

Raw material	*Process*	*Chemicals*	*Units*	*1955*	*1960*	*1965*	*1970*
Dry natural gas . .	Steam reforming	Ammonia	Million m^3		100	200	675
		Methanol	Million m^3		22	60	175
Dry natural gas . .	Partial oxidation to synthesis gas	Ammonia	Million m^3	—	—	—	400
Dry natural gas . .	Partial oxidation to acetylene and synthesis gas	Acetylene with ammonia and methanol	Million m^3	—	—	55	330
Coke oven gas . . .	Low temperature fractionation	Ammonia with ethylene	Million m^3	34	35	60	100
Coke	Water gas sets	Ammonia	Thousand tons	200	627	550	450
Coke	Carbide ovens	Acetylene and calcium cyanamide	Thousand tons	600	900	1,300	1,600
Naphtha	Steam pyrolysis	Ethylene and propylene	Thousand tons			100	500
Butane . . .	Catalytic dehydrogenation	Butadiene	Thousand tons	—	—	—	120

In the 'twenties, research was directed towards utilization of crude oil and natural gas for chemicals. The following processes have been developed and operated on the commercial scale:

Hydrocyanic acid from methane and ammonia in electric arc;

Furnace carbon black from natural gas;

Mixed synthesis gas from coke and natural gas in water gas producers;

Steam reforming of natural gas in tube ovens;

Methanol synthesis from reformed natural gas.

In 1939 half of the total ammonia production capacity and total methanol capacity was based on natural gas reformed catalytically with steam.

ECONOMIC MOTIVATION OF THE PRIORITY GIVEN TO THE PETROCHEMICAL INDUSTRY

Rising capital expenditure for building new coal mines in Poland as well as the necessity of mining coal from deeper strata have contributed to higher prices of bituminous coals.

At the same time, rich natural gas deposits have been discovered in the country and growing quantities of crude oil have been made available on world markets for purchase at competitive prices.

Lately, the trend to reduce manufacturing costs and prices of a growing number of chemicals has been exerting a strong pressure towards a new pattern of raw materials for chemical production. The shift from coal towards natural gas and petroleum fractions is in full swing, being hampered only by the speed with which new production capacities can be built (table 1).

TABLE 2. PLANNED CAPACITIES OF PETROCHEMICAL BUILDING BLOCKS

Chemicals	*1965*	*1970*	*Percentage*
Ethylene	20	150	100
Propylene	12	100	100
Acetylene	30	60	36
Butadiene	—	50	100
Styrene	20	40	100
Benzene	—	80	40
P-xylene	7	20	90
Vinyl chloride	40	140	80
Acrylonitrile	8	20	100
Methanol	70	140	100

The capacities for petrochemical building blocks have been planned to 1970 (table 2) in thousand metric tons. The percentage of petrochemicals in total petro and carbochemical capacity in 1970 is given in the third column.

SUPPORTING ACTIVITIES FOR THE PETROCHEMICAL INDUSTRY

Research organizations. Five research centres are active in the petrochemical field. The number of employees is reported in parentheses.

(*a*) Research Institute of General Chemistry—Warsaw (450);

(*b*) Institute of Petroleum Refining—Cracow and Warsaw (300);

(*c*) Institute of Heavy Organic Synthesis—Blachownia (270);

(*d*) Research Laboratory of Oświęcim Chemical Works specializing in vinyl polymers and synthesis of rubbers—Oświęcim (200).

Research and development in the related fields of rubber and plastic processing, of synthetic fibres, paint and varnish, is conducted by four other centres with 1,000 employees in Warsaw, Łódź and Gliwice. They supply the necessary data for the designing bureaus. Of the fifteen existing bureaus employing 5,160 project engineers, designers and draughtsmen, seven are working on petrochemical projects and another three are designing synthetic fibres plants, plants for processing of rubbers and plastics.

The polish engineering, machine-building and chemical industries have a joint annual capacity of more than 100,000 tons of process equipment valued at approximately $100 million. Several specialized factories, as well as large workshops in chemical plants are manufacturing chemical process equipment from mild steel, heat resistant chromium steel, stainless steel, copper, aluminium, including rubber lined, lined with ceramic or carbon materials, lead lined, stainless steel clad and equipment made from plastics. The production programme includes absorption and distillation columns, evaporators, tube furnaces and ovens, heat exchangers, steam boilers, contact ovens and reactors, autoclaves, rotating dryers, pneumatic dryers, filters and centrifuges, granulators, crystallizers, crushers and grinders, mills, fans, blowers and compressors etc. Refrigeration units and H.P. vessels, valves etc. are also manufactured. Plastic and rubber-processing equipment, and spinning machines for the synthetic fibres industry have been built and are operated in Polish factories. Engineering and machine-building industries in Poland export complete chemical plants to several countries (sulphuric acid, calcined soda, methanol, dye-stuffs, pharmaceuticals etc.). However, quite a substantial part of the existing capacity is scheduled for the expansion of Polish chemical and related industries. The largest factories are the following: Huta Zgoda, Kraków, Wyry, Gliwice, Tarnowskie Góry, Nysa, Skierniewice, Tarnów, Oświęcim, Kędzierzyn-Blachownia.

CHARACTER OF PETROCHEMICAL PLANTS INCLUDING THEIR DEVELOPMENT UP TO 1970

Several large State-owned works comprising petrochemical plants will be in operation in 1970. These factories are: Oświęcim, Tarnów and Puławy, processing natural gas from south-eastern Poland delivered by existing pipelines, and Blachownia, Kędzierzyn and Płock, where steam-pyrolysis of straight-run gasolene will be the source of ethylene, propylene, butadiene and synthesis gas. Production programmes up to 1970 are given below with capacities planned for operation indicated in parentheses.

Oświęcim — 10,000 employees in 1964

Intermediates:

Acetylene.
Acetaldehyde.
Acetic acid and anhydride.
Butanol and 2-ethyl-hexanol.
Ethyl acetate.
Methanol.
Phenol.
Alpha-olefins and oxo-alcohols (5,000 tons from 1966).
Vinyl chloride.
Styrene.
Vinyl acetate (10,000 tons from 1966).
Chloroparaffins.
Kerylbenzene.

Plastic materials:

PVC.
Polystyrene.
Polyvinyl acetate.
Polyvinyl alcohol (1966).
Methacrylates.

Rubbers:

Butadiene-styrene rubber and latices.

Tarnów — 8,000 employees in 1964

Intermediates:

Acetylene and synthesis gas by partial oxidation of natural gas.
Hydrocyanic acid.
Acrylonitrile (16,000 tons in 1965-1967).
Vinyl chloride (90,000 tons in 1965-1967).
Acrylates.
Methanol.
Formaldehyde.
Cyclohexanol (additional 20,000 tons in 1967-1968).
Adipic acid.
Caprolactam (40,000 tons in 1970).
Methylene chloride.
Chloroform.
Carbon tetrachloride (5,000 tons from 1966).

Plastic materials:

PVC suspension type (80,000 tons in 1966-1967).

Fertilizers:

Ammonia.
Nitric acid, nitrates (expansion to 370,000 tons of ammonia in [illegible]).

Puławy — [illegible] employees in 1965

Fertilizers:

Ammonia.
Nitric acid, nitrates.
Urea ([illegible] tons of ammonia in 1968).

Kędzierzyn-Blachownia — 10,000 employees in 1964

Intermediates:

Ethylene and propylene by naphtha steam pyrolysis (100,000 tons in 1965-1967).
Ethylbenzene.
Polyethylene (24,000 tons from 1965).
Butanol and oxo-alcohols (10,000 tons from 1968).
Maleic anhydride from benzene and C_4 hydrocarbons.
Phthalic anhydride and phthalates.
P-xylene from xylenes (1964).
Terephthalic acid by nitric acid oxidation, dimethyl terephthalate and by disproportionation of benzoic acid.
Benzoic acid (3,000 tons in 1969).
Fatty acids by air oxidation of paraffin waxes.
Fatty alcohols (1967).
Melamine from urea (10,000 tons in 1970).
Formaldehyde.
Methylamines.

Resins:

Urea-formaldehyde.
Melamine-formaldehyde resins and adhesives.
Ion-exchangers.

Fertilizers:

Ammonia.
Urea.
Nitric acid and nitrates (expansion by 65,000 tons of ammonia in 1965-1966 to a total capacity of 400,000 t/yr).

Płock — 2,400 employees in 1965

Intermediates:

Ethylene and propylene by naphtha steam pyrolysis (100,000 tons in 1969).
Butadiene from n-C-hydrocarbons (60,000 tons in 1968).
Ethylene oxide and glycol (15,000 tons in 1969).
Phenol and acetone via cumene.
Xylenes from gasoline reformate.
Benzene from toluene (60,000 tons in 1970).

Plastic materials:

High density polyethylene and polypropylene (30,000 tons in 1969-1970).

Rubbers:

Cis-polybutadiene (30,000 tons in 1969).

Sulphur:

Sulphur by the Claus method.

Rokita and Bydgoszcz

These two factories, each employing more than 4,000 employees are already producing and installing facilities for following petrochemical productions:

Intermediates:

Chlorinated derivatives of ethylene and propylene.
Ethylene oxide and glycol.
Glycol ethers.
Ethanolamines.
Ethylenediamine (1,000 tons in 1967).
Propylene oxide.
Propylene glycol (3,000 tons in 1968).
Epichlorohydrin.
Glycerol.
Acetaldehyde.
Peracetic acid (500 tons in 1968).
Pentaerythritol.
Isocyanates for polyurethanes (6,000 tons in 1969).
Phenol.
Cyclohexanol.
Cyclohexylamine.

Resins and plastic materials

Epoxies,
Polyurethanes

Pesticides

DDT
2,4-D and esters
Lindane

Gorzów 4,500 employees

Nylon 6 fibres

Caprolactam filament yarn.
Caprolactam cord machines
Caprolactam staple fibres.

Capacity of Gorzów Works will be doubled by 1975.

Toruń 1,500 employees

Polyester fibres

Elana polyester staple fibres
Elana filament yarn

Capacity of Toruń Works will be tripled by 1970.

Łódź 2,500 employees

Acrylonitrile fibres

Anilana staple fibres.

Capacity of 1966 will be doubled by 1970.

ORIGIN OF TECHNOLOGIES

Petrochemical processes which are in operation and those which have been planned for operation up to 1970 have been developed by Polish research and design organizations or licensed by foreign industries. The following processes originated and have been patented in Poland where they are being operated on commercial or pilot plant scale

Catalytic steam reforming of natural gas in tube ovens to synthesis gas
Capacity of ovens, 60 and 110 tons of ammonia per day

Catalytic partial oxidation of methane to synthesis gas
Capacity, 100 tons of ammonia per day

Ammonia synthesis plants
Capacities of single trains, 60, 80 and 190 tons/day (larger units 300 tons/day have been bought from abroad)

Nitric acid plants under 4 and 8 atm pressures
Capacities of single trains, 40,000 and 60,000 tons/yr of nitric acid calculated as 100 per cent.

Ammonia nitrate fertilizer grade
Plants of capacities of 600 tons/day

Urea plants of a capacity of a single train 100 tons/day also integrated with ammonia nitrate plants

Urea and melamine resins and adhesives
Capacity, 3,000 tons/yr

Methanol synthesis plants
Capacities of single trains, 30 and 130 tons/day

Methylamines
Capacity, 2,000 tons/day

Formaldehyde plants
Capacity, 6,000 tons/yr of 100 per cent formaldehyde from a single unit

Hydrocyanic acid by ammoxidation of methane

Methylmethacrylate plant of capacity of 1,000 tons/yr

Alpha-olefins from paraffin waxes
Capacity, 4,000 tons/yr

Oxo-alcohols
Capacity, 2,000 tons/yr

Fatty alcohols by hydrogenation of fatty acids
Capacity, 2,000 tons/yr

Chloroderivatives of methane
Capacity, 3,000 tons/yr

Chloroparaffins
Capacity, 5,000 tons/yr

Kerylbenzene by condensation of chlorinated straight-chain aliphatic hydrocarbons with benzene
Capacity, 2,000 tons/yr

Trichloroethylene from acetylene
Capacity, 5,000 tons/yr

Ethylene and propylene oxides – glycols by the chlorohydrin method
Capacities, 3,000 tons/yr

Ethylbenzol plants
Capacity, 15,000 tons/yr

Styrene from ethylbenzol
Capacity, 10,000 tons/yr

Styrene-butadiene latex plant
Capacity, 1,500 tons/yr

Vinyl chloride from acetylene and emulsion and suspension polymerization plants with capacities 10,000 and 40,000 tons/yr

Chlorobenzene plant
Capacity, 12,000 tons/yr

DDT plant
Capacity, 3,000 tons/yr

2,4-D plant
Capacity, 1,000 tons/yr

Phthalic anhydride by pressure fluidization
Capacities of single units, 2,000 and 3,000 tons/yr

Maleic anhydride by fixed-bed catalyst
Capacity of a single unit, 1,000 tons/yr

Anthraquinone – fixed-bed catalyst
Capacity, 500 tons/yr

Terephthalic acid by disproportionation of benzoic acid
Capacity, 2,000 tons/yr

Benzoic acid by air oxidation of toluene – technical and pharmaceutical grade train capacities, 3,000 and 300 tons/yr

Cyclohexanol and cyclohexanone by air oxidation of cyclohexane
Train capacity, 10,000 tons/yr

Cumene – phenol and acetone plants
Capacities, 20,000 tons/yr

Phenol-formaldehyde resin plants
Capacity, 5,000 tons/yr

Aniline by catalytic hydrogenation of nitrobenzene
Capacity, 10,000 tons/yr

Toluenediisocyanates from toluenediamine
Pilot plant capacity, 300 tons/yr

Bisphenol plant
Capacity, 1,000 tons/yr

Caprolactam fibre plants – continuous polymerizations filament yarn spinnerettes – capacities 0.9 and 1.5 tons/day
Staple fibre spinnerettes – capacity, 3.0 tons/day

Polyester fibre plants
Staple fibre spinnerettes – capacity, 3.0 tons/day

Modified polyalcohol fibre plant
Capacity, 3,000 tons/yr

Gasoline and lubricating oil additives plants

For some productions planned up to 1970, technologies will be purchased.

The most important are:

Ethylene oxide by direct oxidation process.
Butadiene from C_4-hydrocarbons.
Stereospecific polybutadiene rubber.
Polypropylene.

20. DEVELOPMENT OF THE PETROCHEMICAL INDUSTRY IN THE ROMANIAN PEOPLE'S REPUBLIC

Ion Marinescu, Technical Director, Ministry of Petroleum and Chemicals

I. INTRODUCTION

Romania was among the first of the European countries to begin to use natural hydrocarbons as raw material for the chemical industry. As early as 1934-36, an installation for ammonia production was built at the NITROGEN plant of Tirnaveni, and an installation for 500 t/carton black began to function at the factory of the SONAMETAN Company of Copsa Mica, both based upon the processing of methane gas. At the latter factory, formaldehyde was produced for the first time in the world, by the process of direct oxidation of methane. The yield was, however, extremely low in comparison with that of the existing methods, and in 1938 the consumption of methane used as raw material was as low as 5 per cent of total methane output of the country.

Extensive research work was also directed towards the profitable utilization of petroleum by-products in chemical industry. The procedure of Edeleanu for extraction of aromatic compounds from petroleum hydrocarbons with the aid of fluid sulphur is still used on a wide scale in many countries. Interesting syntheses have been achieved in the field of industrial detergents, of additives for the improvement of the Dean-Davis index, and of synthetic rubbers with chlorine-containing molecules.

Although economic surveys published in 1940 showed a high degree of economic efficiency in the chemical processing of petroleum gas, an industry founded upon this source of raw material could only be created after the victory of the people's masses in Romania and after a switcht had been made to industrialization as the basis for the development of the national economy.

Bearing in mind the importance of chemical industry for all the other branches of the national economy, the Government has paid special attention to multilateral expansion in this field. The main aim has been to build up a powerful petrochemical industry, since this is the cornerstone of high-level utilization of the country's wealth of natural resources. While in pre-war years only three products were manufactured from gas hydrocarbons, at present Romania's petrochemical industry supplies a great variety of agrochemical products for agricultural purposes, new raw materials for all industrial sectors, and a wide variety of consumer goods. Numerous factories and plants, equipped to operate in accordance with the latest world techniques, are already in operation, and more are in an advanced stage of construction.

The harmonious and many-sided development of the economy of the Romanian People's Republic has created a favourable background for the establishment of a petrochemical industry. The fast rate of development of this industrial sector is favoured by the rich sources of natural raw materials. The output of methane gas was over 10,000 million cubic metres in 1963, as compared with 300 million in 1938, and Romania now ranks second among the methane-producing countries of Europe and fourth among all countries in the world. During the same period, the output of crude oil has grown from about 6.6 million tons to over 12.2 million tons. There was also a substantial increase in the output of natural gas. Statistical data show a yield of 42,000 million cubic metres in 1963 as against 17,000 millien in 1938, which represents a 2.5 increase during this interval.

One of the typical features of methane gas occurring in the subsoil of Rumania is its unusual purity. It is entirely free of sulphur compounds and other impurities deleterious to its chemical processing. The 99.4 per cent purity of Romanian methane makes it suitable for utilization, as such, as raw material in the petrochemical industry.

In order to augment the raw material basis for this industry, in the petroleum branch, a catalytic reforming installation is now operating, with a yearly capacity of 1 million tons of gasolene, supplemented by an installation for the extraction and separation of aromatic compounds. A similar installation with a yearly capacity of 500,000 tons of gasolene, which will yield nearly 100,000 tons of aromatic compounds and 120,000 tons of gas and light liquid fractions for chemical processing, will begin to function next year. The necessary amount of petroleum gas for the petrochemical industry is supplied by two installations for gas absorption and separation, having a total yearly capacity of 350,000 tons. The co-ordination of investment works in the oil industry with the requirements of the newly developing petrochemical industry has been one of the main measures meant to ensure the steady progress of the Romanian petrochemical industry.

The necessary electric power and heat supply for the needs of the petrochemical industry is provided for by the setting-up of electrical power stations for district heating in the proximity of large industrial plants. These power stations concomitantly provide for other consumers and are connected to the national power network. Along with the construction of new power plants, the old electric power stations have been re-equipped and expanded.

At present hydro-electric power stations are being built on the Arges River and at the Iron Gates of the Danube, the latter with a planned installed power of 2,000 kW, half of which will go to the Romanian People's Republic. As a result of the above measures, the output of electric power in the country has been increased tenfold since 1938.

Ever since the very first years of planned economy, preparations have been made aiming at the unhampered development of the petrochemical industry. Comprehensive research work was done to process oil and methane raw materials chemically. These studies were started as early as 1948 at the Oil and Chemical Research Institutes of Bucharest (ICEP, ICECHIM). In the following years, two more research institutes came into being, namely the Ploesti Petrochim Institute specializing in studies on the chemical processing of oil products, and Medias "Chimigaz" Institute concerned with research on methane chemical processing.

To assess the value of the industrial installations already designed, a large number of semi-industrial installations are available within the research institutes themselves, allowing a close collaboration between research and chemical engineering work. Apart from these experimental plants for the chemical processing of methane gas and petroleum products have been set up in petrochemical plants. Complex works are, in turn, equipped with modern research laboratories whose paramount aim is the improvement of production technology and product quality, as well as the utilization of by-products resulting from the manufacturing process. A valuable contribution to the development of the petrochemical industry is being made by the scientific research institutes of the Academy of the R.P.R., organized for basic research in the field of petrochemistry.

To provide current information on world technical standards, the petrochemical industry has at its disposal a wide network of documentation offices. The main documentation activity is carried on by the Central Institute for Technical Documentation and the Documentation Centre for the Oil and Chemical Industries which has a library of 40,000 books and 800 periodicals from thirty-five countries. It issues publications, including original papers, and supplies those interested with a number of translations, bibliographic references, and technical economic studies in the field of petrochemistry. To provide for further research into documentation, the big petrochemical centres are equipped with documentation offices having libraries of their own and a staff trained in this field of activity.

The Chemical Designing Institute of Bucharest and the Oil Designing Institute of Ploesti have been organized to draw up plans for petrochemical plants.

The designing teams in these institutes, organized in groups according to their speciality, are solving, in the light of present day techniques, questions both of equipment technology and of buildings, as well as problems connected with the automation and utilities supply of newly designed plants. Alongside the teams specialized in technical problems, there are also groups concerned with the analysis of the economic aspects of the solutions offered. Since 1960 an enterprise specializing in this field of activity (Automatica—Bucharest) has worked out solutions for the more complex problems of automation and the manufacturing of the necessary machinery.

Owing to the ever increasing development of the chemical industry, a new designing institute IPRAN began to function in 1963, staffed with teams specializing in the designing of inorganic chemical plants which formerly belonged to the IPROCHIM Institute. The new institute was entrusted also with the designing of fertilizer plants, including designs for ammonia and nitrogen fertilizer plants.

The institutes of designs in the R.P.R. undertake the designs of scale models thus permitting a reduction in the number of auxiliary personnel and greatly facilitating installing activities.

Many plant designs are worked out within the petrochemical plants themselves, which are provided with workshops and a staff qualified to design new installations within the operating plants.

A typical feature of our petrochemical industry is the modern concept of process designs, which ensures optimum utilization of the raw materials and energy sources. This is provided for by the high technical standard of the installations and the high degree of automation. Many of the up-to-date petrochemical installations operating or now being built have been designed in this country and built by the machine-building industry of the R.P.R. Several large-capacity machine-building plants have been re-organized and specialized for the production of chemical equipment. Owing to these measures, the production of chemical equipment has grown over 3.8 times between 1959 and 1963. The machine-building industry of the R.P.R. is now able to meet a great part of the requirements of the petrochemical industry, supplying it with machines and equipment whose technical performances are meeting international technical standards. The petrochemical equipment made in the R.P.R. is also in demand in the chemical industry abroad. The export of equipment for the chemical industry increased more than seven times from 1960 to 1963.

The experience so far accumulated in the construction and operation of petrochemical plants has provided a basis for the further development of this industrial sector. The plan for the development of national economy, now being implemented, permits a forecast to be made of the main lines of progress in the petrochemical industry until 1970. Petrochemical plants of great capacity will be built with the aim of ensuring as far as possible the diversified utilization of the raw material involved in the manufacturing process. In the nitrogen fertilizer industry, factories with a capacity of at least 300,000 tons of ammonia yearly will be built and the production of high-analysis and complex fertilizers, to be delivered to the agriculture sector either in liquid or in granulated form, will be intensified. The petrochemical raw material basis is due to expand through the building of new plants for gas catalytic reforming and separation. The output in aromatics will be increased about 2.3 times. Alongside petroleum gas, liquid petroleum will be subjected to pyrolysis with the aim of obtaining lower olefins. There is a tendency to simplify technological processes and to reduce the consumption of electric and thermal energy per product unit by adopting the most modern technological methods such as ammonoxidation of propylene for the manufacture of polyacrylonitrile and other fibres. The output of synthetic fibres will be increased, both by developing the existing production capacity and by widening the range of manufactured products.

The types of synthetic rubber will be multiplied by manufacturing new grades of stereospecific rubbers, using isoprene and butadiene raw materials obtained in the single-stage dehydrogenation of the corresponding hydrocarbons. The production of plastics and synthetic detergents will be further developed, particularly by widening the range of manufactured products. By 1970 the total output of the petrochemical industry, in terms of utilization, should be twice that of 1965.

II. DESCRIPTION AND CHARACTERISTICS OF PETROCHEMICAL PLANTS

One of the main characteristics of petrochemical plants built in the R.P.R. is their vertical integration, i.e., each plant turns out both intermediates and goods considered as finished products of the petrochemical industry. Consequently, basic chemicals are manufactured in all petrochemical plants, at present amounting to twelve units, including those still under construction.

According to the availability of two raw materials sources (methane gas and petroleum products), two main development lines can be traced in the R.P.R. petrochemical industry. Some of the petrochemical plants use methane, while others are exclusively based on petroleum.

The whole ammonia output of the R.P.R. is based on methane as raw material which is used in the proportion of about 95 per cent for the production of nitrogen fertilizers. Three plants are at present operating in this sector, namely the chemical complex works of Fagaras, Victoria and Piatra-Neamt, all of which have a joint capacity of 350,000 tons/year. Two other high-capacity plants will start operating this year at Tg. Mures and Craiova.

The entire output of fertilizers produced in 1963 was consumed in the country, with the exception of about 9,200 tons of urea which has been exported to Western Europe and to Socialist countries.

Fertilizer plants in Romania use process flow sheets of different origin. The Piatra-Neamt fertilizer complex works are the most representative of all the operating nitrogen fertilizer factories. The plant has now a yearly capacity of 143,000 tons of ammonia, 210,000 tons of ammonium nitrate and 20,000 tons of urea.

The nigrogen fertilizer factory within the Craiova complex for the chemical processing of methane has a yearly capacity of 200,000 tons of ammonia, 300,000 tons of ammonium nitrate, 100,000 tons of urea and 50,000 tons of liquid fertilizers.

The nitrogen fertilizer plant at Tg. Mures will have a yearly capacity of 90,000 tons of ammonia, 150,000 tons of ammonium nitrate and 50,000 tons of liquid ammonia, which will be used in equal proportions as fertilizer on the neighbouring farms. The technological novelty of the plant consists in the process of methane conversion into synthesis gas at a pressure of 17 atmospheres, thus permitting considerable savings in energy.

Another ammonia plant with a yearly capacity of 200,000 tons is being built at Turnu Magurele. This complex plant includes eleven units among which are a sulfuric acid factory and a phosphoric acid factory for the manufacture of compound fertilizers. The complexity of this plant is due to the fact that both pyrite ashes and apatite fluorine will be utilized therein. Appreciable amounts of non-ferrous metals and noble metals (gold and silver) as well as various fluorine salts will be obtained. Residual pyrite ashes from metal extraction will contain 55-60 per cent iron, to be delivered to the iron and steel industry. The Turnu Magurele fertilizer complex will be one of the most up-to-date fertilizer factories in the R.P.R.

The total capacity of the complex plant is due to reach 400,000 tons yearly of compound phosphatic and nitrogen fertilizers. The establishment of these new plants will raise the output of nitrogen fertilizers to 1.5 million tons yearly by 1965-1966, which represents about 60 per cent of the total fertilizer output of the R.P.R. This proportion corresponds to the climatic conditions of the country and is in accordance with the plans for the development of the main cereal crops and of industrial plants. By 1970, the output of nitrogen fertilizers will be about three times as large as the production planned for 1965. A concomitant increase in other kinds of fertilizers has, of course, been planned as well, in order to maintain an adequate proportion of nutrients in the fertilizer production of our country.

In the field of nitrogen fertilizers, some basic organic chemicals are also produced, particularly those which are technologically related to certain manufacturing stages of nitrogen fertilizers. Thus, at the Victoria chemical combine two methanol plants are operating with a capacity of 40,000 tons yearly. The entire methanol output is converted into 85,000 tons of formaldehyde at the same factory. Part of the combine had been put into service the middle of last year. The 1963 output was entirely consumed in the country, for the production of thermosetting materials and synthetic glues. A small part is used for farming purposes. The highly automated installations are operated, with about twelve workers per shift.

A large variety of basic organic chemicals are derived from methane *via* acetylene. At present, acetylene plants are in operation at the Borzesti Chemical Combine supplying the raw material for the polyvinyl chloride factory. The same acetylene feed is delivered to a trichloroethylene factory. Other installations are operating at the synthetic fibre and yarn factory at Savinesti, where acetylene is used for the manufacturing of acrylonitrile, and at the Risnov experimental works where it is further converted into acetaldehyde and then to acetic acid and vinyl acetate. The total capacity of the acetylene plants is at present of 23,000-24,000 tons yearly. The plants at Risnov and Borzesti are operated according to the method of electric-arc methane cracking, a technological process worked out by the R.P.R. research institutes. The Savinesti plant turns out acetylene based on partial oxidation of methane.

Another acetylene factory also working on the basis of the partial oxidation process will be commissioned next year at the methane processing complex of Craiova. The process and equipment for this factory have been bought from Belgium and it has a capacity of 35,000 tons of acetylene yearly. The same plants will also yield 320 million cubic metres of synthesis gas, which will be consumed by the integrated ammonia factory. The acetylene obtained will be used for the production of 20,000 tons of acetic acid, 30,000 tons of butanol and octanol and 20,000 tons of vinyl acetate yearly.

Among other basic organic chemicals manufactured from methane, mention should be made of the output of hydrocyanic acid at the Carbosin factory of Copsa Mica, where it is used for the manufacturing of methacrylate resins, and the hydrocyanic acid factory within the Savinesti synthetic fibres and yarn factory, where it is used for the manufacturing of the acrylonitrile monomer. Both installations are working according to the Andrusov process. The technological process and the installations for hydrocyanic acid at Copsa Mica are of Romanian manufacture.

Petroleum by-products are also used as raw materials for the production of basic organic chemicals. In Bucharest, the SIN factory has been operating for several years; it produces synthetic fatty acids. The product is further hydrogenated to higher fatty alcohols in a plant set up at the Borzesti chemical combine, which has a yearly capacity of 3,000 tons. The entire yield of this installation is consumed in the country for the production of synthetic detergents.

At the Onesti synthetic rubber and petrochemicals combine, a phenol plant with a capacity of 18,000 tons yearly was commissioned at the end of 1962. This installation also yields 11,000 tons of acetone yearly. The plant is operating according to the Cumene process. The intermediate is also used as raw material for the production of alphamethyl-styrene, used within the plant for the manufacture of synthetic rubber. The installation was entirely designed in the R.P.R. and 40 per cent of its construction carried out in this country. To cover future needs for phenol and acetone, present planning provides for a twofold increase in phenol production and about a threefold increase in acetone production by 1970.

For the processing of petroleum gas into basic organic chemicals at the Brazi petrochemical combine, the first gas pyrolysis and fractioning units will start working during 1964 with an annual output of 35,000 tons of ethylene and 20,000 tons of high-purity propylene, which will be further processed within the same combine. During the first stage of construction of this combine, the following basic organic chemicals will be produced yearly : 10,000 tons of ethylene oxide, 8,000 tons of glycol and 8,000 tons of phthalic anhydride from orthoxylene.

The building of a synthetic glycerine factory with a yearly capacity of 10,000 tons is being envisaged for the future.

The manufacture of macromolecular products has been directed towards the production of plastic materials, synthetic rubber and synthetic fibres.

The types of plastic materials have been steadily developing in recent years. In 1963, about 32,000 tons of plastic materials were produced, as against 6,500 tons in 1959. Particular stress was laid on the production of thermoplastics which are being processed in five factories, as in some particular instances the corresponding monomers are also used for the manufacture of other goods which form the main output of these factories. Thermoplastics made up 72 per cent of the entire capacity for plastic materials available in 1963, not including the output of synthetic glues which alone made up 88 per cent of the production capacity for thermosettings. Two more plastic materials factories are being built within the Craiova complex works for the chemical processing of methane and within the Ploesti petrochemical combine.

The production of polyvinyl chloride is entirely concentrated in the Borzesti chemical combine where the necessary electrolytic chlorine for the production of hydrochloric acid for the vinyl chloride factory is also produced. The plant is designed for a yearly capacity of 24,000 tons of suspension PVC and 12,000 tons of emulsion PVC. The plant uses the latest manufacturing processes. Emulsion polymerization is carried out on a continuous basis, while suspension polymerization takes place in a nitrogen atmosphere, thus providing for a consistent product quality. The polymerization plant is automatically operated according to a pre-established schedule, which allows the manufacture of polyvinyl chloride with different physico-chemical and mechanical properties according to the consumers' demands.

Investments in the entire Borzesti chemical combine, which also comprises two factories for sodium chloride electrolysis with a yearly capacity of 95,000 tons of sodium hydroxide and 85,000 tons of liquefied chlorine along with a number of chlorinated compounds, amount to about 1,667 million lei, of which 56 per cent were for building and installing operations, 35 per cent for equipment and 3.5 per cent for designing know-how.

During 1964, a polystyrene factory has been commissioned at the Onesti synthetic rubber and petrochemical combine, with a yearly capacity of 6,500 tons. The factory manufactures impact resistant polystyrene, expanded polystyrene, and general purpose polystyrene. As distinct from other technological processes, the Onesti factory uses as raw material ethylbenzene resulting from the separation of xylene isomers. The technological process and the necessary equipment for monomer production are of Romanian manufacture while those for polymer production have been bought from the United Kingdom.

Among the thermoplastics manufactured in Romania, an important place will be taken by polyethylene. At the beginning of 1965 Brazi petrochemical combine will be supplemented with a high-pressure polyethylene factory with a yearly capacity of 24,000 tons.

To sum up the production pattern of the Brazi petrochemical combine, it may be seen that it encompasses a plant for petroleum gas pyrolysis, including installations for gas separation and purification, a plant for ethylene oxide and glycols which is to work on the process of direct ethylene oxidation a phthalic anhydride plant from o-xylene as well as a high pressure polyethylene unit

The plastic factory now being built at the Craiova combine for the chemical processing of methane will have a capacity of 20,000 tons of polyvinyl acetate most of which is to be used for the manufacture of water emulsifiable dyes. Part of the yield will be consumed as copolymer in the manufacture of plastic materials with special properties as well as in the production of polyvinyl alcohol and acetals. The designs for the polyvinyl acetate factory are based on the experience gained at the Risnov experimental works which have been operating for several years with a yearly capacity of 1,500 tons. All the equipment for the vinyl and polyvinyl acetate factory at Craiova was supplied by the R.P.R. machine building industry, with the exception of some instruments which are not yet being manufactured in the country.

The polyvinyl acetate factory therefore rounds off the pattern of the Craiova complex for the chemical processing of methane. Owing to the complexity of the plant and the wide range of products manufactured, with numerous ramifications in the technological process, the co-ordination of which requires a considerable amount of brain-work, the plant has been equipped with an electronic computer which will control the operation of the plant and perform technological, economic and administrative computations required by the complex. Total investments in the complex, including the ammonia and fertilizer plants amount to about 2,390 million lei, of which 36 per cent was for building, 42 per cent for equipment, and 2.5 per cent for designing and know-how.

The following range of plastics is manufactured in the R.P.R.: epoxy resins, mainly required by the electrical engineering industry, acrylic resins in various colours produced at the Copsa Mica "Carbosin" factory, phenolic and urea formaledehyde resins produced at the Fagaras chemical combine; glues and insulating materials made at the Victoria chemical plant; and about twenty types of synthetic resins used in the varnish and paint industry. In 1963 the output of thermosettings reached a total of about 17,000 tons, 15,000 of which are urea formaldehyde-based glues which were used up by the wood-processing industry in the country.

The widening of the range of plastics is one of the major concerns of Romania's petrochemical industry. In 1964, experimental polyformaldehyde production was started, and in the near future a polyurethane resins plant will be increased 1.7 times and will include almost all the types for which widespread utilization is foreseeable in the coming years.

The many-sided development of the R.P.R. economy has resulted in a considerable increase of synthetic rubber consumption. Between 1959 and 1963, the production of tyres in the R.P.R. has grown about three times. It is noteworthy that about 70 per cent of the tyres manufactured in the R.P.R. are heavy-duty tyres for tractors and trucks, and, consequently, the amount of rubber required for each set of tyres is larger than in the countries where tyre production mainly depends on motor-car manufacturing. In the R.P.R., large amounts of rubber are also used for the manufacture of driving belts, belt conveyors, electric cables, fire hoses and in the consumer-goods industry for the manufacture of protective clothing, footwear, sanitary equipment etc.

With the exception of small amounts of special rubbers the necessary amount of general-use synthetic rubber will be provided from 1964 onwards, by the output of the Onesti synthetic rubber and petrochemicals combine which was established in 1963 with a yearly capacity of 50,000 tons. The rubber produced at this combine, marketed under the trade name of "Carom", is one of the low temperature polymerized butadiene-styrene rubbers.

For the production of butadiene, the plant uses as raw materials n-butane and a mixture of butane-butylene.

The Onesti synthetic rubber and petrochemicals combine therefore encompasses a synthetic rubber factory whose production includes monomers, a phenol and acetone factory, and styrene and polystyrene factories.

As far as synthetic rubber production is concerned, the country's petrochemical industry is moving to complete the synthetic rubber range, particularly with stereoregular rubbers. The planned capacity for future years will not only cover the needs of the home market, but also will have available amounts to meet possible export demands.

Closely connected with the production of synthetic rubber, process technology has also been steadily developed. The 1964 output of carbon black reaches 37,000 tons, as against 22,300 tons in 1959. The Copsa Mica Carbosin factory now produces, from liquid oil stocks and methane, a wide range of carbon blacks meeting the most varied requirements of the consuming industries. In 1963, almost 55 per cent of the carbon-black output was exported to Western European and to Socialist countries. The considerable amount of carbon black exported compared with the output proves that the carbon-black output of the Copsa Mica Carbosin plant is qualitatively comparable with the carbon black on the world market.

Recently, the construction of a new carbon-black factory has been started at Pitesti, with a yearly capacity of 20,000 tons of high-abrasion carbon black, with polynuclear aromatic-rich liquid petroleum stocks as raw materials and methane gas as a source of dissociation heat. The establishment of this factory will increase carbon-black output in the R.P.R. by over 200 per cent in comparison with the 1965 planned output, taking into account that the expansion of the production capacity of the existing factory has also been planned.

Another section developed within the petrochemical industry is the synthetic fibres and yarn industry. In 1959, the Savinesti synthetic fibres and yarn factory went on stream with a yearly capacity of 2,000 tons polyamide yarn and fibres (Relon), integrated with a phenol caprolactam factory. In the beginning, the factory used synthetic phenol from chemical coke benzene as raw material. It has now been shifted over to phenol supplied by the Onesti synthetic rubber and petrochemicals combine, thus providing for the raw material supply for the development of polyamide fibres.

In 1964 the production of polyacrylonitrile fibres has also been started at the same plant. The yearly capacity of the plant reaches 5,000 tons and it uses the acetylene-hydrocyanic acid process for monomer production.

Important amounts of synthetic fibres and yearn are also envisaged in the manufacture of technical goods such as belt conveyors, V-belts and fishing tools. Soon, the production of polyamidic cord will be started, to be used for heavy-duty tyres working on uneven ground. In view of the many-sided utilization of synthetic fibres, work is now in progress in order to double the production capacity for Relon fibres and yarn, and investments are also planned for the building of a high-yield polyester fibres factory. For several years experimental production of polyester-fibres has been going on at the Icechim-Dudesti plant. As a result of planned investments and of those already undertaken, the output of synthetic fibres will increase about twofold by 1970, as compared with the 1965 output.

Within the petrochemical industry the synthetic detergents industry has also been developed, based on an original process developed by the Romanian research institutes. The procedure is based upon easily available raw materials, i.e., the aromatics and olefins in the thermal cracking gasolene, without a previous separation of the components in the original raw material being required. On the basis of this process, a synthetic detergents factory is operating at Ploesti. The same factory also produces a garden insecticide, mercaptans for fuel gas odourizing, naphthenic acids and naphthenates for the dye industry, and methyl ethyl ketone solvent, including secondary butyl alcohol.

Another factory for synthetic detergents has been operating for several years at Timisoara. The fatty alcohols produced by the Borzesti chemical combine are the raw material used. The capacity of both detergent factories totals about 12,000 tons.

In the near future, the building of a new high-yield synthetic detergent factory will be started, mainly designed for the production of bio-degradable detergents. The establishment of this factory will treble detergent output in 1970 expressed in terms of active material as against 1965 planned production.

An important sector of the country's agriculture — the agricultural pesticides industry — also developed within the framework of the petrochemical industry. The major part of the pesticides is produced by the Borzesti chemical combine whose chlorine output for chlorinated pesticides is the biggest of the pesticide items (Hexachloro-cyclohexane and dichloro-diphenyl trichloroethane (Dextoxan) are being produced at a total capacity of 4,400 tons/year with 40 per cent active substance. The research institutes are continuing investigations to obtain a wider range of insecticides.) The experimental production of organic phosphoric insecticides was recently started for protection against fruit crop pests.

The pesticides manufactured in the petrochemical plants are delivered to agriculture in various mixture and concentrations according to need. For the preparation of these mixtures, the processing plants are equipped with pesticide conditioning units with a total capacity of 150,000 tons/year, which is sufficient to cover the needs of agriculture even in the case of an unexpected invasion of agricultural pests.

From the above account, the paramount importance of the petrochemical industry for the economic progress of the country is evident. The present stage of development of this industry makes it possible to shift over to methane and petroleum as raw materials in the manufacture of most plastics and chemical fibres, almost all nitrogen fertilizers, synthetic rubber and detergents, as well as most of the agricultural pesticides by 1965.

The R.P.R. petrochemical industry has, within a short time, become an activating factor in material production and in raising the technical level in all branches of national economy, thus greatly contributing to the rise in the living standard of the country's population.

21. THE PETROCHEMICAL INDUSTRY OF TRINIDAD AND TOBAGO

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I. Introductory remarks

1. SHORT HISTORICAL SURVEY OF THE DEVELOPMENT OF PETROCHEMICAL INDUSTRY IN THE COUNTRY

Trinidad, the larger of the two islands in the South Caribbean comprising the newly independent nation of Trinidad and Tobago, is one of the older oil-producing territories of the world.

With a population of less than one million, the whole petroleum industry is export-oriented and this is the factor that dominates the development of the local petrochemical industry.

Trinidad's oil production is very small indeed — 131,000 barrels per day — its refining facilities date back almost to the beginning of its commercial oil-producing history, i.e., from about the early years of the second decade of this century. These facilities were never allowed to lag too far behind modern technology and have been expanded rapidly, so that today the two refineries on the island have a total crude throughput of 350,000 barrels per day, with all the modern facilities for secondary processing.

The petrochemical industry was born and, such as it is today, has grown out of these secondary processes. The birth was the natural outcome of advances in refining technology and the first petrochemical must, in effect, be considered a by-product. About the year 1945, the refineries started the recovery of crude naphthenic acids from the lye liquor used in treating gas oils and have since then been marketing these to paint manufacturers.

Chronologically, the second chemical to be produced on a large scale from petroleum in Trinidad was not a petrochemical at all. It was the inorganic element, sulphur. When, after the Second World War, it became difficult because of currency restrictions to procure from traditional United States sources the sulphur used for local manufacture of the sulphuric acid necessary for treating and processing operations in the refinery, one oil company decided to embark on the recovery of sulphur from the H_2S in refinery gases and the first Claus kiln went into production in 1949.

Following this, as markets for specific hydrocarbon intermediates became available, there has been a slow but steady increase in the petrochemicals isolated or manufactured from refinery effluents, both liquid and gaseous. This, of course, has been made possible by continued modernization of the local refineries.

Today there are facilities for thermal and catalytic cracking, thermal and catalytic reforming as well as for alkylation, isomerization and polymerization; and petrochemical products include nonenes and dodecenes, benzene, toluene and aromatic solvents.

In addition, special plants have been and are being erected, designed for the manufacture of particular hydrocarbons, so that there have been added to the list of products such substances as di-isobutylene and cyclohexane.

Until 1959, the petrochemical industry was based solely on the products of refining. In that year, natural gas began to be used as a raw material for the petrochemical industry in Trinidad. In 1959, W. R. Grace Ltd., through its local subsidiary, Federation Chemicals Limited, started the manufacture of ammonia, urea and ammonium sulphate.

2. ECONOMIC MOTIVES

As pointed out above, the development of the petrochemical industry, as far as the refinery operations are concerned, was a natural outgrowth of the development and expansion of refinery operations in Trinidad and Tobago. Further expansion was also encouraged by pioneer incentive legislation. The production of nitrogenous intermediates and fertilizers by W. R. Grace & Co. at its subsidiary plant, Federation Chemical Ltd., at Point Lisas, Trinidad, was due mainly to the special incentive provisions (see following section) offered to the industry, and considering the small size of the market, the proposed establishment of an independent federation of the then British colonies in the Caribbean area. The siting of the industry was also influenced by the protected market offered by the membership of Trinidad and Tobago in the British Commonwealth of Nations.

The larger market promised by the West Indies Federation did not materialize as the proposed Federation failed, the two largest units of the Federation, Jamaica and Trinidad and Tobago, becoming in 1962 independent States. Despite this, the ammonia plant recently completed an expansion programme which doubled its capacity, and plans are well afoot further to increase its facilities.

While the absence of an appreciable domestic market in Trinidad and Tobago has been a disadvantage, the expectation of a strong world demand for ammonia, the marketing outlets and contacts provided by a large international company, low cost energy in the form of natural gas and electricity and a literate, easily trained and adaptable labour force made the development of an intermediate stage petrochemical industry viable.

Given these favourable factors, further expansion will, to a large extent, be affected by external developments, i.e., foreign markets, prices etc.

3. INSTITUTIONAL MEASURES IN FAVOUR OF PETROCHEMICAL DEVELOPMENT

In addition to the concessions offered to industry under the Aid to Pioneer Industries Ordinance, i.e., duty-free imports, income tax holiday, special depreciation allowances, setting off of losses against subsequent profits, extension of pioneer benefits in suitable cases, the Petrochemical Industry Act 1962 makes provision for the grant of pioneer status (as in the Aid to Pioneer Industries Ordinance) and other special concessions for the manufacture of certain petrochemicals in plants of specified minimum capacities, as follows:

Petrochemical	*Minimum plant capacity per 24-hour day (tons)*
Methanol	150
Styrene	50
Naphthalene	60
Phthalic anhydride	25
Ethylene glycol	50
Oxo alcohols	25
Synthetic resins (formalin, liquid and spray-dried urea, formaldehyde and melamine resine)	50

The list of petrochemicals above could be varied by the addition to the list of other approved petrochemicals.

The special concessions granted to approved petrochemical manufacturers include:

(i) Deferment of the factories' production day (i.e., the date on which the income tax holiday commences) to a date not later than four years after the construction day of the factories (the corresponding period under the Aid to Pioneer Industries Ordinance is eighteen months);

(ii) An outright ten-year exemption from customs duty on building materials, tools, plant machinery and other appliances and materials necessary for and used in constructing or equipping the factory;

(iii) An outright ten-year income tax holiday (under the Aid to Pioneer Industries Ordinance, these concessions are for five years with the possibility of extension for a further period not exceeding five years);

(iv) Exemption from payment of export duties on petrochemicals manufactured in Trinidad and Tobago by an approved manufacturer;

(v) Exemption, *in perpetuo*, from customs duties on containers, fuel, raw materials, chemicals and other ingredients and supplies, which are not manufactured or produced in Trinidad and Tobago at a reasonable price, for use in connexion with the manufacture or preparation for sale of approved petrochemicals:

(vi) A ten year exemption from customs duties for the approved manufacturer or his contractors or agents on various articles not exempted from duties under the Aid to Pioneer Industries Ordinance including fencing materials, sea and land transport equipment and articles for use in the operation and administration of petrochemical plants including factory buildings and ancillary facilities for the health, welfare and safety of employees

(vii) Exemption from income tax up to the expiration of the ten-year tax holiday period, of interest in the hands of recipients on certain loans made to the petrochemical manufacturer and employed by him for the purpose of the manufacture or sale by him of approved petrochemicals.

(viii) The right to compulsory acquisition of a "right of user" of land, including the extraction of water and access to land, in connextion with the manufacture of an approved petrochemical, subject to the approval of Government upon Government being satisfied of the desirability of the right of user and that the right of user cannot be acquired by private treaty. These special concessions are in addition to the benefits given to pioneer manufacturers mentioned before

4. SUPPORTING ACTIVITIES FOR PETROCHEMICAL INDUSTRY

In Trinidad, very little, if any, orignal research is carried out in the field of petrochemistry. All the major companies interested is this field Shell, Texaco and Grace operate large research organizations in the larger developed countries of the world. The local subsidiaries contribute to the support of these institutions and share in the knowledge gained by their efforts.

However, Texaco does run a small research and development department associated with its local refinery and a fair amount of work, more in the field of applied chemistry, does take place there. While most of this work is of the pilot-plant development type, some laboratory scale experiments are also undertaken.

As part of this department there is established a reasonably well-equipped physico-chemical analytical laboratory and a great deal has been learned about the detailed composition of various streams of the refinery. This has proved a useful starting point for investigation into the potential of the available hydrocarbons, and considerable experimentation has been carried out in the fields of paraffin, olefin and aromatic chemistry.

Here, too, there are machine-shop, foundry and glass-blowing facilities where metal and glass equipment can be fabricated and virtually all pilot plants have been completely constructed locally.

Up to the present, this is the only research and development organization in the country working in this field, but it is anticipated that with the recent establishment of science and engineering faculties of the University of the West Indies at St. Augustine, there will be increasing interest and activity in chemical and engineering research. It is only natural to expect that the fields of petrochemistry and petrochemical engineering would become the major fields of endeavour.

5. EXPECTED LINES AND RATES OF FUTURE DEVELOPMENT

The impression created by the refinery operators in Trinidad is that because the consumer markets for finished chemicals are so difficult to invade they deem it a more secure and profitable proposition to supply the manufacturers of the finished products with the raw materials they require. Trinidad refineries, therefore, will for the foreseeable future concentrate on the production of the basic intermediates and by-products of the refining industry, future development depending entirely on the demands of this type of market. There would be no problem of supply what with the vast potential of the various refinery streams and with present day advanced separation technology including the use of molecular sieves.

One may therefore confidently anticipate expansion in the production of pure, or nearly pure, hydrocarbons including, very likely, ethyl benzene and the xylenes.

Already a normal paraffins plant is under construction at Pointe-à-Pierre and there are indications in other quarters of the likelihood of an additional sulphur recovery plant in the country.

It appears, furthermore, that certain firms are giving serious consideration to the manufacture of the several chemicals—methanol, glycol, oxo alcohols etc.—that can be produced from the carbon monoxide-hydrogen mixtures obtainable from natural gas by the "methane-stream" or "methane-air" processes. Since this will depend on the availability of natural gas, it is appropriate at this stage to say a brief word on this topic.

The natural gas that is produced in Trinidad is produced incidental to oil production because the hydrocarbon reservoirs under development are crude oil reservoirs of the solution gas drive type. The current gas production rate is just over 300 mmcf/day of which more than 45 per cent is wasted. At this production rate, proven reserves are estimated to last for at least twenty years.

Of the gas being wasted, it is felt that, taking into account the problem of pressures and geographic location of sources, about 100 mmcf/day could easily be made available for industrial use. Of this 25 mmcf/day is already committed to a third ammonia plant now on the drawing board and expected to be in operation by early 1966.

II. Description and characterization of petrochemical plants

1. BASIC INTERMEDIATES

(i) *Olefin hydrocarbons*

There are two plants producing olefin hydrocarbons intermediates. One of these is the propylene polymerization unit of the refinery at Pointe-à-Pierre.

A propane-propylene fraction from the Fluid Catalytic Cracking Unit containing 60 per cent to 70 per cent propylene is charged to the "poly-unit" at a nominal rate of 1,200 barrels/day. The propylene is polymerized over a supported phosphoric acid catalyst. The plant effluent is fractionated to separate the main products, nonenes and dodecenes. The rated product capacities are 250 and 100 barrels/day respectively.

The 1963 output amounted to 87,500 and 29,800 barrels respectively. More than 79,000 barrels of nonene and 1,000 barrels of dodecene were exported to the United Kingdom while 28,500 barrels of dodecene went to the United States. There is no domestic consumption of either product. A slight drop in production is anticipated for 1964.

The second olefin plant, also part of the Pointe-à-Pierre refinery complex, is designed to dimerise isobutylene in the presence of sulphuric acid and produce di-isobutylene (DIB) at the rate of 130 barrels/day. The charge, also obtained from the Fluid Catalytic Cracking Unit, is the butane-butylene fraction. Approximately 30,000 barrels of DIB was produced in 1963 of which 25,000 went to the United Kingdom and the rest to the United States. The 1963 production level is expected to be maintained during 1964.

(ii) *Aromatic hydrocarbons*

The refinery at Pointe-à-Pierre incorporates a complete reforming unit which is on blocked out operation and produces, part-time, a benzene toluene concentrate stock. The charge to this unit is a "heart-cut" from naphtha from the crude distillation units. The nature of this "heart-cut" depends on the relative amounts of the benzene and toluene desired in the final product. The product from the platforming section of the unit is then solvent-extracted to remove the aromatics which are separated by fractionation.

The reformer has a capacity of 10,000 barrels/day of charge on either operation and is capable of producing about 2,300 barrels/day of benzene-toluene mixture.

The products have been sold as a Benzene-toluene concentrate, as aromatic solvent to the local paint industry, and toluene has been sold separately. The benzene was held for conversion to cyclohexane.

During 1963, the reformer output of BT concentrate was about 120,000 barrels of which 9,500 barrels were exported to the United States along with 2,600 barrels of toluene; nearly 900 barrels of aromatic solvent wass sold locally. The 1964 production of these hydrocarbons will be at least double the 1963 figures.

(iii) *Naphthene hydrocarbons*

Benzene from the above-mentioned plant is now being converted to cyclohexane by hydrogenation at Pointe-à-Pierre. Hydrogen is obtained from the platformer. The cyclohexane plant is designed to have an output of 700 barrels/day of product. It was brought on stream late last year and total production was only 10,400 barrels. During the first half of 1964, production was nearly 65,000 barrels.

All plants so far mentioned are owned by Texaco Trinidad Inc., and operate as part of the refinery complex at Pointe-à-Pierre.

2. NITROGENOUS FERTILIZERS

Mention has already been made of the entry of Federation Chemicals Ltd. into the local petrochemical field. The plants owned by this company are situated at Point Lisas on the West Coast of Central Trinidad and use as raw material natural gas from the country's oilfields. This gas usually contains about 90 per cent methane with not more than traces of sulphur. In 1958 natural gas production was of the order of 21.7 million cu ft/day and Federation Chemicals began in 1959 to make use of some of it to produce ammonia, which was then converted partly into urea and partly into ammonium sulphate for sale in and around the West Indies, the Americas and the United Kingdom.

A second ammonia plant was commissioned in early 1964 and anhydrous ammonia is now being exported.

The firm operates its own sulphuric acid manufacturing plant.

(i) *Ammonia manufacture*

Originally the plants at Point Lisas were operated for the end-products ammonium sulphate and urea and the single ammonia unit then operating was designed to produce 100 short tons per day of anhydrous ammonia, virtually all of which was converted to the fertilizers mentioned above.

In early 1964, a second ammonia plant, with a capacity of 615 short tons per day, went on stream and anhydrous ammonia is now an export product from Trinidad. Together these plants consume 27.8 million cubic feet of gas daily, approximately 59 per cent being process gas. Actual production of ammonia in 1963 was 37,000 tons, none of which was exported.

Federation Chemicals Ltd. has planned yet another ammonia plant. It is hoped that by January 1966 this new 750 short tons per day unit will be on stream consuming about 25 million cubic feet per day of natural gas as fuel and process gas.

(ii) *Ammonium sulphate manufacture*

This plant consumes ammonia and sulphuric acid, both being manufactured by Federation Chemicals Ltd. Using the Dutch States Mines process it is capable of producing 275 short tons per day of ammonium sulphate crystals.

In 1963, total production amounted to 85,400 tons. A total of 70,200 tons was exported to British Guiana, Venezuela and the Caribbean Islands. Sales for local use amounted to 18,300 tons.

(iii) *Urea manufacture*

This plant, which employs a process developed by Dutch States Mines involving a mixture of anhydrous ammonia and carbon dioxide, was originally designed to produce 75 short tons per day of urea prills. During 1963, urea production was 23,700 tons, of which 23,100 tons went to the Caribbean, British Guiana, the United States and the United Kingdom. Only 200 tons was sold locally.

The capacity of this plant has recently been doubled.

3. SULPHUR AND SULPHURIC ACID

Reference has already been made to the sulphur recovery plant operated by Texaco as part of its Pointe-à-Pierre refinery complex. It was completely fabricated locally and went on production in 1949. The hydrogen sulphide charged to this Claus kiln is obtained from the Girbotol Unit which recovers this gas from the several refinery gas streams. The plant has a capacity of 22 short tons per day of granulated sulphur, a very small amount of which is used by the company itself to manufacture sulphuric acid, the bulk being sold to Federation Chemicals Ltd. Last year this latter amounted to 8,500 tons. Sulphuric acid is manufactured both at Pointe-à-Pierre and at Point Lisas. At Pointe-à-Pierre very little actual sulphur burning is done, rather H_2S is oxidized to SO_2; there is also a unit for the recovery of the spent acid from the plants. A small amount of acid is sold locally, but the bulk of it is used in refinery processes. The Point Lisas Plant is a sulphur burning one. Apart from supplies from Texaco, sulphur is imported from the United States Gulf States in order to keep the plant at full operating capacity of 190 short tons of acid per day. Last year 14,000 tons of sulphur was imported and the acid production was 64,400 short tons. Federation Chemicals during 1963 exported 170 tons of acid and sold locally 560 tons. Virtually all the acid produced was converted to ammonium sulphate.

4. OTHER PETROCHEMICAL PLANTS

The recovery of crude naphthenic acids was introduced in the local refineries in 1945. Two plants are in existence, one at Pointe-à-Pierre and the other at the Shell refinery at Point Fortin.

Spent caustic used for treating heavy naphthas and gas oils is merely sprung with sulphuric acid. The combined capacity is about 130 barrels per day of crude naphthenic acids with acid values of 180 and 230.

In 1963, production amounted to 23,500 barrels. Inland consumption accounted for 2,600 and 28,000 barrels were exported to the United States and the United Kingdom. The 1964 production is expected to be at least twice that for 1963.

5. EMPLOYMENT IN THE INDUSTRY

The only section of the local petrochemical industry that is independent of the refineries is the Federation Chemicals complex. For the Point Lisas group of plants it is possible to quote over-all employment figures, but in the case of petrochemical plants at Pointe-à-Pierre and Point Fortin, manpower is a common service to the refinery as a whole and any attempt to apportion manpower could be misleading. The fact is that in these instances very little additional manpower is employed. Thus, out of a total of 4,600 employees in the Pointe-à-Pierre refinery, only 50 skilled workers and technicians are considered to be associated entirely with the petrochemical plants.

For Federation Chemicals the employment data are

Manufacturing functions	
Unskilled	22
Skilled	96
Technicians	127
Engineers/scientists	18
	263
Supporting functions (including stores, sales, finance, administration)	150
	413

6. Ownership

All these and similar plants are completely owned by private enterprises. In the case of petrochemical plants, these are all foreign companies.

7. Origin technology

The processes employed in these petrochemical plants are all of foreign origin principally the United States for those allied to refining, and the Netherlands for nitrogenous products.

8. Origin of investment

The design and construction of our petrochemical plants are the work of foreign specialist contractors. Local sub-contractors, technicians, skilled and unskilled workers and materials (e.g. cement paints etc. during the construction stage) represent a small proportion of the total investment, the greater part of which represents the importation of foreign equipment and know-how.

9. Description of above plants

See annex I to this paper.

10. Domestic prices of feedstocks and products

Price data are not available for general use. Except in rare instances, they are supplied to the Government on a confidential basis. It would be unwise to apply to one project, charge stock and product prices obtained from another project. For example, natural gas (at similar pressures) is sold at prices ranging from about $US0.15 to $US0.20 per m.c.f. Similarly, sulphur for example, is sold at between $US7.00 and $US14.00 per ton.

11. Total capital investment

The total capital investment in the petrochemical industry is estimated to be $38 million, most of which is invested in the nitrogenous fertiliser plants.

The capital is derived from the following sources: new foreign investment, reinvestment and profits earned in petroleum production and refining, and reinvestment of allowances given under income tax and other regulations.

12. International co-operation: prospects for regional integration

Efforts by Trinidad and Tobago to gain admission to the European Economic Community with associate status were suspended when the United Kingdom failed to gain admission as a full member.

Trinidad and Tobago have been in the forefront of efforts to promote some form of integration of the islands and other territories in the Caribbean area. Since the break-up of the British sponsored Federation in 1958, no concrete steps have been taken towards integration of the area.

Given the importance of establishing a home base for petrochemical end-products, the economic integration of the area is necessary for the continued development and expansion of the industry.

Note: Annex I summarises for ready reference some of the information given in the text of this paper.

ANNEX I

Summary of petrochemical plant and products (Trinidad and Tobago)

	Basic intermediates					Nitrogenous chemicals			Other chemicals	
	Olefin hydrocarbons			Aromatics	Naphthenes					
Name of plant	"Poly-Unit"		"D.I.B. Unit"	"Reformer"	"Cyclohexane Unit"	Ammonia Plant	Ammonium sulphate	Urea Plant	"N.O.R." Plants	Claus kiln
Number of plants	1		1	1	1	2	1	1	2	1
Location	Pointe-à-Pierre		Pointe-à-Pierre	Pointe-à-Pierre	Pointe-à-Pierre	Point Lisas	Point Lisas	Point Lisas	Pointe-à-Pierre and Point Fortin	Pointe-à-Pierre
Raw materials										
(a) Nature	Propane/propylene mix		Butene-Butane	Special fractionated naphtha	Benzene and Hydrogen	Natural gas	Ammonia and sulphuric acid	Ammonia and carbon dioxide	Spent caustic ex gas oil treating	Hydrogen sulphide ex Girbotol Unit
(b) Source	Catalytic cracking unit		Cat cracker	Rerun units	"Reformer"	The oilfields	F.C. Ltd.	Fed. Chem Ltd.	Texaco and Shell	
Nature of products	(a) Nonenes	(b) Dodecenes	Di-isobutylene	(a) Benzene (b) Toluene	Cyclohexane	Ammonia	Ammonium sulphate crystals	Urea	Crude naphthenic acids	Sulphur
Product capacity	250 bbl/day	100 bbl/day	130 bbl/day	B.T. Conc.: 2,300 bbl/day	700 bbl/day	715 tons/day [a]	275 tons/d	150 tons/d [b]	130 bbl/day	22 tons/day
Output 1963	67,531 bbl.	29,758 bbl.	29,204 bbl.	B.T. Conc.: 120,000 bbl.	10,430 bbl	37,814 tons	85,400 tons	23,697 tons	23,505 bbl	
Output Jan-June 1964	26,393 bbl.	12,039 bbl.	12,730 bbl.		64,704 bbl				16,511 bbl	
Domestic consumption — 1963	Nil	Nil	Nil	*See note* (1)	Nil	Company's own use	18,307 tons	386 tons	2,605 bbl	8,366 tons
Exports — 1963	79,574 bbl.	35,096 bbl.	30,875 bbl.		Nil	Nil	70,227 tons	23,062 tons	28,057 bbl	Nil

Note (1): Some benzene-toluene mixture was sold under the name of "B-T Concentrate" (export: 9,492 bbl.) and some as "Aromatic solvent" (local sale: 867 bbl). Some was blended back into gasoline and some was fractionated into the two components. The benzene was charged to the cyclohexane unit and the toluene was exported.

[a] No. 2 Unit attained full production of 615 tons (short)/day in March 1964.

[b] Original capacity 75 tons (short)/day; capacity doubled in 1964.

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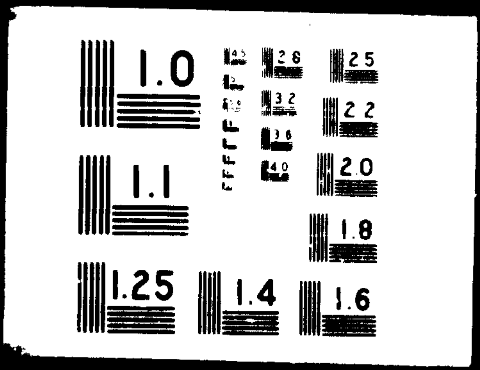

22. THE PETROCHEMICAL INDUSTRY IN THE UNITED ARAB REPUBLIC

M. El-Halfawy, Director, UAR Petrochemicals complex project

The only petrochemical industry that existed in the United Arab Republic before the 1952 revolution was the manufacture of calcium nitrate fertilizer based on refinery gases. That plant was erected in Suez and went on stream in 1951. Its production during 1952 did not exceed 111,000 tons of calcium nitrate.

With the advent of the 1952 revolution, the Government decided to give industry all the encouragement it needed. In 1954, a council for the development of national production was formed and this was followed by the setting up of a Ministry of Industry in 1956.

Early in 1957, the newly established Ministry submitted to the nation its first five-year industrial plan. In the petrochemical field, the plan included the expansion of the Suez fertilizer factory to produce 270,000 t/year of calcium nitrate and the setting up of an ammonium sulphate plant with an annual capacity of 100,000 tons/year.

In July 1960, an over-all five-year plan for economic and social development was drawn up, which included an industrial sector. In the petrochemical field, a delayed coking plant was envisaged to process 2.5 million tons of heavy crude oil annually, and to which were attached reforming, Udex extraction, propylene tetramer and a 6,000 ton/year dodecyl benzene units. This plant will go on stream within the next few months. The programme included also the expansion of the Suez fertilizer plant by another 160,000 tons/year of calcium nitrate and 260,000 tons/year of calcium ammonium nitrate. A petrochemical complex for organic chemicals was also part of that programme and was estimated to cost about 70 million dollars. However, after detailed market research and economic feasibility reports, it was decided to increase the capacity of some of the units in the complex and to add several new units. Accordingly, the Alexandria Chemical Company, as it appears in the second five-year economic and social plan (1965-1970) is based on a full-range naphtha feedstock and will consist essentially of the following plants.

Plant	*Capacity t/y*
Ethylene	35,000
Calcium ammonium nitrate (20.5 per cent N)	150,000
Polyethylene	15,000
Polyvinyl chloride	20,000
Polybutadiene	12,000
Acrylonitrile	5,000
Polyacrylonitrile spinning	5,000
Phenol	6,000
Caprolactam	4,000
Tyre cord	2,000
Methyl alcohol	10,000

Tyre cord and carbon black for the motor-car tyre industry will also be produced.

The site of the company has been chosen and most of the licences and know-how agreements have been entered into. It is expected that bid books containing equipment and machinery specifications will be issued next summer (1965).

It is worth noting that almost all the production of the company is expected to be consumed in the local market.

It should also be stated that the fertilizer plants mentioned in this report are only those based on petroleum feedstocks. In addition, there exists the "Kima" plant at Aswan which utilizes hydro-electric power for the production of hydrogen, and under construction in the Cairo area is another plant using coke-oven gases. The total fertilizer capacity is expected to reach in 1970 the equivalent of 450,000 tons of nitrogen, of which about 20 per cent will be allocated for export.

23. URUGUAY, ITS CHEMICAL AND PETROCHEMICAL INDUSTRY

C. Vanrell and M. Cratsmar, ANCAP, Uruguay

AREA, POPULATION, GEOGRAPHICAL SITUATION

Uruguay is a country of 187,000 square kilometres with a population of 2.8 million. Contrary to what is happening in most South American countries, its population is increasing at a very moderate rate: 1.3 per cent annually.

Situated in the temperate zone, it forms an enclave on the Rio de la Plata and the Atlantic Ocean between the two largest countries in South America, Argentina and Brazil. It consists of well-irrigated, gently rolling land, 88 per cent of which is suitable for crops and cattle-raising.

POLITICAL SITUATION

Uruguay adopted its first Constitution as a sovereign nation in the year 1830, and since the beginning of this century the political situation has been stable.

CULTURAL LEVEL

In Uruguay, education in State institutions at all levels is free. There are also private primary and secondary schools, but no private institutions of higher education.

Primary education is compulsory. The rate of illiteracy is very low and is estimated at only 9.5 per cent of persons over fifteen years of age. There are two universities, one providing training for the professions (law, engineering, medicine, chemistry, etc.), and the other turning out skilled manpower and graduates with sufficient technological skill to become efficient assistants to university-trained professionals.

INCOME LEVEL

Per capita income is about 600 dollars per year.

Although there are no accurate statistics to confirm it, this income is believed to be distributed quite equitably among the various sectors of the population, with the possible exception of the rural unskilled labour force.

There are no closed social classes and any citizen may, by his own efforts, reach the highest posts. There are no racial or religious problems and minorities are respected.

PRODUCTION

Of the 16.5 million hectares of productive land, 14,850,000 hectares are used for cattle-raising and 1,540,000 for crops.

Uruguay has attained a certain level of industrialization. From the years immediately preceding the outbreak of the Second World War up to 1961, total industrial output rose at a cumulative rate of 3.5 per cent a year. From the end of the war until 1954, this expansion proceeded at an accelerated rate (8.5 per cent annually) but then lost momentum. In any event, the contribution of manufacturing to the *per capita* gross national product, which was lower than that of the agricultural sector until the end of the nineteen-forties, has since surpassed it.

Most of the industries are concentrated in the capital, Montevideo, where almost one third of the total population of Uruguay lives. Although a policy has been launched to promote decentralization, in 1960, 78.6 per cent of the total value of industrial output came from the Montevideo area.

POWER SUPPLY

Uruguay's principal source of power is petroleum, which must be imported. An effort has been made to develop water resources, and two hydroelectric power plants with an installed capacity of 236 MW are now in operation, supplemented by thermal plants and small diesel plants scattered throughout the territory.

In 1961, the electricity generated amounted to 1,342 million kWh, 78 per cent of which came from the hydroelectric plants. However, the output of those plants is very variable owing to the wide fluctuations in the contents of the watershed where the plants are situated.

An idea of Uruguay's power supply may be formed from the fact that in 1961, out of a total of about 1,764,000 tons of petroleum equivalent consumed, 1,145,000 tons consisted of petroleum products, 361,000 tons of hydroelectricity, 36,000 tons of coal, 160,000 of vegetable fuels and 62,000 of wind power.

FOREIGN TRADE

Exports

Uruguay's principal exports are farm and cattle products, particularly wool and meat, and industrial products of the same origin. Thus, for example, in 1961, unprocessed agricultural and cattle products accounted for 47.9 per cent of total exports and processed goods 51.8 per cent; only 2.3 per cent consisted of products from other sources.

The principal importers are the countries of western Europe, which normally take over 50 per cent of Uruguay's exports, and the United States, which purchases approximately 13 per cent. Exports to the countries of the Latin American Free Trade Association (ALALC) amount to only 4 per cent.

To meet its needs comfortably, Uruguay has to export approximately 250 million dollars' worth of goods each year. In the last few years, after the boom that accompanied the hostilities in Korea, exports have generally been well below that figure, partly as a result of a decline in volume, but also, to a large extent, as a result of the decline in international prices. Thus, in 1961, total exports amounted to 174,800,000 dollars.

Imports

Uruguay imports mainly from the countries of the European Common Market and the European Free Trade Association. From them it buys over 40 per cent of its imports; 20 per cent comes from the United States.

Imports from countries of the immediate area amount to 16 per cent.

Since no petroleum has yet been discovered in Uruguay's sub-soil, imports of that fuel are considerable. In 1961, out of total imports amounting to 207,700,000 dollars, fuel, particularly petroleum, accounted for 28,700,000 dollars. In the same year, the raw materials for industry involved an expenditure of 97,500,000 dollars.

CHEMICAL INDUSTRY

The analysis of the situation in the chemical industry, including the petrochemical industry, was made on the basis of data for 1960, i.e., one year before the establishment of ALALC. It may be said that the effect of that association began to make itself felt early this year. In analyses of the situation in the Uruguayan chemical industry, particular reference must be made to the year 1960.

Value of production in 1960

In 1960, the gross value of the output of the Uruguayan chemical industry was approximately 424 million pesos at domestic producers' prices, or 33 million dollars at producers' prices FOB United States.

These figures, when compared with previous studies, indicate that the Uruguayan chemical industry accounts for 1.65 per cent of the total value of the production of the chemical industry in Latin America, a percentage which is higher than the ratio of Uruguay's population to that of the region. *Per capita* output is about 13 dollars, 30 per cent higher than the average for Latin America, but barely one fifth of the *per capita* average output of the countries of western Europe and barely one tenth of the *per capita* output in the United States. Given the income levels prevailing in Uruguay and the *per capita* output of chemical products compared with some countries with lower or similar incomes in Europe, it will be noted that the development of the chemical industry is lagging considerably behind.

Production structure of the chemical industry

The bulk of Uruguayan chemical production consists of traditional consumer goods and para-chemical products (mixtures, preparations, formulae, etc.). The manufacture of intermediate products accounts for less than one-seventh of the value of output, and traditional consumer goods and para-chemicals account for the remaining six-sevenths. In other words, a little more than 4 million dollars out of a total value of 33 million dollars is represented by the manufacture of industrial chemical products, a figure which illustrates the fact that the chemical industry proper is in its infancy in Uruguay. It should be noted that, taking the average for seven Latin American countries which together represent 90 per cent of the region's chemical production, intermediate products account for one third of the value of chemical output, which is one half the figure for an industrially advanced country like the United States.

The value added by the chemical industry in 1960 was estimated at 236 million pesos on the basis of the sample constructed by the Banco de la República by linear extrapolation.

The share of the value added in the gross value thus obtained is 55.7 per cent, very similar to that in other countries.

Apparent consumption and imports

In 1960, Uruguay imported 27,720,600 dollars worth of chemical products. The most significant imports are sodium alkali, sodium carbonate and caustic soda; ethyl alcohol; fertilizers and active agents for pesticides; polyethylene, polystyrene, polyvinyl chloride and cellophane, viscose rayon, cellulose acetate, nylon and polyester fibres; synthetic rubber and lampblack (not to speak of substantial imports of natural rubber which are not entered in the statistics of the chemical industry); aniline and a large variety of colouring agents, particularly for the textile industry, and extract of quebracho; auxiliary chemical products for the textile industry; many pharmaceutical products; and a large group of non-specified products. Only a small percentage of chemical imports come from the countries of the Latin American Free Trade Association. There are no statistics on the subject, but this proportion can be inferred from the fact that, on the basis of the average for Latin America, a little more than 2 per cent of chemical imports are now supplied through intra-Latin American trade. Nevertheless, it has been estimated that this percentage will increase and that the figure will be many times higher within the next ten years.

The consumption of chemical products in 1960 has been estimated at a little more than 64 million dollars, 27.7 million representing imports and 36.4 million products manufactured in Uruguay evaluated at prices CIF of similar products made in the United States. Consequently, as regards the chemical industry, nearly 57 per cent of Uruguay's supply comes from national sources (level of import substitution).

Per capita consumption of chemical products is about the same in Uruguay as in Argentina. Hence, taking into account the population, the Uruguayan market for chemical products is approximately equivalent to one-eighth of the Argentine market. This proportion should be considered in the light of the fact that the Argentina chemical industry is about thirteen times bigger than the Uruguayan. The difference is due to the respective levels of import substitution, namely, 83 per cent in Argentina as compared with the aforesaid 57 per cent for Uruguay. The basic reason why Uruguay does not yet have such a high level is the smallness of the market, which makes it difficult to attain economic scales of production in respect of many chemical products. This obstacle will become only a little less serious as internal demand grows in the next decade, since the gap which still has to be bridged before minimum economic scales can be attained is too great in the case of most of the major chemical products in modern industry. Given the conditions prevailing in the Uruguayan market, future prospects for import substitution seem limited; hence, if the Uruguayan chemical industry is to expand significantly despite everything, its expansion will be contingent on exports of large surpluses from new industries or on the direct establishment of export industries.

Over-all projections for 1970

Projections of apparent demand for chemical products over the period 1961-1970 show a cumulative annual increase of 7.2 per cent, compared with a rate of 8.9 per cent for the same period for Latin America as a whole. A slower increase in Uruguay may be expected principally because of the slower growth in population. In absolute figures, it is estimated that apparent consumption of chemical products will amount to between 130 million and 150 million dollars by 1970.

The following groups and sub-groups of products will show a dynamic increase: plastics and synthetic resins, detergents and intermediate organic products, particularly those used for manufacturing synthetic fibres. Fertilizers, which constituted a little over 3 per cent of the total value of the chemical products consumed in 1960, will represent from 7 to 8 per cent by 1970; plastics will increase from approximately 6 per cent to 8 per cent; detergents, from less than 1 per cent to some 5 per cent; and the intermediate organic products also from less than 1 per cent to something under 3 per cent. If we take the consumption of intermediate products intended mainly for the chemical industry itself, it will be noted than an increase in their share in consumption is anticipated, from some 7 per cent in 1960 to about 14 per cent in 1970. By way of illustration, it may be pointed out that the share of those same groups in the consumption of chemical products in the United States has been estimated at 26 per cent for 1960, a figure which indicates the high level of development of the chemical industry in that country.

Structural changes in the petrochemical industry

With the growing internal consumption of chemical products, the prospects of raising the domestic level of supply are limited owing to the smallness of the national market. Consequently, concentrated efforts should be made to open up export possibilities which will improve the balance of foreign trade in chemical products. At the same time, it is imperative to include in the programme of development of the chemical industry at least a limited number of export alternatives, even though the projects forming part of the efforts to establish international machinery (agreements on complementarity and general perferences within ALALC) are still at the initial study stage. Progress in the feasibility studies for those projects might alter their content and original premises and lead to changes in the amounts of the relevant output, export or import values, but it will not lessen the urgent need to guarantee Uruguay a share within Latin America in the future development of intra-regional trade in chemical products commensurate with its needs and technical and economic potential. This implies that, if subsequent studies of the projects were to cause some of them to be discarded, there would have to be a vigorous search for new projects to replace them and also intensive negotiations within the context of the regional planning of chemical industries in order to guarantee Uruguay an export trade at least equivalent to the amounts involved in the projects now under consideration.

PETROCHEMICAL PRODUCTS

Projection of consumption for 1970

Projections for the year 1970 of a few principal categories.

	Tons
Synthetic resins and related products	15,000
Artificial and synthetic fibres	12,000
Rubber, lampblack	10,000
Surface-active agents.	15,000
Ammonia[1]	15,000

Potential consumption of fertilizers

Uruguay is now considering a plan for reorganizing its agrarian structure which is regarded as vital for the development of its economy.

An agricultural development plan should ensure that there is an ample and timely supply of all the material facilities required and encourage the introduction of modern techniques and the widespread use of the skills necessary for development.

Of all the techniques used in agricultural production, the application of fertilizers is perhaps the one which produces the greatest impact. It implies not only that fertilizers should be in adequate supply but also that the techniques necessary for their use shall be available.

Consequently, the plan for the production of fertilizers is complementary to any agricultural development plan.

Fertilizer requirements

It is important to emphasize that the quantities and types of fertilizers being considered for production are

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[1] Depending on the agricultural development plan.

not predicated on the past needs of our agriculture as projected into the future, but are based on the estimated requirements of future agricultural production. When that increased demand is generated will depend on the speed with which the agricultural technique called for in the programme is developed. That development may be rapid if the necessary remedies are applied intensively, and they should be in view of Uruguay's economic situation.

The amount of fertilizer which may be added to any soil to economic advantage increases with the value of the agricultural products (at the producer's prices), irrigation, the intensity of cultivation and the value of the land. It also increases as the cost of the fertilizers put into the soil decreases. Fertilizer requirements for agriculture have been estimated by many writers at some 736,000 tons per year (in terms of present concentrations). On the basis of the present intermediate analysis, it is estimated that the following amounts of fertilizer would have to be used (3.1):

	Tons per year
Nitrogen (N)	30,000
Phosphorus (P_2O_5)	70,000
Potassium (K_2O)	20,000

Present development policy

In pursuance of its policy of promoting the wider use of fertilizers, Uruguay has instituted a marketing system favouring both the manufacturer and the user.

Under this system it establishes maximum amounts to be subsidized, depending on the size of the holding. Thus, for holdings under 200 hectares, the maximum amount to be subsidized is computed at the rate of 1,500 kg per hectare *per annum*. For holdings over 200 hectares, the rate is 500 kg per hectare *per annum*.

Since Uruguay is a producer of phosphate and nitrogen fertilizers, the procedure outlined applies only to them and is expressed in terms of units of assimilable and non-assimilable P_2O_5 and of units of nitrogen in the fertilizer. This subsidy may amount to as much of 20 per cent of the marketing price.

Present import price of nitrogenous substances

In the form of solid compounds, imported nitrogen costs over 200 dollars per ton, whereas in the form of ammonia it costs less than 100 dollars per ton.

This results in a substantial saving in foreign exchange, and the difference makes the production of solid fertilizers more worth while.

Using synthetic ammonia, fertilizers containing nitrogen and phosphorus (NP) or nitrogen, phosphorous and potassium (NPK), i.e., "complexes", can be produced at much lower cost than imports of the nitrogenous and phosphatic ingredients separately, because nitrogen in the form of low-cost ammonia can be converted directly into complexes. It is therefore to Uruguay's advantage, from the point of view of foreign exchange and cost, to produce phosphatic fertilizers (provided they are also nitrogenous) instead of importing the separate ingredients, as is the present practice.

Present and future status of the fertilizer industry

The present fertilizer industry produces fertilizers which are generally of low concentration. In order to obtain concentrates, it has to import expensive ingredients.

By producing ammonia, private industry could incorporate nitrogen in its mixtures at much less cost than at present.

Moreover, private industry would be able to ammoniate and granulate its superphosphates under better economic and technical conditions than exist at present.

PROJECTS UNDER STUDY FOR THE PETROCHEMICAL INDUSTRY

Bases for the projects

The projects being considered for the possible development of a basic petrochemical industry and/or an industry manufacturing intermediate products are based on three assumptions:

(*a*) Possible import substitution;

(*b*) Projection and stimulation of demand for products regarded as economically strategic, such as fertilizers;

(*c*) Zonal integration.

Import substitution

The analysis of the Uruguayan market indicates that it would be uneconomic to establish an industry on the basis of import substitution, at least for the next few years, and that the capital invested in such a project could be put to better use in other industrial activities, except for the utilization of the installed capacities of a few industrial plants manufacturing primary products. Polyvinyl chloride and any more or less direct by-product of petroleum refining are cases in point.

Projection and stimulation of demand

Here ammonia is a case in point: its high cost and the difficulty of importing it may have adverse effects on agricultural development plans. On the other hand, (1) the fact that Uruguay's normal consumption of petroleum distillates leaves a surplus of naphtha amounting to some 4 to 6 per cent of the total consumption of petroleum, and (2) the fact that the urban gas supply system is now fed with coke gas has made it possible to carry out preliminary studies which quote the estimated price for ammonia at 50 to 60 dollars per metric ton for combined plants producing 30,000 tons of ammonia per year.

Zonal integration

It is generally believed that Uruguay, in view of its limited market and its present lack of primary commodity production, should actively seek to participate in the zonal integration of the industry. Its participation might be linked with its consumption of petroleum, its market for petrochemicals and the structure of its refineries.

General description of petroleum production

At present Uruguay consumes approximately 1,800,000 m^3 of petroleum each year. As indicated, its normal consumption would leave it a surplus of naphtha amounting to from 50,000 to 60,000 tons a year. Its refinery uses the catalytic cracking and catalytic reforming processes, etc., and could, in the case of cracking, supply about 100 to 150 tons a day of raw material for the separation of olefins, and, in the case of reforming, some 100 tons a day for the separation of aromatics.

CONCLUSIONS

Uruguay is a country with a small but active market, which requires a high level of industrialization. Past experience indicates that it would be wise to avoid concentrating on a single sector or on a single branch of industry. Uruguay is therefore endeavouring to promote its harmonious development and is determined to participate in the petrochemical industry.

It understands that its participation would be geared to zonal integration, but on a fully reciprocal basis. It believes that the most appropriate course for its development to follow is to be found in ALALC and, in particular, in the agreements already concluded among the various State-operated petroleum industries.

24. THE ECONOMIC ASPECTS OF DEVELOPMENT OF THE PETROCHEMICAL INDUSTRY IN THE USSR

Academician N. Fedorenko, Director, Central Institute of Mathematical Economics

In the output of chemical products the Soviet Union now holds the first place in Europe and the second place in the world.

Capital investments in the construction and reconstruction of enterprises in the different branches of the chemical industry have, during the 1959-1963 period alone, totalled over 5 thousand million roubles, which is almost 1.5 times more than in all the previous forty years of Soviet power, and 2.5 times more than in the 1951-1958 period. The annual growth of capital investment in the chemical industry during the above-mentioned five years averaged 27 per cent, as against 9.6 per cent for the national economy as a whole.

The planned growth of the output of basic types of chemical products up to 1970 is characterized by the data listed in table 1.

The next planning stage in the development of the Soviet chemical industry has taken two main directions :

(1) Increased output of mineral fertilizers and toxic chemicals in order to boost the yield of farm crops and make livestock production more efficient. This is being undertaken in order to meet fully the need of the population for foodstuffs and the industrial demand for raw materials.

(2) Accelerated development of synthetic materials, according to the following principles:

(*a*) Eliminating the use of natural fibres for technical needs and increasing the use of man-made fibres in the manufacture of textiles (fabrics, knitwear). This is undertaken with the purpose of providing the population with textile goods according to scientifically based standards.

(*b*) Introducing plastics to the fullest possible extent, as a technologically and economically highly efficient construction material, in mechanical engineering, construction and other branches of heavy industry and in agriculture, in an effort to achieve the maximum saving of non-ferrous metals and other traditional natural materials, as well as the fullest possible supply of plastics to the consumer goods industry.

(*c*) Extending the production of synthetic rubber to satisfy completely the demand of the tyre and rubber industry for raw materials.

Considering the great economic significance of synthetic materials, the national economic development plans of the USSR for 1963-1970 stipulate a faster growth rate for their production compared with that for the chemical industry as a whole. During these seven years the output of man-made fibres will increase 4.4 times, and of plastics and synthetic resins, 6 to 6.9 times, with the gross output of the chemical industry growing 3 to 3.3 times.

Since the production of organic products and synthetic materials consume a great quantity of inorganic products — such as caustic soda, sulphuric acid, and chlorine — the whole chemical industry will grow.

Economic indices of many industries are largely determined on the basis of the raw materials and the expenditures connected with the production of the various products. The expenditures on raw materials, basic and auxiliary materials make up 69.2 per cent of the total costs of the chemical industry.

The significance of the raw material factor in the economics of synthetic materials production is conditioned by the rather high share of the cost of intermediates used, in some cases making up more than 75-80 per cent of the production cost.

The share of raw materials cost in the main branches of the synthetic materials production is higher than the

TABLE 1. THE GROWTH OF THE OUTPUT OF BASIC TYPES OF CHEMICAL PRODUCTS IN THE USSR UP TO 1970

Description	*1963*	*1965*	*1970*	*1970 growth over 1963*
Gross output of basic branches of chemical industry in comparable prices (thousand million roubles)	8	10.5	24-26	3-3.3 times
Mineral fertilizers total (million tons)	20.0	35	70-80	3.5-4 times
Chemical means of protection of plants and combating pests in terms of effective agent (thousand tons)	59.7	125.9	450	7.5 times
Plastics and synthetic resins (thousand tons)	580	950	3,500-4,000	6-6.9 times
Man-made fibres (thousand tons)	310	44[illegible]	1,350	4.4 times

average for the industry as a whole, reaching from 77 to 78 per cent in the production of synthetic rubbers, from 77 to 79 per cent in the production of plastics and varnish and colour goods, from 86 to 88 per cent in the tyre industry, and from 70 to 80 per cent in man-made fibres production.

Taking into account the fairly high cost of individual chemical products, the effectiveness of cutting costs on raw materials, and consequently of the selection of economical types of raw material becomes self-evident.

The importance of the raw material factor is stressed further by the fact that in most chemical productions rather large amounts of raw materials are used, the actual amount used sometimes reaching several tons per one ton of finished product.

For example, in the production of one ton of cellulose acetate 3.3 tons of raw material is used; of polyethylene, 2.1 to 2.3 tons; of caprolactam, 4.0 tons; of phenol-formaldehyde resins, 2.6 tons; of synthetic rubber, from 2.5 to 3.0 tons.

The characteristic feature of many chemical productions, primarily of synthetic materials, is that one and the same product can be obtained from different types of raw material. As an example, phenol, used in the synthesis of caprolactam, can be obtained from coal, oil or wood processing products. Butadiene, the main intermediate for the production of synthetic rubber, can be obtained from fermentation ethanol, synthetic ethanol or directly from natural gases (butane) or gasolene. At the same time, one raw material may serve as a starting material in the production of a great number of chemicals (for instance, from natural gases can be obtained acetic acid, acetic anhydride, ethanol, various types of synthetic rubber, synthetic resins, plastics etc.). This feature considerably enlarges the raw materials basis of the chemical industry, creates favourable conditions for a rational location of enterprises, makes it possible to manœuvre when choosing the most economical type of raw material for every particular production.

Chemical productions, along with the diversity of technologies, processes and the products manufactured, deal with equally diverse types of raw material, coming either directly from the extracting industry without substantial pretreatment, or in the form of by-products from various branches of the processing industry. The achievements of modern science and technology permit many materials to be used as chemical raw materials, constantly enlarging the choice.

The characteristic feature of a rapidly developing chemical industry is ***a sharp reduction in the share of the raw materials of vegetable and animal origin*** and the priority use of mineral raw materials, primarily combustible minerals, and their products.

Until very recently the organic synthesis industry had used as starting raw material chiefly aromatic hydrocarbons. In the last fifteen to twenty years, the consumption pattern of different types of starting raw material has sharply changed. Especially rapid is the growth of consumption of aliphatic hydrocarbons. *Products from coal move into the background* as the main type of mineral raw material in the organic synthesis industry, superseded by hydrocarbon gases, the main source of which are petroleum derivatives, casing head, and natural gases.

With the growth of the coke output the resources of the chemical products of coking will also grow, with the chemical branch of the coke industry outstripping coke output, owing to more intense processing of chemical raw materials. Thus, from 1946 to 1962 the output of coke went up 4.3 times, of raw benzene 6 times, of ammonium sulphite about 10-11 times, and of concentrated liquefied gas liquor 13 times.

The main ways of increasing the resources of chemical coking products are the systematic raising of the share of coal as in the coke charge and the percentage of chemical products recovered from coke-oven gas.

However, when evaluating the role of coke as a source of raw materials, it should be borne in mind that with the coke output in 1965 going up 37 per cent over 1958, and 63 per cent in 1970, the demand for, say, benzene will grow more than threefold during this period; the production of plastics and man-made fibres will during the 1965 to 1970 period alone grow fourfold and threefold, respectively. The conclusion about the insufficiency of this source of raw material for meeting the rapidly growing needs of the consumers, is quite evident.

This makes it necessary to turn to other, more abundant sources: oil and gas.

Hydrocarbon gases, which for a long time served only as fuel, are now considered to be the best and cheapest type of raw material for the organic synthesis industry.

It should be mentioned that some 80 per cent-90 per cent of aliphatic compounds are received by the present-day organic industry from products of petroleum origin. Petroleum products acquire also an ever-greater significance as a raw material for the production of aromatic compounds, eliminating the monopoly of coke products in this field. Especially high is the share of petroleum raw materials in the production of synthetic rubber, many types of plastics, man-made and synthetic fibres.

As a consequence, a young but very promising branch of the present-day chemical industry — petroleum chemistry — has appeared and is rapidly developing. The volumes available for exploitation and the resources of the different primary hydrocarbons in this country considerably exceed the potentiality of their complete utilization in the chemical industry. The necessity arises therefore to develop a production of high molecular weight materials based on the most effective types of hydrocarbon raw materials, in order to ensure the predetermined scope of their production with the minimum use of manpower.

The main technico-economical factors determining the rapid growth in the output of petroleum chemicals are as follows:

(*a*) The vast resources of raw materials of oil origin;

(*b*) The ever-growing demand for raw materials from many branches of the economy, and especially from the synthetic materials industry, which it is simply impossible to cover from other sources of raw materials;

(*c*) The high economic effectiveness of the production of chemicals on the basis of oil and gas raw materials;

(*d*) The scientific and technological achievements which have made it possible to use oil and gas resources as an economically profitable raw material;

(*e*) The necessity of release of other types of raw materials (such as food) to be used for their immediate purpose.

With the threefold growth of the total chemical production in this country during the 1964-1970 period, the consumption of oil and gas raw materials will rise fivefold. In place of coal, food and other vegetable raw materials, the production of basic petroleum chemicals, synthetic materials, nitrogenous fertilizers, and many other chemicals is based now on the processing of petroleum and natural gases, oil and oil products.

The production of synthetic products from oil and gas raw materials is characterized by a rather high economic effectiveness:

(a) *Ethyl alcohol*

Types of alcohol	*Prime cost (percentage)*
1. Synthetic	100
2. Sulphite	102
3. Hydrolytic	
(*a*) From wood raw materials	230
(*b*) From vegetable agricultural waste	450
4. Food	410

Capital investment in the production of synthetic ethanol is justified in some 1.5 years.

(b) *Ammonia*

PRIME COST OF SYNTHETIC AMMONIA AND CAPITAL INVESTMENT DEPENDING ON THE TYPE OF RAW MATERIAL

Sources of raw material	*Prime cost (percentage)*	*Capital investment (percentage)*
Coke (batch gasification)	100	100
Water electrolysis	124	162
Coke-oven gas	57	87
Natural gas	55	85

(c) *Methanol*

Technico-economical indices	*Coal*	*Coke-oven gas*	*Natural gas*		*Synthesis gas*
			Conversion without pressure	*Conversion under pressure*	
Capital investment	100	70	60	50	45-50
Prime cost	100	37-40	37	33	30-33

The development of petroleum chemistry leads to the release of great quantities of food raw materials.

In 1964-1965, because of the production of ethyl alcohol from non food-stuffs there will be a large saving of food-stuffs, equivalent to 1.7 million tons of grain. The using of food raw materials for technical purposes will be completely discontinued in the next few years on account of the accelerated development of petroleum chemistry.

This will not only increase the resources of food-stuffs, but also effect a great annual economy; for example, up to 300 million roubles in the production of ethyl alcohol, and in excess of 200 million roubles in the manufacture of synthetic detergents.

The characteristic traits of the development of the basic branches of the chemical industry which have governed the increased demand for intermediates, the output of which can be practically provided for by the petroleum chemical industry alone, are:

(1) The change in the framework of production and the widening of the range of products of the synthetic resins and plastics industry is characterized by the rapid growth of the share of polymerization products with the growth of the absolute output of such types of plastic as phenolic, urethane and others, as well as polystyrene and other plastics on the basis of aromatic raw materials.

(2) The present-day stage of development of the synthetic rubber industry is characterized by a sharp turn in the direction of new types of stereoregular polymers replacing natural rubber. Ethyl alcohol, which constituted more than 90 per cent of raw materials for synthetic rubber in 1958, will make up only one-third in 1966, with some 60 per cent taken up by butanes and pentanes for dehydrogenation. The largest tonnage (in terms of the amount consumed) raw-materials of petrochemical origin, playing the decisive role in the development of the synthetic materials industry, are olefins (ethylene, propylene) butadiene, acetylene, as well as aromatic hydrocarbons (especially benzene, xylenes).

Butadiene remains the principal monomer in the production of synthetic rubber and finds application in a number of syntheses of chlorine derivatives and other products. The change of the raw material basis of its production, application of dehydrogenation techniques of butane obtained from oil production and processing products, allows a cut in capital investment of from 10 to 20 per cent and a saving of production cost of from 7 to 10 per cent.

Acetylene, obtained from calcium carbide, could be used as a raw material for petrochemical processing only as long as it was the only type of raw material for separate products important in the national economy. Now, there has risen a possibility of effecting many of those syntheses on the basis of the more accessible and cheaper ethylene. Especially in acetylene syntheses an ever-wider use is made of acetylene obtained from oil and gas raw materials. Carbide acetylene is still used for welding and cutting metals.

Ethylene and propylene: their production is based mainly on the pyrolysis (high-temperature decomposition) of saturated oil hydrocarbons — ethane, propane, normal butane and the higher boiling paraffin hydrocarbons, including gasolenes (also kerosene, ligroin, heavy and light oils, and crude petroleum can be used for these purposes). Only a very small share (in 1959, some 7 per cent, and in 1966, some 5 per cent of productive capacity) of ethylene is separated in the form of "ethylene fraction" from coke-oven gases at nitrogenous fertilizer plants.

Currently, in the USSR as in other countries, cracking gases from petroleum refineries are also utilized as starting raw material in the production of ethylene and propylene.

Studies indicate that the technico-economical indices of ethylene and propylene production from liquid hydrocarbon raw material, which is a petroleum refining product (specifically raffinates and straight-run gasolenes), are not inferior in effectiveness to the production of olefins from casing-head gas components. At the same time, an efficient use should be made of the process by-products, including the butylene-butadiene fraction and pyrolysis resin.

TABLE 2. THE DYNAMICS AND PROSPECTS OF DEVELOPMENT OF THE RAW MATERIAL BASIS OF OLEFIN PRODUCTION IN THE USSR FOR THE NEXT PLANNED PERIOD

	1966 (percentage)	1970 (percentage)
1. Pyrolysis raw materials including:		
Gasolenes	45.0	68.8
Casing-head gasolene	—	1.2
Liquefied gases	55.0	26.5
Ethane	—	3.5
TOTAL	100.0	100.0
Consumption growth (per cent)	100.0	282.0

The sources for obtaining lower olefins are closely connected with petroleum refining techniques. With the growing scope of petroleum refining processes, characterized by an increased yield of unsaturated hydrocarbons (as takes place, for instance, in catalytic cracking), the share of the ethylene obtained from refinery gases may rise.

Development of the chemical industry in the USSR is helped by a rapid growth in the production of basic petrochemicals.

The growth rates of *petrochemical production* surpass those of the industry as a whole. This can be confirmed by the data on the percentage increase of the volume of production of basic petrochemicals.

Product	1963	1965 (percentages)	1970
Ethylene	100.0	170.0	500.0
Propylene *	100.0 (1959)	800.0	2,300.0
Benzene	—	100.0	2,200.0
Phenol	10.0	160.0	340.0
Acetaldehyde	100.0	165.0	1,020.0
Higher alcohols	100.0	540.0	5,000.0

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* Also great resources of propylene, making up about one half of its special production (together with ethylene at pyrolysis plants), are obtained at oil refineries.

Petroleum chemistry is becoming the dominant supplier of the most important types of chemical raw materials.

(*a*) THE DYNAMICS OF DEVELOPMENT OF THE RAW MATERIAL BASIS OF AMMONIA PRODUCTION

Raw material sources	1958	1962 (percentages)	1965 (planned)
Natural and casing-head gases	0.6	39.2	60.5
Coke-oven gas	35.4	24.5	16.5
Gas raw materials total	36.0	63.7	77.0
Coke and coal	44.9	23.7	17.4
Electrolysis and others	19.1	12.6	5.6
TOTAL	100.0	100.0	100.0

(*b*) THE DYNAMICS OF THE PATTERN OF THE RAW MATERIAL BASIS OF THE PLASTICS INDUSTRY

Raw material type	1960	1965 (percentage)	1970
Oil and gas processing products	24.5	66	90
Coal treatment products	59.5	22	2
Basic chemistry products and vegetable raw materials	16	12	8
TOTAL	100	100	100

(*c*) THE DYNAMICS OF THE PATTERN OF THE RAW MATERIAL BASIS OF ETHYL ALCOHOL PRODUCTION IN THE USSR

	1958	1959	1960 (percentage)	1965 (planned)
1. Alcohol from food raw materials	70.8	65.0	61.6	50.0
2. Alcohol from non-food raw materials	29.2	35.0	38.4	50.0
Including:				
Synthetic	16.1	31.3	24.2	32.0
Hydrolysis	7.7	8.1	8.4	18.0
Sulphite	5.4	5.6	5.8	
TOTAL GROWTH	100.0	104.0	105.0	138.0

The demand of the chemical industry of the USSR for oil and gas raw materials remains low as compared with the quantities of oil and gas being produced. From 3 to 5 per cent of the total weight of oil and gas produced will be used for the needs of chemical plants.

Therefore the chemical industry does not have a strong influence on the scope of oil and natural gas production.

The paramount task now is to choose from the abundance of raw material sources available, those that would require minimum capital and production expenditures.

Currently shallow processing methods are prevalent at oil refineries in the USSR, yielding relatively small amounts of unsaturated and aromatic hydrocarbon by-products. For this reason petroleum chemistry in this country is paying attention to the resources of low-octane gasolene fractions and the pyrolysis of heavy petroleum ends.

According to available calculations, the oil industry can provide for chemical needs the necessary amount of raffinates and low-octane fractions of distilled gasolene without reducing the production of liquid fuel.

As confirmed by calculated economic indices, the pyrolysis of crude oil at least incurs no loss compared with such a raw material source as liquid gases.

However, when assessing the prospects of development of the raw material basis of petroleum chemistry, account should be taken of the trend in the development of oil processing towards the production of high-octane fuels, and therefore, a rise in the yields of propylene, ethylene and other types of raw material for petrochemical reactions. Simultaneously liquid gases will fall in price, mass production will make them available to all consumers and the free resources of low-octane distilled gasolenes will be reduced.

All this demands that the need to utilize all types of oil and gas raw materials should be taken into account for the planned period in question, a raw material being selected each time that would meet the demands of specific complexes of petrochemical production at the lowest possible cost.

In the different regions of the country the whole range of hydrocarbon raw materials have to be resorted to, from petroleum distillation gas fractions and natural gases to crude oil.

The progress in science and technology, aided by an improvement of technico-economical indices of the production of petrochemicals, determines the basis for the raw material selection, affecting its pattern in the course of development of the industry. This can be judged by the examples of production of a number of basic petroleum chemicals.

(*a*) TECHNICO-ECONOMICAL INDICES OF THE PRODUCTION OF ACETALDEHYDE BY THE DIRECT OXIDATION OF ETHYLENE AND THE VAPOUR-PHASE HYDRATION OF ACETYLENE (FROM OIL AND GAS RAW MATERIALS)

Indices	*Units of measure*	*Obtaining of acetaldehyde from acetylene*	*Obtaining of acetaldehyde from ethylene*
1. Production capacity .	Thousand tons	30.0	30.0
2. Cost price	Percentage	100.0	65-70
3. Specific capital costs (including related industries)	Percentage	100.0	86.0

The method of acetaldehyde synthesis from ethylene is planned to become the leading one in the near future.

(*b*) TECHNICO-ECONOMICAL INDICES OF THE PRODUCTION OF PHENOL (percentage)

	Cumene method	*Sulphurisation method*
1. Cost price	100.0	170
2. Specific capital investment:		
(a) In phenol production	100.0	160
(b) Ditto, including related industries	100.0	140

The high economic effectiveness of the cumene method has conditioned the priority development of the above-mentioned products by this method, and this trend will continue in the future.

In 1963, the share of cumene phenol in the over-all production of synthetic phenol reached 79 per cent, as against 63 per cent in 1960, and it will be in excess of 89 per cent in 1965. Technico-economical indices of the cumene method continue to improve. By way of illustration the following data (percentage) for one plant can be given.

Indices	*Initial design*	*After first expansion*	*After second expansion*
1. Phenol and acetone capacity (1 ton to 0.6 ton)	100	333	535
2. Prime cost (1 ton phenol plus 0.6 ton acetone) . .	100	65	55
3. Specific capital investments (ditto) . . .	100	74	58
4. Number of personnel . . .	100	130	135

In 1963, the share of cumene acetone in the over-all production of synthetic acetone reached 84 per cent, as against 76 per cent in 1958, and it will be 89 per cent in 1965.

The new methods of acetone synthesis, by direct oxidation of propylene, are highly economical. However, the problem of acetone production must be solved not separately from phenol production, but by taking into account the demand for both products.

The main progressive technico-economical trends in the development of the present-day petrochemical industry are as follows:

Enlargement of production plants conditioned by a material improvement of the production economy (the capacities of ethylene plants went up from 5,000-10,000 tons a year to 60,000-100,000 and 160,000-230,000 tons a year);

Wide introduction of direct single-stage syntheses of basic petrochemicals, including acetaldehyde (by direct selective oxidation of ethylene), butyl and higher alcohols (by oxo-synthesis) acrolein (by direct oxidation of propylene) and acrylonitrile (by oxidising ammonolysis from propylene and ammonia);

Conversion of multitonnage productions from batch to continuous methods, ensuring the possibility of complete automation and control of production process by electronic computers;

Orientation towards new available types of raw material and their composite utilization;

Securing of economical production of high-quality products (in particular by the concentration of the basic substance).

Oil and gas raw materials and petrochemical processes presuppose a complex, a composite character of utilization and lead to productions being combined. At the same time, the whole practice of the petrochemical industry indicates that the highest economy is effected with the specialization and concentration of enterprises.

Therefore, the most effective type of organization of petrochemical enterprises becomes *the construction of combines* including technologically interconnected *large specialized plants.*

The most rational combination would simplify the process technique of one or several of the plants included in the combine. Thus, a single unit, serving the whole combine, for the pyrolysis of saturated hydrocarbons and the gas separating system, will make it possible to cut the number of processing stages for several plants.

The problem of the number and the size of separate plants included in a combine is the most complex of all.

Technico-economical calculations and the practice of construction of large combines have helped us overcome the passion for combines of over-complicated composition, at which no clear-cut specialization of the constituent plants could be achieved, and the scope of each of them lagged behind the economically optimum ones.

It would seem that the most effective way is to try to achieve the maximum size for every plant included in a combine, which would provide for a decrease in the specific capital and maintenance costs. The size of such plant is limited chiefly by the maximum output of the basic equipment unit, which is achieved when the industrial technique has been mastered. For example, transition from a stationary catalyst bed to a suspended, quasi-liquefied one will permit the apparatus output to be stepped up several times over, and hence the whole operation of the enterprise. Indeed, a mere increase in the number of apparatus of the same capacity attenuates the economic effect, thereby making it senseless, in some cases, to enlarge further the volume of production.

The limitation of the range of the combined productions is determined also by *the availability of raw materials and the demand for the products within the area of their economical consumption.*

Under the conditions of accelerated development of the chemical industry the greatest importance is being attached to the time taken in the construction and commissioning of new enterprises. Over-expansion of the scope of construction lengthens the time and makes it undesirable to consolidate combines.

Along with combines specialized enterprises are being constructed on a large scale especially at the finished product stage (such as synthetic rubbers, tyres and plastic goods).

Construction of specialized enterprises and combines is planned as a rule within regional complexes including not only the chemical but other industries as well.

The problem of allocation of petrochemical productions is very complex in the USSR, a country of vast territory, an uneven density of population and with unequal levels of industrial development of separate areas.

Concentration of oil and gas raw materials in separate small regions of the country and the high material index of the petroleum chemistry make it necessary to bring the initial stages of processing (including, as a rule, production of monomers) nearer to the sources of raw materials.

However, the great consumption of fuel in the course of chemical syntheses, reaching from 7 to 10 tons and more per 1 ton of finished product, limits the regions having raw material reserves, in which it is advantageous to develop petroleum chemistry, to those which combine both raw materials and fuel, or makes it necessary to transfer petrochemical plants to the deposits of fuel and to the sources of energy, raw materials being transported there.

On the other hand, synthetic material goods are often not economical to transport because of great bulk and low weight, as is the case with tyres, plastic articles and others.

This necessitates bringing the final production stages nearer to the regions in which mass consumption of the product is concentrated. There then arises the need to break up the process flow into two or three parts, the primary processing being concentrated in the starting material supply area, the production of monomers (sometimes polymers as well) where there are cheaper and more abundant energy and fuel, and the manufacture of goods being transferred nearer to consumption areas.

The great diversity of conditions arising, especially in connexion with the variety of utilizable raw materials, demands that in each particular case the solution should be sought of the problem of finding the minimum expenditure throughout the whole complex of stages, from the production of the raw materials to the consumer of the finished product.

25. THE VENEZUELAN PETROCHEMICAL INDUSTRY

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INTRODUCTION

The development of the petrochemical industry in Venezuela started in 1953 with the creation by the Government of the Venezuelan Petrochemical Institute, whose objects as defined by its statutes are the study, establishment, operation and development of those industries utilizing hydrocarbons as raw materials and all related industries. During 1958, the production of a fertilizer mixing plant was started in order to increase the markets for the existing nitrogenous fertilizer plants. Plants for ammonia and its derivatives started production in the first part of 1963. Around this time, a small unit for the extraction and separation of aromatics B-T-X, owned by the Venezuelan Oil Corporation, started operating. Parallel with these plants, a private group associated with the United Carbon Co. installed a carbon black factory. This plant came into operation during 1962. In 1964, a plant to produce formaldehyde from methanol was started. There also exists a number of small polymerisation plants for thermosetting resins, paint resins and polyamidic fibres, utilizing imported raw materials.

Venezuela being the third largest producer of oil in the world should lead Latin America in the petrochemical field, but up to now it has lagged behind some other countries.

The reasons for this slow growth have been (1) the industrial policy, (2) size of markets; (3) lack of information, and (4) lack of trained personnel.

(1) The industrial policy followed up to 1964 was oriented towards the development of consumer goods industries, which create a large number of employment opportunities and develop markets for basic intermediates. The aims of this policy having been accomplished to a large extent, it is being replaced by a policy which places its emphasis on the development of basic industries. For example, there are already two detergent sulfonation plants, three synthetic fibre spinners, four rubber tyre and accessories manufacturers, and more than fifty plastic products manufacturers.

(2) The total population of Venezuela is 7 million of which more than 50 per cent cannot be considered consumers; this fact makes the installation of petrochemical industries for local markets almost impossible. However, the large rate of growth both of population and individual income, adds to a rapid increase in domestic markets. The impending entrance of Venezuela to the Latin American Common Market creates the possibilities of greatly increased markets, especially if accords can be reached with the other member countries.

(3) In developing countries it is quite difficult to obtain information with the accuracy that permits accurate evaluations. The main reasons are the distrust with which consumers report data, and secondly, the correct systematization of these data. By the strictly correct use of the information obtained, it has been possible to lower the resistance of the consumers towards information gatherers. Great efforts have been made to train personnel from poll samplers to statisticians, in the systematic use of data.

(4) The number of technical personnel available in Venezuela is very limited and it was only during the fifties that the first chemical engineers were graduated. Now there is a tendency to increase the number of students in the industrial, chemical, mechanical and electrical engineering faculties. Also, during the last five years a number of technical schools and skilled workers' training programmes have been established. The operation of the fertilizer plants have given a number of professionals and workers practical training in the technical and administrative aspects of petrochemical industries.

These problems have been partially solved and, owing to the extreme importance of this industry, it is necessary to undertake short and medium-range projects to advance its development. On the short range, the projects already in existence are being conducted with the utmost dispatch. The most important projects concern explosives, synthetic rubber, plastics and detergents and the expansion of fertilizers. Of these projects that for explosives is in its initial stages of construction and expected to start partial operations in 1965 and full operations by mid-1966. Synthetic rubber-plastics and detergents are in the final project phase and the tentative starting date is by 1968. The project for the increase in fertilizers is at the economic analysis stage and is tentatively set to start by 1967.

On the medium range, a national office for chemical and petrochemical industry is in the process of being formed. The aim of this office is the preparation of a plan for the development of the industry and the means to accomplish this plan. The main functions of the office will be:

(*a*) Determining the bases of policy most suitable for the country.

(*b*) Studying the participation of public and private national and foreign capital.

(*c*) Promotion of new industries.

(*d*) Co-ordination of different government agencies in charge of incentives like credits and tariff protections, etc.

(*e*) Watching that the industry develops in a rational way, utilizing to the utmost the available resources.

On the whole, the prospects for the development of the industry are very promising since the basic structure already exists throughout the country:

(*a*) The refining capacity of Venezuela is around 1 million barrels per day and is able to supply all types of raw materials.

(*b*) Most of the country has adequate amounts of natural gas distributed through an ample network of pipelines.

(*c*) There are four deep-sea ports connected to all other points of production.

(*d*) Distribution of electricity is ample throughout the country and with the construction of the Guri Dam there will be available large quantities of low-cost power.

(*e*) In most regions there are adequate supplies of water and water treatment facilities.

(*f*) Certain related chemicals like chlorine are already being produced.

(*g*) Some large factories are able to supply part of the equipment such as tanks, piping etc.

(*h*) The oil revenues allow the acquisition of foreign equipment without undue hardship to the economy.

(*i*) The prevailing interest rates (6-9 per cent) are lower than those in most other developing countries.

If the Venezuelan economy is to develop in the future at a rate which will permit the continuous increase in the welfare of its growing population, ways must be found for the diversification of its exports, which are now mainly of oil.

Two of the promising industries are the manufacture of steel and its derivatives and the petrochemical industry. In order that the latter may really earn a large volume of foreign exchange, a great effort must be made in this field by carrying out the present plans and creating newer and better ones. The exact lines of development will be determined by the composition of the domestic and foreign markets, especially that of the Latin American Common Market, but its general lines will bein: synthetic rubbers, fertilizers, explosives, polyamides, polyesters, polyethylene, polyvinyl chloride, polystyrene, detergents, carbon black as final products and ethylene, propylene, butylene, butadiene, benzene, toluene, xylene as basic products.

ANNEX

Characteristics of petrochemical plants

CARBON BLACK

United Carbon de Venezuela
Valencia, Estado Carabobo

	Tons/year
Installed capacity	10,000
Production, 1963	3,000
Domestic consumption	4,000

Exports (to Colombia)
Employment (around 50)
Privately owned
Raw materials

Gas oil	Cardon Refinery Shell Oil
Natural gas	Pipeline from Anaco Field

Capital Bs. 2,500,000

FERTILIZERS

Instituto Venezolano de Petroquímica
Moron, Estado Carabobo

Production

	Capacity (Tons/day)	*Production 1963*[a] *(Tons)*
Ammonia	100	8,500
Nitric acid	185	8,000
Calcium ammonium nitrate	150	8,000
Ammonium sulfate	240	23,000
Urea	50	4,600

Employment

Unskilled	50
Skilled	250
Technicians	8
Engineers	5

Wholly owned by the Government
Technology: Italian and United States

Raw materials

Natural gas	Pipeline from Anaco

Cost: US \$6.00/1,000 m^3

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[a] Production started in June 1963.

FORMALDEHYDE

Leros C.A.
Caracas, Venezuela

	Tons/year
Installed capacity	8,000
Production, 1963	3,000

Private Company
United States Technology

Raw materials	Methanol
Investment	US\$ 800,000

FUTURE DEVELOPMENT

The Government through the Venezuelan Petrochemical Institute has the following short term projects: 1. explosives; 2. synthetic rubber-plastics; 3. expansion of fertilizers.

1. *Explosives*

The project for explosives already under construction will start partial production during 1965 and will be ready during 1966. It will be composed of the following plants:

	tons/year
Nitroglycerin	1,000
Nitrocellulose	500
Trinitrotoluene	3,000
Dynamites	23,000

It is expected that most of the production will be consumed locally with a slight export.

Employment

Skilled	540
Unskilled	60

Technology: Germany

Capital investment	$US 13,500,000
Raw materials	Nitric acid Toluene

2. *Synthetic rubber-plastics*

Under this heading is a project which contemplates a series of integrated facilities which will start from an oil fraction and end in three main products: synthetic rubber; polyethylene and polyvinyl chloride. At present the following characteristics are being determined to obtain maximum economic benefit from this project:

1. Raw product specifications;
2. Process selection;
3. Optimum raw materials;
4. Plant capacity;
5. Localization;
6. Economic evaluation;
7. Investment programme;
8. Training programmes.

The approximate investment required is $US 50,000,000. This investment is part of the National Development Plan, 1963-66.

3. *Expansion of fertilizers*

Motivated by the great increase in domestic consumption of fertilizers and the large foreign demand, an expansion of the actual facilities is being considered. The economic evaluation which is being realized contemplates the possible production of:

Ammonia
Urea
Complex fertilizers

This expansion will be carried out with the utmost speed and it is expected to be in operation by early 1967.

26. THE PETROCHEMICAL INDUSTRY IN YUGOSLAVIA

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1. REVIEW OF PAST DEVELOPMENT IN THE CHEMICAL INDUSTRY

The post-war economic development in Yugoslavia, and especially the development of basic industrial branches, required a rapid development of chemical industry.

In the period 1952-1963, chemical industry in Yugoslavia has been developing substantially faster than industry as a whole. Therefore, while the average annual rate of growth of the production of industry as a whole amounted to 12.4 per cent, the average annual rate of growth in chemical industry amounted to 19.2 per cent.

In the above-mentioned period, production facilities were erected for the following:

Fertilizers: calcium ammonium nitrate, ammonium sulphate;

Inorganic chemicals: ammonia, nitric acid, ammonium nitrate, carbon disulphide, sodium sulphate, sodium chlorate, sodium tripolyphosphate, phosphoric acid, hydrogen peroxide, borate and perborate, cryolite, pesticides;

Organic chemicals: methanol, formaldehyde, 2-ethylhexanol, butyl alcohol, diethyl and dibutyl phthalate, aniline, pesticides;

Plastic materials: cellophane, nitro-cellulose, polyvinyl acetate, phenolic and amino resins, alkyd resins;

Man-made fibres: viscose staple, viscose rayon, cord;

Pharmaceutical products: penicillin, oxitetracyclene, C-vitamin, hormones, alkaloids, glucosides, various vegetable extracts, mercuric oxide, bismuth salts;

Various other chemical products: explosives, pigments, intermediates and organic dyes, flotation agents, finishing agents for textile, leather and rubber industry, anti-corrosive agents, synthetic glues and adhesives, detergents, laboratory chemicals, pesticides.

Some other new plants for the production of polyethylene, polystyrene, PVC (polyvinyl chloride), PV acetate, phenol, styrene, acetone, lindane, polyacrylonitrile fibres and monochloro-acetic acid were put into operation in 1963, and others will come into operation at the end of 1964.

The following table shows the growth of production of the main chemical products in Yugoslavia:

	(In thousand tons)		
	1952	*1963*	*Index*
Nitrogenous fertilizers (20.5 per cent N)	18.9	303.0	1,600
Phosphatic fertilizers (16.5 per cent P_2O_5)	48.7	775.7	1,590
Sulphuric acid 66° Bé	36.4	390.8	1,073
Caustic soda	15.0	41.6	277
Electrolytic caustic soda	5.4	27.1	502
Chlorine	4.8	25.9	540
Soda ash 98, per cent	33.0	90.9	275
Calcium carbide	39.7	106.8	269
Plastic materials — total	3.0	26.4	880
Within them: PVC	2.0	8.4	420
Paints and lacquers	10.1	42.6	422
Soaps, 60 per cent f.a.	23.3	34.9	150
Detergents, 15 per cent a.b.	—	30.3	—
Viscose staple	—	16.8	—
Viscose rayon	—	3.5	—
Ammonia, 100 per cent	—	91.3	—
Nitric acid, 100 per cent	—	164.5	—

2. REVIEW OF THE DEVELOPMENT OF THE PETROCHEMICAL INDUSTRY

In 1939 Metan, an enterprise at Kutina (Sava basin), began to produce carbon black. In 1950 Jugokarbon at Bakar on the Adriatic Coast was the second enterprise to start producing carbon black.

In 1962, the construction of the first plant for organic petrochemicals in Yugoslavia intended for the production of methanol was completed by Nafta, an enterprise at Lendava (Mura basin).

At the end of 1962, the first inorganic petrochemical project intended for the production of ammonia and calcium ammonium nitrate was put into operation by Hemijska Industrija, Pancevo (Banat, petrol basin).

In 1964, the construction of the first plant for the production of organic chemicals and plastic materials was completed by Organska Kemijska Industrija at Zagreb. The production of this plant is based on petrochemical raw materials from the Moslavina basin and from the oil refinery at Sisak.

3. PLANT EXPERIENCES

In the field of chemical industry, priority was given to products of basic inorganic chemical industry because of the insufficient supplies available. Subsequently, when domestic needs increased and it became feasible to meet them through domestic production, the construction of petrochemical plants was considered. The few years' existence of petrochemical industrial enterprises in Yugoslavia provides valuable experiences with regard to a further development of petrochemical industry.

For example, when drawing up plans and during the construction of the first big petrochemical plants in Yugoslavia (at Zagreb and Pancevo), efforts were made to study fully the fundamental characteristics of petrochemical industry, making appropriate use of foreign experiences in this field.

Starting from this conception, it was decided that petrochemical plants should be constructed at an appropriate rational pace corresponding to the circumstances and the available investment resources of Yugoslavia. Simultaneously, a decision was made that the construction would be carried out in stages, so that the construction of initial facilities provides possibilities for their future expansion.

4. Raw material basis for development of petrochemical industry

There are favourable conditions for the development of petrochemical industry in Yugoslavia with regard to the availability of raw materials, as there are considerable deposits of natural gas and substantial surpluses of gasolene.

Industrial deposits of natural gas in exploitation amount to about 25 thousand million Nm^3. Therefore, it is expected that in the near future they should provide an output of over 2 thousand million Nm^3 a year, with an upward trend. The deposits are situated in the eastern areas from Zagreb (Moslavina and along the Drava river) and to the north of Belgrade (Banat) as well.

A great proportion of the gas is very wet and contains 10-15 per cent of ethane, 7-12 per cent of propane fractions, 5-8 per cent of butane fractions and 2-3 per cent of pentane. There are fields which give gas with over 6 per cent of butane fractions containing as much as 50 per cent of butane.

Currently, there are two up-to-date gas plants in Yugoslavia having the capacity of over 300 millions Nm^3 of gas annually, with production capacity of 40,000 tons of ethane, about 80,000 tons of C_3 and C_4 fractions and about 25,000 tons of pentane.

It is planned to build two new gas plants with the capacity of 300 millions Nm^3 per year each; in that way the output of liquefied petroleum gases will be increased approximately to a total 250,000 tons of propane-butane, and if necessary it will be possible to produce even 100,000 tons of ethane. It should be pointed out that oil refining will produce about 200,000 tons of propane-butane intended for thermal purposes, so that the total output of gas plants could be employed in the development of petrochemical industry.

There is a particular pattern in the consumption of liquid fuels in Yugoslavia. Namely, owing to the relatively small number of automobiles which are the only consumers of petrol (all the trucks, tractors and other heavy-duty vehicles are driven by diesel engines), there was a sharp variance between the consumption of gasolene and diesel fuel over the last few years. This ratio has been continuously widening, and now it amounts to 1.0:2.3 (gasolene-gas-oil) with a tendency to widen still further. As a result there are surpluses of petrol, and because of the impossibility of exporting it, it must be employed as a raw material in chemical processes or used for thermal purposes. There is about 100,000 tons of such gasolene surplus today, and at the end of this decade, there will be over 250,000 tons.

On the completion of the works for expanding and modernizing the oil refineries, which are now under way and are expected to be completed by 1965, Yugoslavia will have four catalytic reforming units (Platforming) with at least two Udex units which will be able to produce, if necessary, without any detriment to the quality of the motor gasolene, about 100,000 tons of aromatic hydrocarbons.

5. Description of petrochemical enterprises

(*a*) Metan-Kutina together with "Jugocarbon"-Bakar produce carbon black ROF type (inactive) and MPC type (semi-active). The installed capacities for ROF type amount to 4,000 tons annually and for MPC type, 6,000 tons a year. The total domestic consumption of carbon black amounts to about 600 tons, so that certain quantities of active carbon black are imported, while the ROF type is exported. The production of the ROF type is based on fuel oil while the MPC type is based on the processing of natural gas.

In 1964, the construction of a new plant for highly active carbon black of types SRF, GPF, AAF and IFAE was started. The total volume of the plants will amount to 12,000 metric tons; the total investments will amount to 6.2 million dollars. This plant will be highly automated and there will be only 55 workers employed. It will operate by United States licence.

(*b*) Nafta Lendava has a capacity of 6,000 metric tons/year of methanol. It has been processing about 10 millions Nm^3 of natural gas which is supplied from the Mura gas basin. The preparation of synthesis gas is carried out according to the SOC licence Belge de l'azote et de produits chimiques de Marly, while the synthesis of methanol is carried out by Italian patent Amer Casale Company. In the course of 1964, Nafta will also undertake the production of formaldehyde at 6,000 metric tons/year.

(*c*) Hemijska Industrija, Pancevo is located on the Danube River, 18 km from the mouth of the Sava River. Thus, it is situated on the two biggest navigable rivers in Yugoslavia, and near the capital. Also the enterprise is situated almost in the centre of an area which consumes synthetic fertilizers and has a very developed network of roads and railway lines which facilitates the distribution of fertilizers.

The available capacities provide for the production of 97,000 metric tons of anhydrous ammonia with the minimum degree of purity of 99.5 per cent, 1,650 metric tons of 99.5 per cent ammonia, 170,000 metric tons of 56 per cent nitric acid (calculated at the 100 percentage basis), 360,000 metric tons of calcium ammonium nitrate with 20.5 per cent of nitrogen.

Production is based on the consumption of 83 million Nm^3 of natural gas, and if necessary on fuel oil. The partial oxidation technique is applied to methane (Texaco process). Liquefaction of air for synthesis gas is carried out according to "Air Liquid" and the synthesis of ammonia by the NEC procedure. Factory construction was supervised by Chemico Corporation from the United States.

The investments amounted to 56 million dollars, including customs duties for the import of foreign equipment.

In 1963 (the first production year, i.e. the year of trial production), 205,000 metric tons of calcium ammonium nitrate were produced, while in 1964 it is expected to reach its full capacity. The 1964 production of this petrochemical plant would then amount to 80 per cent of the total output of nitric fertilizers in Yugoslavia, which means that it will overfulfil the production of other nitric fertilizers produced on the basis of other raw materials (gasification of lignite, coke gas, carbide).

(*d*) Organska kemijska Industrija — Zagreb (OKI — Zagreb), is situated on the outskirts of Zagreb, the most industrially developed town and the second largest in Yugoslavia. The plant has been put into operation this year and is now in the early stages of production.

The annual output of the newly constructed plants can increase with relatively small investments, and in a short period of time. The increases are given in parentheses: ethylene and propylene 19,000 tons (38,000 tons), styrene 8,000 tons (22,000 tons), polystyrene 6,000 tons (15,000 tons), polyethylene 15,000 tons (30,000 tons), cumene 10,000 tons, phenol 6,000 tons and acetone 4,000 tons.

Ethylene and propylene are produced through pyrolysis of either liquid or gaseous derivatives of petroleum. Gaseous derivatives of petroleum are conveyed from the gas plant Klostar, which is situated 36 km from OKI, and is connected with it by pipeline, while gasolene is supplied from the Sisak refinery, 50 km from the plant.

OKI is supplied with another basic raw material, benzene, from a coke plant at Lukavac. So, in order that the quality of benzene for synthesis will be adequate, and for purposes of additional refining, equipment for hydrodesulphurization of benzene has been installed, with a capacity of 17,000 metric tons/year.

Manufacturing and technical experience was supplied by the Foster Wheeler Corporation, United States. Hydrodesulphurization of benzene and the production of styrene and cumene is carried out according to the Universal Oil Product Co's process. The technical experience and the licence for cumene were supplied by the Hercules Powder Co., United States. The licence and experience for the production of polystyrene are supplied by Koppers Co., United States. Imperial Chemical Industries gave the licence for the production of high pressure polyethylene. The equipment was supplied by more than sixty suppliers from the United States and the United Kingdom.

Investments amounted to about 60 million dollars, including customs duties for imported equipment.

Installed capacities exceed the present domestic production, so that certain quantities, especially of styrene, phenol, and polystyrene and polyethylene are intended for export.

(*e*) Other:

Except for PVC, the production of which is based on acetylene from carbide, production of other plastic materials and detergents is mainly based on raw materials and intermediates of foreign origin which are imported. The production of synthetic fibres — polyacrylonitrile fibres — will also be based or imported acrylonitrile in its early stage (the capacity will amount to 4,500 metric tons/year and it will be put into operation by the end of 1964).

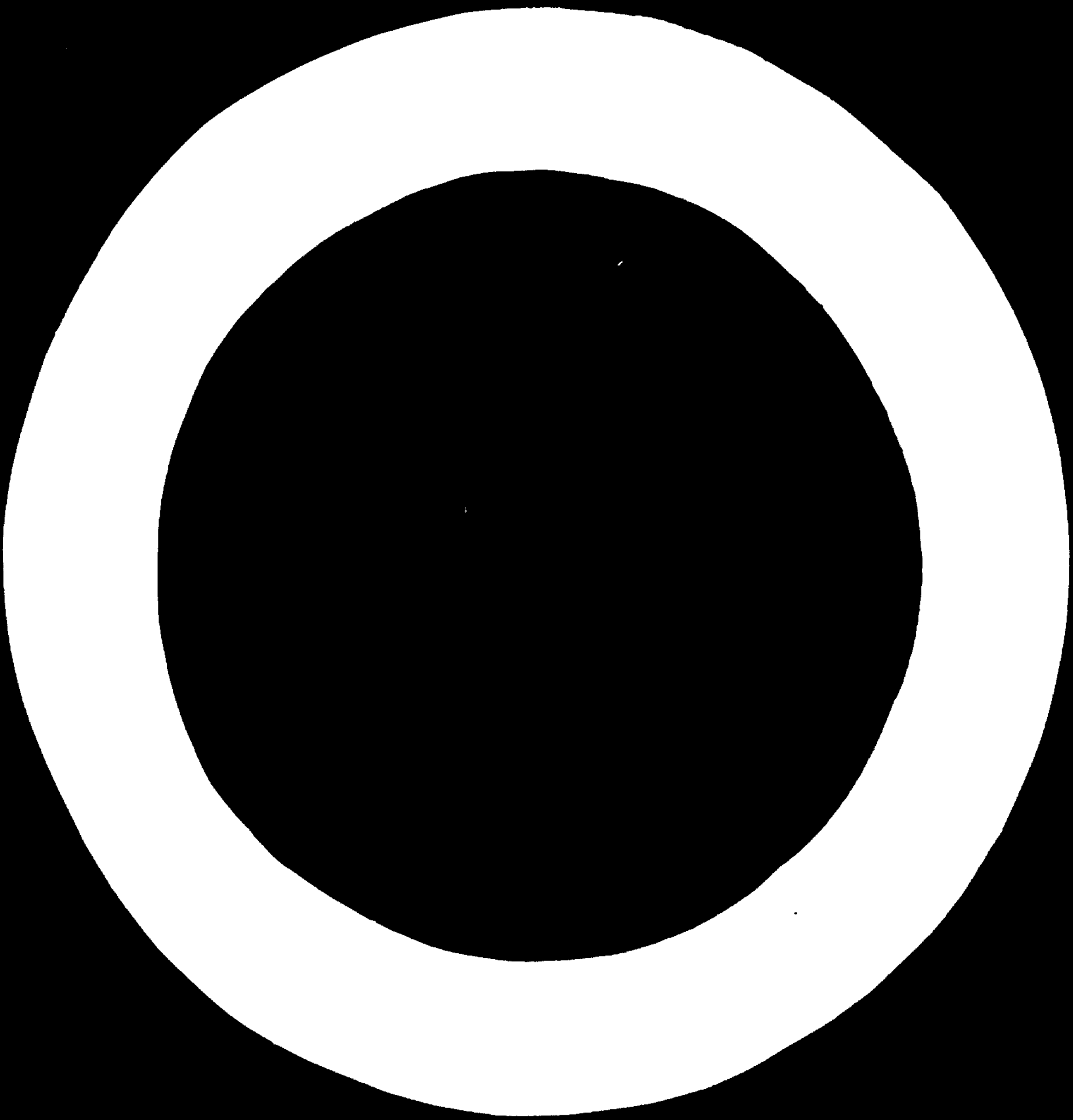
6. FUTURE DEVELOPMENT

The long-term development plan for the petrochemical industry is still under consideration, so that the industry does not yet have a final frame of reference. However, it can be expected that future petrochemical construction will be carried out in the direction of increased capacities for ammonia, i.e., nitrogenous fertilizers. There will be a substantial expansion of the existing capacities at Pancevo and also a new plant will be built at the new location in Kutina. Thus there will be specialized plants in Yugoslavia for the production of nitrogenous fertilizers based on natural gas. It must be expected that both plants will be equipped for the production of most highly concentrated fertilizers — urea and complex fertilizers.

The present plants for manufacturing organic chemicals and plastic materials at OKI will be completed, and later expanded, and thus the optimal capacities for polyethylene and polystyrene will be achieved.

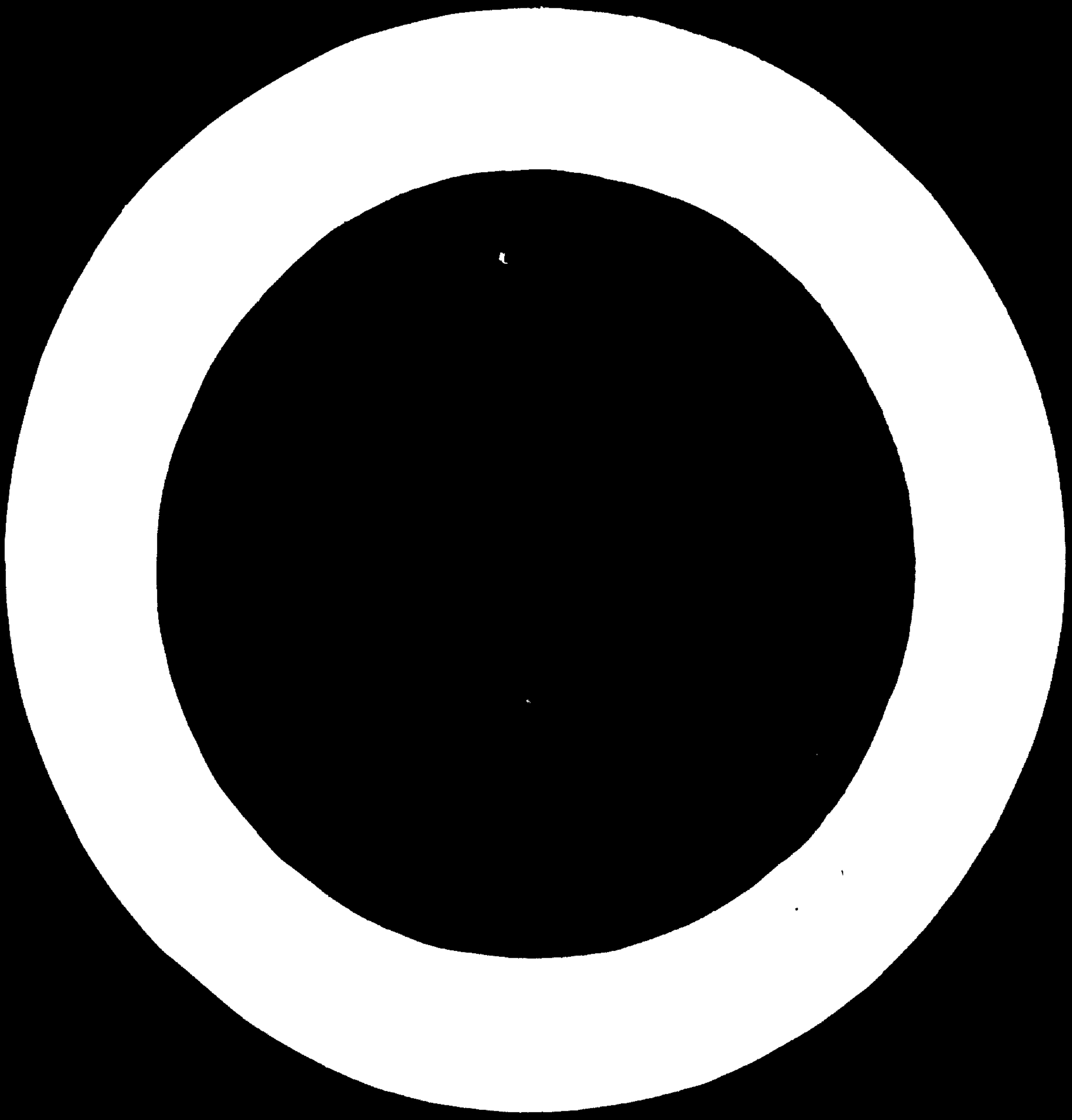
It is most likely that further development of petrochemical industry in Yugoslavia will move in the direction of construction of new plants for ethylene, propylene and acetylene, as well. Therefore, it is necessary to organize plans around the production of those petrochemical products, for which sufficient markets already exist in Yugoslavia.

This raw material basis also enhances the construction of the plants for the production of aromatics so it could be expected that by 1970 and 1975, respectively, depending upon available investment resources, it would be possible to achieve a wider range of most significant petrochemical production.



Chapter VI

REGIONAL DEVELOPMENT OF THE PETROCHEMICAL INDUSTRY



INTRODUCTORY SUMMARY

This introduction gives briefly the conclusions of the three papers contained in this chapter, which were presented at the session of the Teheran Conference on this subject. It ends with a resumé of the discussion on Africa that took place during that session.

In reviewing the development of the petrochemical industry in the ECAFE region, this chapter notes that the consumption in the region of petrochemical products such as nitrogen fertilizers, plastics and synthetic resins, non-cellulosic man-made fibres, and synthetic rubbers has had a high rate of growth. Between 1953/1954 and 1960/1961, the annual rate of growth for nitrogen fertilizers was 7 per cent. Between 1960 and 1963, the annual rate of growth for plastics and synthetic resins was 21 per cent, that for non-cellulosic man-made fibres 23 per cent and that for synthetic rubbers 23 per cent.

The production of petrochemical products in the region has also grown rapidly. Between 1960 and 1963, the annual rate of growth for nitrogen fertilizers was 14.5 per cent, that for plastics and synthetic resins 24 per cent, that for non-cellulosic man-made fibres 26 per cent, and that for synthetic rubbers 65 per cent.

However, both the production and consumption of petrochemical products was concentrated in Japan.

The ECAFE region has been a net importer of nitrogen fertilizers, plastics and synthetic resins, and synthetic rubbers. It has been a net exporter of non-cellulosic man-made fibres, although Japan is the only exporter in the region of such fibres.

The ECAFE region is characterized by very low levels of consumption and production of petrochemical products, with potentialities of expansion. In 1961, the *per capita* consumption of nitrogen fertilizers in the region was 1.4 kg in terms of nitrogen, compared with 14.9 kg in the United States, 10.8 kg in the European Economic Community (EEC), 8.7 kg in the European Free Trade Association (EFTA), and 3.5 kg in the Soviet Union. For plastics and synthetic resins, it was 0.96 kg in the ECAFE region, as against 14.4 kg in the United States, 9.7 kg in EEC and 8.86 kg in EFTA. For non-cellulosic man-made fibres, it was only 0.16 kg in the ECAFE region, compared with 1.7 kg in the United States, 1.04 kg in EFTA, and 0.9 kg in the EEC.

On the production side the *per capita* production of nitrogen fertilizers in the region was 1.3 kg in terms of nitrogen, compared with about 14.9 kg in the United States, 18.7 kg in EEC and 11.7 kg in EFTA. For plastics and synthetic resins also, it was only 0.81 kg in the ECAFE region compared with 11.5 kg in EEC and 9.4 kg in EFTA. *Per capita* production of non-cellulosic man-made fibres was 0.17 kg in the ECAFE region compared with 1.86 kg in the United States, 1.03 kg in the EEC and 0.87 kg in EFTA.

There are various factors which impede the growth of the petrochemical industry in the countries of the ECAFE region. Factors responsible for the slow growth of the fertilizer industry were brought out at the recent United Nations Conference on the Development of the Fertilizer Industry in Asia and the Far East, which was held at Bombay, India, in 1963. Price relationship between crops and fertilizers, non-availability of credit, lack of adequate distribution facilities and inadequate measures for promotion of the use of fertilizers were cited as the factors responsible for the low level of consumption in most countries of the region. The slow growth of the industry was due to the shortage of foreign exchange, lack of capital, lack of know-how, shortage of trained personnel and under-developed infrastructure.

The basic obstacle to the development of an integrated petrochemical industry is the limited market in most countries of the region for the major petrochemical products such as plastics and synthetic resins, non-cellulosic man-made fibres and synthetic rubbers.

Although India, Iran and Pakistan are actually planning to establish petrochemical complexes in their countries, there are at present only two countries in the ECAFE region, namely Japan and Australia, which have a developed petrochemical industry.

The major problem faced by these two countries is the keen competition from overseas suppliers which have solid advantages of size, technology, access to cheap raw materials, and highly efficient financial and organizational structures.

In Australia, with the elimination of import licensing, the local chemical industry, including the petrochemical industry, became vulnerable to dumping by overseas suppliers. In Japan, which has attained international level in the petrochemical industry, the small size of production units and the high price of naphtha, which is the basic material for Japan's petrochemical industry, were listed as major problems. For example, Japan's maximum unit capacity of ethylene in 1964 was 120,000 tons per year as against 250,000 tons in the United States, 200,000 tons in the United Kingdom, 150,000 tons in the Federal Republic of Germany and 80,000 tons in France.

Price comparison of selected petrochemical products showed that in Japan, in 1962, the domestic price per kilogramme of polyethylene was about 58 cents compared with the imported price of about 51 cents, that of polystyrene about 69 cents compared with 36 cents and that of styrene-butadiene (SBR) about 53 cents compared with about 48 cents for the imported product.

The paper on the development of the petrochemical industry in Europe, notes that immediately after the Second World War the growth in Europe was slower than that in the United States. Factors cited as responsible for this slower growth were: the reconstruction problems which arose during that period; the time-lag in technological progress; the policy of the oil companies of locating the refineries near oil or natural gas reserves in order to avoid adding transport costs to the heavy capital costs; and the existence of a well-developed chemicals-from-coal industry, which was less expensive because of the existence of rich coal resources. At the end of the Second World War, nearly all European countries were still dependent for their organic chemical products on coal and raw materials of vegetable origin. After modest and discontinuous beginnings, the petrochemical industry has made great strides in the last decade, as evidenced both in the increases in production (in Western Europe an almost eightfold increase was registered during the period 1953-1960), and in investments, which were estimated to have reached nearly $3 thousand million in 1964. A significant increase was also noted in plastics, synthetic rubbers and synthetic fibres.

However, although the trend in Europe is now towards the use of petroleum feedstocks, they have so far been used as a supplementary source of supply to coal.

Although refinery gases and natural gas form the most important source of raw material in the United States, naphtha would form the major raw material for the petroleum industry in Europe.

From the experience of the European countries it is evident that there is a close interrelationship between the development of the petrochemical industry and industrial development and technological progress. In fact, the most rapid strides in the petrochemical industry have taken place in the highly industrialized countries and it is only now that less industrialized countries, such as Spain, Portugal and Greece, are beginning to build their petrochemical plants.

In the structure of the European petrochemical industry, there is a strong tendency towards vertical integration to provide a more rapid and economic diversification and to ensure adequate sources of raw materials as well as outlets for sales.

There is a considerable concentration of capital in the most important producer countries of Europe to support the heavy investments necessary, not only for fixed assets, but also for the research required to keep pace with technological progress. In the Federal Republic of Germany, for instance, 75 per cent of petrochemical production comes from only five companies, two of them combined with oil companies; in the United Kingdom about 25 per cent is in the hands of one major enterprise; in Italy, the industry is largely controlled by three firms and their subsidiaries and joint ventures. Even in France, where the most striking feature of the petrochemical industry is its apparent dispersal, most of the basic feedstocks are supplied by five firms only.

Nevertheless, Europe's petrochemical industry is not yet fully developed and, in spite of current over-capacity in some areas, investments in research and development, continue to be high and construction activity is increasing rapidly, the petrochemical industry being considered the most promising sector within the chemical industry.

Although a few small petrochemical plants were already established in Latin America twenty years ago, the petrochemical industry in the region really started only after the Second World War in an effort to supply the continuously expanding domestic markets. An exception to this is the development in Tobago and Trinidad of a petrochemical industry for export.

The financial structure of the industry in Latin America is characterized by the existence of State enterprises as well as of foreign investment. On the other hand, Latin America does not as yet have the necessary means for research and development at the same level as in the developed countries.

With reference to the raw materials for the petrochemical industry, in Argentina and Mexico the consumption of natural gas has been growing steadily and long gas pipelines have been constructed. In other countries of the region having big supplies of natural gas, different proportions of the gas are still being flared according to different patterns of utilization. Oil reserves account for 4,518 million m^3, and natural gas 1,211 thousand million m^3.

The refining capacity of Latin America in 1963 was 2.5 mm bbls per day, of which 92 per cent was accounted for by refineries in seven countries. The consumption forecast for refinery products in all Latin America is 2,280,000 bbls per day for 1970.

However, not all the volume refined can be considered from the point of view of petrochemical raw materials because of the existence of relatively small refineries dispersed in a number of countries over wide areas.

Projects being prepared have taken this into account and a number of countries think of erecting new and bigger units, especially of catalytic cracking and reforming, although there will be some differences depending on the supply of fuel oil and natural gas. Also, in some cases, special units of steam cracking operations will be installed, especially where there are no refining facilities or supplies of natural gas. Steam cracking is already being installed in Mexico and Brazil.

With reference to the petrochemical market in Latin America, according to ECLA studies almost two-thirds of the Latin American chemical production corresponds to sectors of the industry producing consumer goods such as paints, cosmetics, detergents, etc.

In the last decade there was an accelerated process of import substitution but as this stage of development has been practically completed, emphasis must be transferred to an industrial sector able to produce the primary and intermediate materials necessary to achieve higher rates of growth.

It is in this respect that the petrochemical industry may play a very important role and, considering the natural expansion of the petroleum industry, it can be expected that petrochemicals will become the main area of development in the chemical industry in Latin America.

Consumption forecasts for 1970 are presented for a sample of twenty-four chemicals. For these products, 75 per cent of the total demand will be absorbed by Argentina, Brazil, Mexico and Uruguay. Principal fields of growth will be plastics, synthetic fibres, synthetic rubber and detergents. Special attention is being paid to the production of fertilizers, and it is expected that in 1970 Latin American production will be about 900,000 tons (N) of nitrogenous fertilizers.

Because of the limitations in market size and the big investments required, there are relatively few petrochemical plants in Latin America. There is a trend towards installing groups or complexes of plants in the same place, concentrating different units of production on one site, for example in Mexico, Argentina and Brazil.

It was stated at this session of the Conference that the Economic Commission for Africa had been very active in the promotion of industries, particularly the chemical industry, in Africa. Taking into account the vastness of the African continent, ECA has divided the continent into four sub-regions, namely North, West, East and Central. Branch offices of ECA have been opened in three of these sub-regions. With a view to promoting the industrial development in the sub-regions of Africa, a Conference on Industrial Co-ordination in West Africa was held in Bamako, Mali. It recommended the development of industries such as basic chemicals, fertilizers and some petrochemicals such as polyvinyl chloride, DDT and BHC based upon imported intermediates, and envisaged similar meetings in East Africa and Central Africa in the near future.

It was noted in the discussion that some countries in Africa especially those in North and West Africa having huge reserves of oil and natural gas, have already initiated feasibility studies for the development of petrochemical industry in their countries.

1. DEVELOPMENT OF THE PETROCHEMICAL INDUSTRY IN THE ECAFE REGION

Secretariat of the Economic Commission for Asia and the Far East

I. INTRODUCTION

The growth of the petrochemical industry in the world has been one of the most striking phenomena of post-war industry. In the United States, the proportion of organic chemicals produced from petroleum has risen over the last fifteen years from 15 to about 80 per cent. Petrochemical production in the United States rose from 420,000 tons in 1958 to 640,000 tons in 1962 in terms of carbon content. In other major industrial countries, the growth rate during this period was more spectacular. In the United Kingdom, production nearly trebled from 30,000 tons to 76,000 tons; in the Federal Republic of Germany it more than trebled from 25,000 tons to 81,000 tons; in France it more than trebled from 12,000 tons to 40,000 tons, in Italy it rose to nearly six times from 8,000 tons to 47,000 tons and in Japan it grew to twelve times from 4,000 tons to 48,000 tons.

The major petrochemical end-products, such as plastics and synthetic resins and non-cellulosic man-made fibres, are becoming well known in many countries of the region and petrochemical industry makes a special appeal to them, especially to those with large reserves of oil and gas.

In this paper an attempt is made to present the trend and growth rate in the consumption of major petrochemical end-products and their future demand, in order to see whether the level of consumption is high enough to warrant the establishment of petrochemical plants. Then, an assessment of the availability of raw materials in the region is made; pattern and the rate of growth in the output of various petrochemical products are given; trade in the major end-products is presented to show the magnitude of imports and exports and whether the region is a net importer or exporter; and the plans for expansion in this industry either by expanding the existing facilities or establishing new plants are analysed. The final two chapters deal with special features and problems and with the scope for regional or international co-operation.

Japan is the only country in the region which has developed the petrochemical industry to a level comparable with those of the principal industrial countries of the world; both consumption and production of petrochemical products within the region are largely concentrated in Japan. In fact, apart from Japan and Australia, no country in this region has established petrochemical plants except for the production of ammonia to manufacture nitrogenous fertilizers. As Japan provides important lessons regarding the various facets of the industry such as production, financing, technological development and other related matters, a separate study of Japan's petrochemical industry is presented in appendix A to this paper.

II. APPRAISAL OF THE PRESENT AND FUTURE MARKETS FOR MAJOR END-PRODUCTS

Nitrogenous fertilizers

With the acceptance of the role of the chemical fertilizers in raising the productivity of land in most countries of the region, the consumption of plant nutrients has increased over the past years. Between 1953/54 and 1960/61, consumption of nitrogenous fertilizers increased from 805,291 metric tons N to 1,279,784 metric tons N by an annual growth rate of 7 per cent. Almost all the nitrogenous fertilizers were derived from ammonia with the exception of some quantities of calcium cyanamide which were produced in China (Taiwan) and Japan.

Table 1 shows the estimated needs for nitrogenous fertilizers in the ECAFE countries in 1963/64 and 1966/67. During this period, the consumption of nitrogenous fertilizers will increase from 2 million metric tons N

TABLE 1. ECAFE COUNTRIES: ESTIMATED NEEDS FOR NITROGENOUS FERTILIZERS

(Metric tons N)

Country	1963/64	1966/67
Afghanistan	4,950	16,830
Brunei	350	500
Burma	6,000	12,000
Ceylon	31,630	40,000
China (Taiwan)	118,000	125,200
Hong Kong	2,100	2,640
India	920,000	[illegible]
Indonesia	200,000	300,000
Japan	700,000	700,000
Korea, Republic of	[illegible]	[illegible]
Pakistan	111,000	140,000
Philippines	50,000	90,000
Thailand	18,000	28,300
Viet-Nam, Republic of	20,400	31,500
TOTAL	[illegible]	[illegible]

SOURCE: Report of the United Nations Conference on the Development of Fertilizer Industry in Asia and the Far East, [illegible].

to about 2.7 million metric tons N at an annual growth rate of 9 per cent, which is 2 per cent higher than that between 1953/54 and 1960/61.

An attempt is made to forecast the consumption of nitrogenous fertilizers in the region based upon consumption figures between 1953/54 and 1960/61 and by using the straight line method.

It is found that the projected consumption of nitrogenous fertilizers in 1975/76 is 5.3 million metric tons N. It is interesting to note that the projected quantity for 1963/64 amounts to 1.95 million metric tons N and that for 1966/67 comes up to 2.5 million metric tons N, both of which are slightly lower than the estimates furnished by the countries themselves in table 1. Hence, it is felt that the projected figure of 5.3 million metric tons N for 1975/76 is a conservative and reasonable estimate.

For the ECAFE region, nitrogenous fertilizers will continue to constitute a major product of the petrochemical industry, especially as the production of ammonia for conversion into nitrogenous fertilizers is being based more and more on the petroleum feedstocks.

TABLE 2. ECAFE COUNTRIES: CONSUMPTION[a] OF PLASTICS AND SYNTHETIC RESINS

(Metric tons)

Country	1960	1961	1962	1963
Australia[a]	76,986[b]	79,219[b]	97,665[b]	114,035[c]
Burma[a]	1,320	1,940	2,470	3,500
Ceylon	798	1,500	2,020	1,800
China (Taiwan)	4,029	6,207	21,963	27,490
Hong Kong	38,470	47,490	92,960	62,500
India	17,405	25,980	28,500	27,593
Indonesia	2,000[d]	4,537[d]	6,200[e]	8,500[e]
Iran	1,979	3,397	3,851	5,400
Japan	526,900	681,000	745,500	995,000
Korea, Republic of	6,694	8,179	9,971	8,000
Malaysia:				
Malaya	1,464	1,734	2,000	3,000[e]
North Borneo	...	13	14	
Sarawak	..	86	71	..
Singapore	...	..	1,270	
Pakistan	..	2,000[f]	5,130[f]	5,130[g]
Philippines	..	3,605	3,170	...
Thailand	4,600	6,588	6,191	7,140
Viet-Nam, Republic of	...	1,740	4,300	2,956
New Zealand[a]	10,020	12,000	...	16,200
TOTAL	685,736	888,130	986,486	1,240,886

SOURCE: Information provided by Governments.

[a] Production + imports − exports or re-exports.

.. Not available.

[a] Year ending June.

[b] Calculated from *Australian Production Statistics and Manufacturing Industries*, Commonwealth Bureau of Census and Statistics, Australia.

[c] Calculated from *Australian Production Statistics* and estimates based on value in national customs returns.

[d] National customs returns.

[e] Estimates.

[f] Estimates based upon value in national customs returns.

[g] Figure for 1962.

Plastics and synthetic resins

The market for plastics and synthetic resins in the countries of the region has grown at a phenomenal pace similar to that witnessed in other countries of the world.

Between 1960 and 1963, the consumption of plastics and synthetic resins rose from about 690,000 metric tons to over 1.2 million metric tons at a growth rate of 21 per cent (table 2).

Consumption was, however, concentrated mainly in Japan and Australia. These two countries accounted for 88 per cent in 1960 and 86 per cent in 1963 of the region's total. In 1963, there were only four other countries, namely China (Taiwan), Hong Kong, India and New Zealand which consumed more than 10,000 metric tons.

The projected demand for plastics and synthetic resins for the region is 2.2 million metric tons in 1967 and 7.9 million metric tons in 1975.

From available information it appears that various plastics and synthetic resins showed varying degrees of importance in the total consumption of different countries. In 1963, for example, *in Japan*, polyvinyl chloride was the highest with 31 per cent, followed by urea resins with 22 per cent, polyethylene 21 per cent, polystyrene 8 per cent, phenolics 7 per cent, and melamine resins 3 per cent. *In China (Taiwan)*, urea resins occupied the highest position with a share of 41 per cent, followed by polyvinyl chloride with 32 per cent, polyethylene with 19 per cent and polystyrene with 3 per cent. *In India*, polyethylene accounted for 32 per cent, polystyrene and urea resins 20 per cent each, polyvinyl chloride 16 per cent and phenolics 12 per cent. *In Hong Kong*, the share of polyethylene was 53 per cent, polystyrene 25 per cent, polyvinyl chloride 12 per cent, phenolics 2 per cent and urea resins 1 per cent.

As information on the consumption of individual plastics and synthetic resins was not available for many countries of the region and as Japan accounted for 77.5 per cent of the region's total in 1963, the regional picture in the relative shares of individual plastics and resins will be similar to that of Japan.

End-uses

In Japan, in 1962, *polyvinyl chloride resin* was used for making flexible products (such as film, sheets, leather, general extruded products, moulded products, and miscellaneous products) which accounted for 42 per cent; electric wire 10 per cent, and rigid products (such as rigid sheets, extrusion products, and moulded products) 48 per cent. *For polyethylene*, film constituted the major product, representing 53 per cent; injection products 19 per cent, paper coating 9 per cent, bottles 7 per cent, wire covering and miscellaneous 5 per cent each, and pipe 3 per cent. Regarding the end-uses for the thermosetting resins, *phenolic resins* were used for making moulding material 39 per cent, laminates 28 per cent, miscellaneous 25 per cent, and shell mould use 9 per cent. *For urea resin* the major use was in adhesives representing over 56 per cent, moulding material 28 per cent, textile treatment 14 per cent, paper treatment over 2 per cent,

TABLE 3. ECAFE COUNTRIES: CONSUMPTION* OF NON-CELLULOSIC MAN-MADE FIBRES AND YARNS

(Metric tons)

Country	1960	1961	1962	1963
Australia [a]	5,455	6,775	6,275	6,275 [b]
Burma	603	720	1,055	1,055 [b]
Ceylon	42	50	99	40
China (Taiwan)	740	2,570	2,880	1,500
Hong Kong	191	18	212	436
India	1,900	2,000	2,636	2,655
Japan	103,900	131,200	147,100	192,700
Korea, Republic of	2,137	2,494	5,902	5,622
Pakistan		306	430	430 [b]
Thailand [c]	702	1,376	1,546	1,546 [b]
Viet-Nam, Republic of	40	134	273	1,100
New Zealand	535	727		1,264
TOTAL	115,453	140,270	167,928	216,003

SOURCE: Information provided by Governments.

*Production + imports — exports or re-exports.

.. Not available.

[a] *Industrial Fibres*, 1964, Commonwealth Economic Committee.

[b] Figure for 1962.

[c] Estimates based upon values in national customs returns.

[d] National customs returns.

and miscellaneous over 1 per cent. *For melamine resin*, major use was found in decorative plate, 32 per cent, followed by coating material 25 per cent, miscellaneous 23 per cent, fibre treatments about 8 per cent, moulding material about 7 per cent and paper treatment about 5 per cent. *For unsaturated polyester resins* it was estimated that, in 1961, the major consumption was in coating material which accounted for 28.4 per cent, button material 26.3 per cent, corrugated and plain sheet 19.7 per cent, moulding material 13.5 per cent, decorative sheet 6.6 per cent, coating material 2.5 per cent and miscellaneous uses 3 per cent.

Non-cellulosic man-made fibres

From available information, the consumption of non-cellulosic man-made fibres and yarns almost doubled between 1960 and 1963. It rose from over 115,000 metric tons to about 217,000 metric tons at an annual growth rate of 23 per cent (table 3).

As in the case of plastics and synthetic resins, the major consumers were Japan and Australia. They accounted respectively, for 90 per cent and 5 per cent in 1960 and 89 per cent and 3 per cent in 1963 of the region's total.

Projection for the regional consumption of non-cellulosic man-made fibres based upon figures between 1960 and 1963 and by using the straight-line method gives 409,000 metric tons for 1967 and 2.4 million metric tons for 1975.

Owing to non-availability of data on consumption of individual types of fibres for many countries of the region, detailed analysis for the region is not attempted here. Nevertheless, the consumption pattern in a few countries is presented for study.

The estimated use of non-cellulosic synthetic fibres in *Australia* for 1960/61 indicated that polyamides accounted for 60 per cent, acrylics 22 per cent and polyesters 18 per cent. Polyamides (nylon) formed almost the only yarn consumed in *Burma* between 1960 and 1962. It increased from 603 metric tons in 1960 to 1,055 metric tons in 1962. *In China (Taiwan)*, consumption in 1960 was characterized by polyamides occupying 95 per cent and polyesters 5 per cent. However, in 1963, when acrylic fibres came into use, the consumption pattern was changed to polyamides 62 per cent, acrylics 24 per cent, and polyesters 14 per cent. *In Hong Kong*, the share of polyamides was 57 per cent in 1960 with the rest representing 43 per cent. However, in 1963, polyesters represented 46 per cent of total consumption and polyamides only 5 per cent. *In Japan*, polyamides (nylon) continued to lead the others in total consumption. It is estimated that, in 1962, consumption of individual fibres was of the order of polyamides (nylon) 40,400 metric tons, polyesters 36,700 metric tons and acrylics 24,700 metric tons. Japan is the only country in the world producing, with the possible exception of the Republic of Korea which produced about 500 metric tons of polyvinyl alcohol fibre in 1963. It is estimated that Japan's consumption of vinylon amounted to 31,900 metric tons in 1962. *The Republic of Korea* somewhat resembled China (Taiwan) in pattern of consumption. In 1960, polyamides accounted for 92 per cent, whereas in 1963, their share declined to 73 per cent and the share of acrylics rose from almost nothing to over 17 per cent.

TABLE 4. ECAFE COUNTRIES: CONSUMPTION* OF SYNTHETIC RUBBERS

(Metric tons)

Country	1960	1961	1962	1963
Australia [a]	22,800	28,400	28,400 [b]	35,000 [c]
Burma	4	..		—
China (Taiwan)		916 [d]	670 [d]	670 [e]
Hong Kong	676	137	1,380	3,207
India [c]	8,985	10,640 [f]	10,475 [f]	16,000 [f]
Indonesia [d]	10	280	280	
Japan	75,100	90,300	113,000	140,200
Korea, Republic of	1,474	1,835	2,160	2,570
New Zealand	4,200	5,726		4,300 [e]
Pakistan		695 [g]	975 [g]	975 [g]
Philippines	3,633	4,606	4,640	5,000
Thailand [d]	10	120	170	77
Viet-Nam, Republic of	8	5	10	10
TOTAL	116,946	140,225	161,600	203,100

SOURCE: Information provided by Governments.

*Production + imports — exports or re-exports.

[a] Year ending June.

[b] Figure for 1961.

[c] Estimates by the Management Committee of the International Rubber Study Group, England. *Australia Plastics and Rubber Journal*, June, 1964.

[d] National customs returns.

[e] Figure for 1962.

[f] Year beginning 1 April.

[g] Estimate from value in national customs returns.

End-uses

With the exception of Japan and Australia, the non-cellulosic man-made fibres find their use essentially in apparel, and polyamides (nylon) will continue to be the major fibre. Regarding Australia, the prospect for growth of the consumption of nylon fibre lies in their industrial use, especially in making tyre cords. In the case of Japan, the relative shares in the end-uses vary with individual fibres. It is estimated that, in 1962, nearly 57 per cent of nylon filaments went into making apparel, 43 per cent into industrial use, namely, tyrecord, fishing net, etc., whereas, over 80 per cent of staple was for apparel. For polyesters, nearly 94 per cent was for apparel. For acrylic fibres, apparel accounted for 80 per cent, and household uses accounted for 10 per cent. For vinylon, which was produced mostly as staple fibres, 30 per cent of the demand was for apparel and some 60 per cent was for industrial use, especially for fishing nets and ropes.

Synthetic rubbers

Table 4 shows that the consumption of synthetic rubbers in the ECAFE region nearly doubled from about 117,000 metric tons in 1960 to over 210,000 metric tons in 1963 at a growth rate of 23 per cent.

Japan, Australia and India were the three major consumers of synthetic rubbers in the region. It was estimated that the share of Japan in the region's total increased from 64 per cent in 1960 to 68 per cent in 1963, while that of Australia declined from 19 per cent to 16 per cent and that of India remained almost the same, at 8 per cent.

TABLE 5. RESERVES OF CRUDE OIL AND NATURAL GAS IN THE ECAFE COUNTRIES

Country	*Crude Oil (million metric tons)*		*Natural gas (million m³)*	
	Proven	*Probable*	*Proven*	*Probable*
Afghanistan	—			70,000 [e]
Australia	—	6.40	—	1,062
Burma		4.15		71
China (Taiwan)	0.735	—	12,036	7,113
India	72.000 [f]	—	14,750 [a]	5,600 [a]
Indonesia [b]	1,650.000		3,400 [c]	4,910 [c]
Iran	3,000.000 [f]	—	—	2,450,000
Japan	6.920	—	15,000	—
New Zealand	—	—	—	15,300
Pakistan	2.740 [f]	—	—	406,000 [d]
Thailand	0.0779	0.162	—	—
TOTAL	4,732.5	10.7	45,286	2,960,056

SOURCE: Information provided by Governments.

[a] Report of the Petro-chemical Committee, Government of India, February 1963.

[b] "Development of fertilizer industry in Indonesia", a paper presented at the United Nations Conference on the Development of Fertilizer Industry in Asia and the Far East, 1963.

[c] Reserve fields in South Sumatra only.

[d] "The role of fuels and power in the economy of Pakistan", a paper presented at the Regional Seminar on Energy Resources and Electric Power Development, [illegible].

[e] "Fertilizer use in Afghanistan", a paper presented at the United Nations Conference on the Development of Fertilizer Industry in Asia and the Far East, 1963.

[f] Mining Developments in Asia and the Far East, [illegible]. A United Nations publication (E/CN.11/[illegible]).

TABLE 6. PRODUCTION OF CRUDE OIL IN THE ECAFE COUNTRIES
(Thousand metric tons)

Country	*1960*	*1961*	*1962*
Australia			—
Brunei [a]	4,583	4,124	3,824
Burma	453	462	503
China (Taiwan)	2	2	2
India [b]	440	420	1,050
Indonesia [c]	20,696	21,257	22,647
Iran	52,083	58,438	64,631
Japan	593	738	858
Malaysia Sarawak [a]	60	60	59
New Zealand	1	1	1
Pakistan [b]	360	410	470

SOURCE: Information provided by Governments.

[a] *United Nations Statistical Yearbook*, 1963.

[b] *World Oil Statistics*, October, 1963.

[c] "Development of fertilizer industry in Indonesia", a paper presented at the United Nations Conference on the Development of Fertilizer Industry in Asia and the Far East, 1963.

It is also estimated that the region's consumption of synthetic rubbers would climb to 440,000 metric tons in 1967 and nearly 2 million metric tons in 1975. This forecast is based upon its consumption between 1960 and 1963 and by using the straight-line method.

Available information indicates that SBR formed the bulk of the synthetic rubbers consumed in countries of the region. *For Australia*, in 1960/61, styrene-butadiene rubber (SBR) made up 90 per cent of the synthetic rubbers and over 85 per cent of it went into passenger tyre tread stocks, and the rest into mechanical goods. However, it was expected that some of its share would be taken away by the new synthetics, such as Cis-4 polybutadiene and Cis-polyisoprene as polybutadiene should find its greatest application in blends with natural rubber in large truck tyres for which SBR is unsuitable. *In Japan* the share of SBR increased from 75 per cent in 1960 to 78 per cent in 1963.

III. SURVEY OF THE SOURCE OF RAW MATERIALS FOR THE PETROCHEMICAL INDUSTRY

Of a total of twenty-three countries in the region, eight have reserves of both crude oil and natural gas; one has only crude oil; and two others have only natural gas. These may be seen in table 5. Production of crude oil and natural gas in the region are shown in tables 6 and 7, respectively.

Iran has the largest crude oil reserve in the region and is the largest producer and exporter of crude petroleum. Its production increased steadily from 52.1 million metric tons in 1960 to an estimated 80 million metric tons in 1964. Its export of crude petroleum likewise

TABLE 7. PRODUCTION OF NATURAL GAS IN THE ECAFE COUNTRIES

(Million cubic metres)

Country	*1960*	*1961*	*1962*
Australia	—	—	2
Brunei [a]	82	80	…
Burma	63	74	82
China (Taiwan)	25	37	38
Indonesia [a]	2,431	2,561	2,706
Iran	7,000	8,414	9,178
Japan	731	950	1,209
New Zealand	5	5	4
Pakistan [a]	845	982	1,191

SOURCE: Information provided by Governments.

… Not available.

[a] *United Nations Statistical Yearbook*, 1963.

increased from 33.2 million metric tons to an estimated 60 million metric tons in 1964. Its reserves of natural gas were estimated in 1961 to be 2.45 million million cubic metres. Production of natural gas increased from 7,000 million cubic metres in 1960 to an estimated 12,000 million cubic metres in 1964. Iran is planning to increase this quantity to 14,200 million cubic metres in 1968. As this gas is in the form of dissolved and associated gas, the surplus gas after being used in the refineries or oil wells has to be flared. In 1962, the amount of this surplus gas flared in the southern fields of Iran was 672 million cubic feet daily or about 19 million cubic metres per day and this quantity will be increased with the increased production of crude oil.

Indonesia, which has the second largest reserves of crude oil in the region, is also the second largest producer and exporter of crude petroleum. The production of crude petroleum increased from 20.7 million tons in 1960 to 22.7 million tons in 1962. Exports declined from 7.4 million metric tons to 5.5 million metric tons during the same period. Regarding natural gas, determination of the accurate amount of reserves has not been done in many places where it has been discovered. Hence, with the exception of the reserves at the Radja field reservoir, upon whose supply of natural gas the ammonia plant at Palembang is based, the reserves given are estimates. Radja field reservoir contains about 3,480 million cubic metres of associated and non-associated gas which is considered to be sufficient for that ammonia plant for 20 years. It is estimated that, at the end of 1962, the gas reserves in the Stanvac fields in south Sumatra stood at, non-associated gas 3,860 million cubic metres, associated gas 3,290 million cubic metres, dissolved gas 1,240 million cubic metres, making up a total of 8,390 million cubic metres. In addition, a reservoir with a reserve of 3,400 million cubic metres will probably be found in the region of Lubuk Linggau and there are indications of natural gas in the region of Cheribon and North Subang in West Java where "Permigan", a national oil company, is conducting extensive investigations.

India's proven reserve of crude oil in 1960 was estimated at 375 million barrels or about 52 million metric tons. Production of crude petroleum increased from 440,000 metric tons in 1960 to 1,050,000 metric tons in 1962.

Natural gas has been discovered in the Nahorkatiya, Nacholia, Kathalguri and Moran areas. A summary of the estimated gas reserves as on 1 January 1961 is presented in table 8 and the composition of gas from Nahorkatiya and Moran fields is shown in table 9. It has been estimated that the gas available for the market will be 10 million cu. ft or 283,000 cubic metres per day in 1962 which will progressively increase to 60 million cu. ft or 1.7 million cubic metres per day in 1967 and thereafter will remain the same up to 1983 (table 10).

TABLE 8. ESTIMATED GAS RESERVES AS ON 1 JANUARY 1961 IN INDIA

(Million standard cu. ft)

Area	*Solution gas* [a]		*Associated gas* [b]		*Non-associated gas* [c]	
	Proved	*Indicated*	*Proved*	*Indicated*	*Proved*	*Indicated*
Nahorkatiya area	150,989	26,735	197,144	21,136	50,406	12,326
Nacholia area	22,927	1,460	20,369	—	10,440	18,856
East Nacholia area	2,463	1,254	—	—	31,455	9,214
Kathalguri area	1,252	2,545	—	—	—	—
Moran field	14,279	35,037	—	42,155	19,211	31,235
TOTAL	191,910	67,031	217,513	63,291	111,512	71,631
Total proved gas reserve		520,935				
Total indicated gas reserves		201,953				
GRAND TOTAL		722,888 (20,400 million cubic metres)				

SOURCE: Report of the Petro-chemical Committee, Government of India, February 1963.

[a] Solution gas: is the gas dissolved in the oil within the formation.

[b] Associated gas: is the gas associated with significant deposits of oil, e.g. cap gas. For efficient oil recovery, production of this gas is not desirable. After a certain state of depletion it unavoidably gets produced with the oil.

[c] Non-associated gas: is the gas found in formations having little or no oil.

TABLE 9. TYPICAL ANALYSIS OF NON-ASSOCIATED GAS FROM NAHORKATIYA AND MORAN FIELDS IN INDIA

	Nahorkatiya					*Moran*
Area Well No.	12	19	25	30	37	9
Sand	Extra (9,280 ft)	IV II	IV	9,720 ft	7,170 ft (Tipam)	19,810 ft
Sp. gr. (air-l)	0.66	0.63	0.61	6.63	0.57	0.63
Percentage gas volume						
CH_4	90.17	92.14	95.43	89.95	99.03	92.53
C_2H_6	5.65	3.54	1.58	5.65	0.59	2.68
C_3H_8	2.56	1.64	1.26	2.64	0.38	1.85
Iso C_4H_{10}	0.60	0.84	0.59	0.50		0.98
n-C_4H_{10}	0.77	0.79	0.55	0.44		1.08
C_5	0.25	1.05	0.59	0.82		
Air	Nil	Nil	Nil	Nil	Nil	Nil
CO_2	Nil	Nil	Nil	Nil	Nil	Nil
TOTAL	100.00	100.00	100.00	100.00	100.00	99.12

SOURCE: Report of the Petro-chemical Committee. Government of India, February 1963.

In India, surplus naptha will constitute a major raw material for the petrochemical industry. Accordingly the surplus expected for each year of the third five-year plan has been compiled and is presented in table 11.

Refinery gases may be considered as a source of raw material for the petrochemical industry. The availability of hydrocarbon fractions from various refineries in India is presented in table 12. The quantity and composition of the gas obtained from the various refineries will vary according to operating conditions. The figures given are average yields and may not present an assured supply at a given time. It may be mentioned here that, apart from Burma Shell which has agreed to sell 50,000 tons of refinery gas a year to the Trombay Fertilizer Plant, the refineries have indicated that no gas can be made available for outside consumers.

Pakistan has the second largest natural gas reserves in the region. One significant fact is that all the gas

TABLE 10. TENTATIVE ASSESSMENT OF THE AVAILABILITY OF NATURAL GAS IN INDIA
(Million cu. ft. per day)

Year (1)	*Total gas (solution, associated, recycle)* (2)	*Fields' gas requirement* (3)	*Surplus gas to be injected into underground storage* (4)	*Deficit to be made from non-associated gas and storage* (5)	*Gas available for market* (6)
1962	37	17	10	—	10
1963	55	20	10	—	25
1964	64	20	9	—	35
1965	75	25	5	—	45
1966	88	30	3	—	55
1967	102	35	7	—	60
1968	115	40	15	—	60
1969	125	40	25	—	60
1970	135	40	35	—	60
1971	137	40	37	—	60
1972	130	40	30	—	60
1973	105	39	6	—	60
1974	84	38	—	14	60
1975	68	37	—	29	60
1976	55	36	—	41	60
1977	47	34	—	47	60
1978	40	28	—	48	60
1979	35	22	—	47	60
1980	30	16	—	46	60
1981	27	10	—	43	60
1982	25	9	—	44	60
1983	18	8	—	50	60

SOURCE: Report of the Petro-chemical Committee. Government of India, February 1963.

is found as non-associated gas. It has been found in Sui, Zin, Uch, Mari, Khairjour, Mazarani and Khandkot in West Pakistan and at Sylhet, Chhatak and Rasidpur in East Pakistan. The total recoverable reserves of raw gas is 14.35 million million cu. ft. or 406,000 million cubic metres. The composition and reserves of natural gas in Pakistan are shown in table 13. Total production of gas during the year 1955 was 1,780 million cu. ft. or about 50 million cubic metres, which rose to 28,840 million cu. ft., or about 845 million cubic metres in 1960. The Sui gas field is situated almost midway between the industrial area of the south and the agricultural area of the north. This field was discovered in 1952 and the gas from it has been used for industrial and domestic heating since September 1955. During 1960, production of gas from Sui field was 20,533 million cu. ft., or about 580 million cubic metres which is equal to 514,000 tons of fuel oil. Gas transmission lines from the Sui gas field to Karachi and Multan, 347 and 217 miles in length respectively, have been laid. These lines are capable of transporting 75 million cu. ft., or about 2.2 million cubic metres, of natural gas per day without compression. With the planned industrial development under the second five-year plan, the demand in the north for energy is likely to rise. In order to cope with it, the construction of a 700-mile pipeline network to supply Sui gas to the northern part of West Pakistan was planned in 1964.

The Sylhet gas field in East Pakistan, with an estimated reserve of 280,000 million cu. ft., or 7,930 million cubic metres of natural gas, supplies the ammonia plant at Fenchuganj, and the entire quantity of gas is intended for use in that plant. Gas for Chhatak is destined for use as fuel at the Chhatak cement factory situated at a distance of about twelve miles from the field.

The proven crude oil reserve in Pakistan was 20 million barrels, or about 2.74 million metric tons, in 1960 which is very small compared with its natural gas reserves.

Japan's proven reserves of crude oil stood at 6.92 million metric tons in 1964. Japan has relied heavily on the imports of crude oil for its requirements; these imports increased from 32.9 million metric tons in 1960 to an estimated 76 million metric tons in 1964. It is estimated that this quantity will increase progressively to 129.5 million metric tons in 1968.

Proven natural gas reserves stood at 15,000 million cubic metres in 1964. Production of natural gas increased from 731 million cubic metres in 1960 to an estimated 2,000 million cubic metres in 1964. It is planned to step up its production of natural gas to 2,800 million cubic metres in 1967.

China (Taiwan), as its proven reserve of crude oil is small, has been depending largely upon imports for its requirements of crude oil. It imported about 1.16 million metric tons of crude oil in 1961 and this amount was increased to about 1.3 million metric tons in 1963. Production in 1960 and 1963 was 1,920 and 2,510 metric tons, respectively, and planned production in 1970 is 45,100 metric tons.

Proven and probable reserves of natural gas in 1964 stood at 12,036 million cubic metres and 7,113 million cubic metres, respectively. Between 1960 and 1963, production of natural gas increased steadily from 25.4 million cubic metres to 50.7 million cubic metres. However, starting

TABLE 11. ANTICIPATED AVAILABILITY OF RAW NAPHTHA IN INDIA
(Million metric tons per annum)

Production	*Refining capacity (1960)*	*1960 (actual)*	*1961*	*1962*	*1963*	*1964*	*1965*	*1966*
Public sector refineries								
Gauhati (NHK crude)	0,75	—	—	0.170	0.170	0.170	0.170	0.170
Barauni (NHK crude)	2.00	—	—	—	0.290	0.410	0.510	0.410
Gujarat (Ankleshwar)	2.00 [a]	—	—	—	—	—	0.500	0.500
TOTAL	4.75	—	—	0.170	0.460	0.580	1.180	1.080
Private Sector refineries								
B.S.R. (Arabian and Safaniyan) . .	2.84	0.425	0.425	0.425	0.425	0.425	0.425	0.425
S.V.O.C. (Arabian and Safaniyan) .	1.95	0.361	0.361	0.361	0.361	0.361	0.361	0.361
Coril (Iranian and Mines)	0.88	0.165	0.165	0.165	0.165	0.165	0.165	0.165
AOC (NHK and Digboi).	0.45	0.088	0.088	0.088	0.088	0.088	0.088	0.088
TOTAL	6.12	1.039	1.039	1.039	1.039	1.039	1.039	1.039
GRAND TOTAL	—	1.039	1.039	1.209	1.499	1.619	2.219	2.119
Consumption (All-India) as motor gasolene	—	0.830	0.887	0.939	0.996	1.066	1.141	1.220
Surplus	—	0.209	0.152	0.270	0.503	0.553	1.078	0.899
Export	—	0.204	?	?	?	?	?	?

SOURCE: Report of the Petro-chemical Committee, Government of India, February 1963.

[a] Provisional.

TABLE 12. OUTPUT OF REFINERY GASES IN INDIA
(Metric tons per annum)

Hydro-carbons	*Burmah Shell (Bombay) Refinery-gas Total qty. about 80,000 tons p.a.*	*Stanvac (Bombay) Refinery-gas Total qty. about 100,000 tons p.a.*	*Caltex (Vizag) Cracking unit gas. Total qty. about 16,000 tons p.a.*	*I.R.L. (Gauhati) Design Refinery-gas including all LPG Tatal qty. about 34,000 tons p.a.*	*I.R.L (Barauni) Design Refinery-gas including all LPG Total qty. about 137,000 tons p.a.*
Methane	3,400	12,800	300		17,700
Ethylene	1,400	4,300	1,000	12,000	5,600
Ethane	6,500	13,000	2,000	—	16,700
Propylene	8,000	17,000	3,600	8,500	14,700
Propane	16,000	17,000	1,000	—	26,700
Butylene	8,300	7,600	1,000	2,000	9,700
Iso-butane . . .	—	—	500	4,000	—
N-Butane	25,000	20,000	200	6,000	46,500

SOURCE: Report of the Petro-chemical Committee. Government of India, February 1963.

from 1964, production will rise significantly to 204.5 million cubic metres and will reach 945 million cubic metres in 1970.

In *Australia*, with the first discovery of crude oil at Moonie field, exploration and drilling activities have been stepped up. In 1964 the estimated probable reserve of crude oil is 6.4 million metric tons. Before the above discovery, Australia imported all its requirements of crude oil. It was planned to produce 190,000 metric tons in 1964 and to increase this quantity progressively to 800,000 metric tons in 1966. However, as its requirements for crude oil are large, Australia will still have to depend heavily upon imports in quantities increasing from 16 million metric tons in 1964 to 23 million metric tons in 1970.

Australia's probable reserve of natural gas as of 1964 is given as 1,062 million cubic metres. This figure does not include the probable reserves of a number of locations in Australia and Papua where potentially large discoveries of gas have been made, since they are still one-well fields. The production of natural gas started in 1961 with 345,000 cubic metres which increased to 3 million cubic metres in 1964. Plans for future production are not available.

In *Afghanistan* it is reported that some 70,000 million cubic metres of natural gas have been discovered in the northern provinces.

Discovery of crude oil has also been reported although no exact figures have been given.

TABLE 13. COMPOSITION AND RESERVES OF NATURAL GAS IN PAKISTAN

	Raw	*Sui (purified)*	*Zin*	*UCH*	*Khairpur*	*Kandhkot*	*Mazarani*	*Mari*	*Rashidpur*	*Sylhet*	*Chhatak*
Methane (per cent)	88.52	94.42	46.1	27.3	12.2	79.2	87.0	77.3	97.3	95.4	99.05
Ethane (per cent)	0.89	1.05	0.4	0.7	0.2	1.1	2.5	0.2	1.0	2.67	0.24
Propane (per cent)	0.26	0.28	0.15	0.3	0.1	0.2	0.1	—	0.4	0.3	—
Butane and higher (per cent)	0.37	0.17	0.15	0.3	—	0.4	1.2	—	0.2	0.78	—
Nitrogen (per cent)	2.46	3.89	8.5	25.2	16.9	16.6	8.0	19.5	0.4	0.37	0.67
Carbon dioxide (per cent).	7.35	0.02	44.7	46.2	70.6	2.5	0.3	14.1	0.06	0.48	0.04
Hydrogen sulphide gr/100/ SCF	92.2	Oxygen 0.17 H2 S nil	13.3	33.5	2.0	30.8	10.7	—	—	—	—
Mercaptan sulphur gr/100/ SCF	3.8	0.39[a]	2.3	10.2		1.2	2.2	—	Negligible	0.2928[a]	0.787[a]
Reservoir pressure p.s.i.g. .	1,950	—	279	2,016	953	1,940	2,924	1,140	—	1,944	1,815
Reservoir temp. °F	195	—	142	173	120[b]	190[b]	210[b]	136	—	135	Various
Gross heating value BTU/ cu.ft. (calc.)	933	975	—	—	—	826	976	673	1,020	1,043	988
Recoverable reserves of raw gas (million million cu. ft.)	5.0	4.5	0.1	2.5	1.0	0.2	0.3	4.95	Not yet known	0.28	0.02

SOURCE: "The Role of Fuels and Power in the Economy of Pakistan" (I&NR/Sub. 1/ER/121) presented at the Regional Seminar on Energy Resources and Electric Power Development, 6-16 December 1961.

[a] Total sulphur.

[b] Estimated.

Burma has a probable reserve of 4.15 million metric tons of crude oil. In 1960, it produced 452,500 metric tons and this was increased to 556,300 metric tons in 1963. Although there were no imports in 1960, it imported 11,725 metric tons in 1961 and this amount was increased to 30,445 metric tons in 1963.

A natural gas field was discovered in Chauk, Central Burma. The Government has plans for establishing an ammonia plant with an annual production capacity of 40,000 metric tons based upon this gas.

The production of associated gas from the oil fields in Burma was given as 6.12 million cu. ft. or 173,000 cubic metres per day in 1960 and 11 million cu. ft. or 312,000 cubic metres per day in 1964. By 1970, it is estimated that this quantity will be reduced to 3 million cu. ft. or 84,900 cubic metres per day.

In *New Zealand* there are two natural gas reservoirs, one with a capacity to produce 60 million cubic feet or 1.7 million cubic metres of raw gas a day for 25 to 30 years at Kapuni in the North Island, and another smaller reservoir at Nangahewa.

In *Thailand* there has been no discovery of natural gas. The proven and probable reserves of crude oil as of 1964 were 77,900 metric tons and 162,000 metric tons respectively. Between 1960 and 1964, production increased from 680 metric tons to 6,800 metric tons. Thailand's requirement of crude oil was supplemented by imports of 33,554 metric tons in 1962, 52,606 metric tons in 1963, and an estimated 31,323 metric tons will be imported in 1964.

IV. RATES AND PATTERN OF GROWTH IN THE PETROCHEMICAL INDUSTRY

Intermediates

Ammonia represents the most important intermediate for countries of the region as it is the basic material for the manufacture of nitrogenous fertilizers which are in increasing demand in the ECAFE countries. Table 14 shows that, between 1960 and 1963, total production of ammonia increased from about 1.4 million metric tons to about 2 million metric tons, representing an increase of nearly 600,000 metric tons or 42 per cent at an annual growth rate of 12.4 per cent.

In 1960, ammonia based upon petroleum or natural gas represented 45 per cent of the total, while, in 1963, after only three years, it increased to 70 per cent of the total. Significant increases were achieved both in physical output and in terms of growth rate. During this period an increased output of over 750,000 metric tons was noted at an annual growth rate of 30 per cent, while output of ammonia based upon coal or other sources declined by about 168,000 metric tons.

Between 1960 and 1963 there has been no production of other intermediates such as methanol, acetylene, ethylene, propylene, butadiene, benzene, toluene and xylenes from petroleum or natural gas in the ECAFE countries with the exception of Japan, Australia, and China (Taiwan). China: Taiwan produced insignificant quantities of benzene, toluene and xylenes from petroleum feedstocks.

End-products

Major end-products are presented for study in this paper.

Nitrogenous fertilizers

Between 1960 and 1963, eight countries in the ECAFE region were producing nitrogenous fertilizers. While there were only three countries in the region in 1960 utilizing petroleum feedstocks for the production of ammonia for conversion into nitrogenous fertilizers, this number had increased to six in 1963 (table 14).

With the exception of a small percentage of calcium cyanamide used for nitrogenous fertilizers in Japan and

TABLE 14. PRODUCTION OF AMMONIA IN THE ECAFE REGION
A. FROM PETROLEUM OR NATURAL GAS; B. FROM COAL OR OTHER SOURCES
(Metric tons)

	1960		*1961*		*1962*		*1963*	
	A	*B*	*A*	*B*	*A*	*B*	*A*	*B*
Australia[a]	—	26,700		25,500	—	27,900	—	32,800
China (Taiwan)[b]	11,000	31,000	11,260	37,200	16,800	56,800	25,450[c]	54,400[c]
India	—	10,700	—	13,600	—	15,520	13,000	18,100
Iran	—	—	—	—	—	—	1,000	—
Japan	606,000	678,000	830,000	596,000	1,003,000	525,000	1,243,000	466,000
Korea, Republic of	3,000	—	18,400	—	19,000	—	45,000	3,000
Philippines	—	7,500	—	8,300	—	10,000	—	10,000
Pakistan	—	12,659	780	14,666	24,780	14,638	45,443	14,305
TOTAL	620,000	766,559	860,440	695,266	1,063,580	649,858	1,372,893	598,605
GRAND TOTAL	1,386,559		1,555,706		1,713,438		1,971,498	
Per cent of grand total	45	55	55	45	62	38	70	30

SOURCE: Information provided by Governments.

[a] Ammonia for fertilizers. Based upon *Nitrogen*, January, 1964.

[b] Calculated from papers submitted by the Government of the Republic of China at the United Nations Conference on the Development of Fertilizer Industry in Asia and the Far East, 1963.

[c] Scheduled.

TABLE 15. PRODUCTION OF FERTILIZERS FROM AMMONIA IN THE ECAFE REGION
(Metric tons N)

Country	*1960*	*1961*	*1962*	*1963*
Australia [a]	22,000	21,000	23,000	27,000
China (Taiwan) [b]	34,600	39,950	60,600	65,850
India	91,369	134,501	163,785	219,182
Iran	...	...	...	26,800
Japan	912,000	1,013,000	1,071,000	1,184,000
Korea, Republic of	2,831	13,714	17,195	44,873
Pakistan	9,630	11,250	31,550	48,750
Philippines	6,111	6,752	8,274	8,400
TOTAL	1,078,541	1,240,167	1,375,404	1,624,855

SOURCE: Information provided by Governments.

[a] *Nitrogen*, January 1964. Year ending June.

[b] Calculation based on the papers presented at the United Nations Conference on the Development of Fertilizer Industry in Asia and the Far East, 1963.

China (Taiwan), production of nitrogenous fertilizers in the region is based upon ammonia. The output of nitrogenous fertilizers based upon ammonia increased from 1,079,000 metric tons N in 1960 to 1,617,000 metric tons N in 1963, which means an increase of over 538,000 metric tons N. The annual rate of growth between 1960 and 1963 was 14.5 per cent (table 15).

Japan was the major producer of nitrogenous fertilizers from ammonia and accounted for over 73 per cent of the total regional output in 1963.

In 1960, 95 per cent of ammonia produced was converted into nitrogenous fertilizers; in 1963, the percentage rose to 99.5. It can be assumed that almost all ammonia produced in countries of the region with the exception of Japan and Australia is converted into nitrogenous fertilizers.

As mentioned above, the trend is now towards petroleum feedstocks in the production of ammonia. Thus, with increased production of nitrogenous fertilizers, there will be a significant increase in the future demand for petroleum feedstocks in the ECAFE countries.

Plastics and synthetic resins

Examination of table 16 reveals that only five countries in the region were producing plastics and synthetic resins. Between 1960 and 1963, production of plastics and synthetic resins in the region increased from 609,000 metric tons to 1,163,000 metric tons. The increase in 1963 over 1960 was 554,000 metric tons or 91 per cent. The annual rate of growth during the period was 24 per cent.

Production was concentrated in Japan which accounted for 88 per cent of the region's total output in 1963.

Production statistics, given for individual resins, are available only for China (Taiwan), India and Japan (tables 17 and 18). It will be noticed that levels of production of individual plastics and synthetic resins are still very low in these countries with the exception of Japan. In addition to the individual resins listed in the above tables, Japan produces alkyde, polypropylene, metacrylic, and unsaturated polyester resins.

Non-cellulosic man-made fibres

Production of non-cellulosic man-made fibres in the region increased very sharply from about 121,000 metric tons in 1960 to 243,000 metric tons in 1963 (table 19), at an annual growth rate of 26 per cent.

Production is, however, concentrated mainly in Japan. It accounted for 98 per cent in 1960 and nearly 99 per cent in 1963 of the region's total.

In India, the present production is all in the form of nylon yarns. It is planned to start producing 4,500 metric tons of polyester fibre in 1965 and 10,000 metric tons of acrylic fibres in 1967. In *Japan*, a variety of non-cellulosic man-made fibres are produced. Between 1960 and 1963, the share of nylon decreased from 34 per cent to 33 per cent, that of vinylon from 19 per cent to 12 per cent, that of acrylic from 19 per cent to 17 per cent, that of polyvinyl chloride from 5 per cent to 2 per cent, vinyliden chloride from 3 per cent to 1 per cent, while,

TABLE 16. PRODUCTION OF PLASTICS AND SYNTHETIC RESINS IN THE ECAFE REGION
(Metric tons)

Country	*1960*	*1961*	*1962*	*1963*
Australia [a]	54,385	54,385 [b]	69,745 [b]	83,035 [b]
China (Taiwan)	3,418	7,054	22,264	28,696
India	10,748	14,098	20,180	23,661
Japan	539,500	672,780	804,300	1,025,500
Korea, Republic of	850	1,500	2,110	2,500
TOTAL	608,901	749,817	918,599	1,163,392

SOURCE: Information provided by Governments.

[a] Year ending in June.

[b] *Source*: "Australian Production Statistics", Commonwealth Bureau of Census and Statistics.

TABLE 17. PRODUCTION OF PLASTICS AND SYNTHETIC RESINS IN THE ECAFE REGION (THERMOPLASTICS)
(Metric tons)

Country	*1960*			*1961*			*1962*			*1963*		
	Poly-ethylene	*Polyvinyl chloride*	*Poly-styrene*	*Poly-ethylene*	*Polyvinyl chloride*	*Poly-styrene*	*Poly-ethylene*	*Polyvinyl chloride*	*Poly-styrene*	*Poly-ethylene*	*Polyvinyl chloride*	*Poly-styrene*
China (Taiwan)	—	3,418	—	—	7,054	—	—	10,924	—	—	15,890	—
India	4,213	—	3,676	5,800	917	3,484	8,058	2,580	3,887	7,923	2,964	5,515
Japan	41,200	258,100	21,900	58,100	308,900	29,000	142,500	303,500	43,100	223,400	348,100	61,400
TOTAL	45,413	261,518	25,576	63,900	316,871	32,484	150,558	317,004	46,987	231,323	366,954	66,915

SOURCE: Information provided by Governments.

the share of polyesters increased from 19 per cent to 27 per cent and that of polyethylene from 1 per cent to 3 per cent.

Synthetic rubber

Until 1963, Japan and Australia were the only countries in the ECAFE region producing synthetic rubber. In 1963, India started producing SBR type rubber. The production of synthetic rubber in the region increased from 23,500 metric tons in 1960 to 106,100 metric tons in 1963 at an annual growth rate of 65 per cent.

SBR forms the bulk of the synthetic rubber produced in the ECAFE countries. *In Australia* there is only one company producing it. It has an annual production capacity of 30,000 tons of SBR. *India* started the production of 7,000 metric tons of SBR in 1963, which increased to an estimated 12,000 metric tons in 1964. *In Japan*, out of 23,000 metric tons of synthetic rubber produced in 1960, 21,400 metric tons were SBR, representing 91 per cent of total production. In 1963, 91,300 metric tons of SBR were produced out of a total of 99,100 metric tons, accounting for 92 per cent. In 1964, it is estimated that 131,200 metric tons of SBR will be produced out of a total of 148,100 metric tons, accounting for 89 per cent. Planned production in Japan indicates that in 1967, the share of SBR will be further reduced to 67 per cent although the total production will increase to 243,900 metric tons.

V. TRADE IN MAJOR END-PRODUCTS OF THE PETROCHEMICAL INDUSTRY

Nitrogenous fertilizers

Table 20 shows that the ECAFE region has been a net importer of nitrogenous fertilizers. Total imports into the region increased from about 478,000 metric tons N in 1956/57 to 671,000 metric tons N in 1960/61, while total exports expanded from 195,000 metric tons N to over 297,000 metric tons N during the same period. Anticipated imports and exports of nitrogenous fertilizers (table 21) also indicate that the ECAFE region will continue to be a net importer of this commodity for many years to come.

During the period 1956/57 to 1960/61, Japan was the only net exporter of this product in the region. In 1956/57, the net importing countries were the Republic of Korea, which accounted for over 33 per cent, India about 18 per cent, China (Taiwan) about 14 per cent and Pakistan over 8 per cent. In 1960/61, the Republic of Korea represented about 30 per cent, India about 26 per cent, China (Taiwan) over 9 per cent, and Pakistan about 9 per cent of the region's total imports.

Anticipated imports and exports in the region (table 21) indicate that by 1966/67, besides Japan, both China (Taiwan) and Pakistan would have surpluses for export and that the major importers would be Indonesia, India, and Philippines, which would account for over 40 per

TABLE 18. PRODUCTION OF PLASTICS AND SYNTHETIC RESINS IN THE ECAFE REGION (THERMOSETTING)
(Metric tons)

Country	*1960*			*1961*			*1962*			*1963*		
	Phenolic resins	*Urea resins*	*Mela-mine resins*	*Phenolic resins*	*Urea resins*	*Mela-mine resins*	*Phenolic resins*	*Urea resins*	*Mela-mine resins*	*Phenolic resins*	*Urea resins*	*Mela-mine resins*
China (Taiwan)	—	—	—	—	—	—	800	10,000	40	840	11,400	44
India	2,134 [a]	725 [b]	—	2,111 [a]	1,786 [b]	—	2,423 [a]	3,232 [b]	—	2,886 [a]	4,373 [b]	—
Japan	42,800	127,900	11,500	55,600	155,500	16,900	56,200	178,700	21,500	64,800	207,300	27,000
TOTAL	44,934	128,625	11,500	57,711	157,286	16,900	59,423	191,932	21,540	68,526	223,073	27,044

SOURCE: Information provided by Governments.

[a] Phenol formaldehyde moulding powder.

[b] Urea formaldehyde moulding compounds and resins.

TABLE 19. PRODUCTION OF NON-CELLULOSIC MAN-MADE FIBRES IN THE ECAFE REGION
(Metric tons)

Country	*1960*	*1961*	*1962*	*1963*
Australia [a]	2,275	2,275	2,725	2,725
India [b]	—	—	136	655
Japan	118,300	153,100	182,700	239,200
Korea, Republic of . .	158	225	158	499
TOTAL	120,733	155,600	185,719	243,079

SOURCE: Information provided by Governments.

[a] Source: *Industrial fibres — 1964.* The Commonwealth Economic Committee.

[b] Nylon yarn.

cent, 30 per cent, and over 9 per cent, respectivel, , of the region's total.

Plastics and synthetic resins

The ECAFE region has also been a net importer of plastics and synthetic resins. Tables 22 and 23 show that imports increased from about 126,000 metric tons in 1960 to over 190,000 metric tons in 1963, while exports expanded from about 49,000 metric tons to over 105,000 metric tons during the same period.

In 1960, Hong Kong was the largest importer of these products in the region, accounting for 27 per cent, while Japan and Australia, the other two major importers, accounted for about 26 per cent and 18 per cent, respectively. In 1963, the share of Hong Kong increased to 36 per cent, while the shares of Australia and Japan decreased to 16 per cent and about 12 per cent, respectively.

On the export side, Japan was the major exporter, with Australia and China (Taiwan) as minor exporters. In 1960, Japan exported 92 per cent of the region's total, which declined to 88 per cent in 1963.

TABLE 20. IMPORTS OF NITROGENOUS FERTILIZERS IN THE ECAFE REGION
(Metric tons N)

Country	*1956/57*	*1957/58*	*1958/59*	*1959/60*	*1960/61*	*1961/62*
Australia	9,607	10,907	12,293	4,197	4,992	11,279
Burma	800	867	889	2,992	3,808	...
Cambodia	...	...	133	159	144	144
Ceylon	25,679	19,921	24,938	31,035	29,914	34,662
China (Taiwan)	65,824	89,816	67,864	71,630	61,584	64,600
Malaysia : Malaya	14,465	13,487	...	20,840	21,754	25,331
North Borneo	128	207	207	313	332	238
Singapore	3,961	3,978	4,752	5,892	7,732	...
Hong Kong	30,000 [a]	...	...	...	...	...
India	84,229	97,900	99,103	142,943	173,156	...
Indonesia	25,000	23,589	27,749	45,512	21,097	...
Iran	648	1,592	3,137	5,702	7,612	...
Japan	1,280	1,552	1,760	1,900	9,290	2,480
Korea, Republic of [b]	158,778	143,614	163,545	160,581	199,572	179,866
Nepal	...	...	...	...	74	133
New Zealand	2,349	2 037	2,515	3,536	4,555	4,687
Pakistan	39,100	3,175	3,255	22,391	59,705	37,904
Philippines	5,008	7,045	6,150	...	35,322	47,304
Thailand	3,500	5,350	7,752	8,331	11,058	...
Viet-Nam, Republic of . . .	6,221	14,600	12,900	19,800	19,319	15,503
TOTAL	476,577	439,637	438,942	547,754	671,020	424,131

SOURCE: FAO, "Fertilizers, an annual review of world production, consumption and trade", 1962.

[a] 1955/56.

[b] Fertilizer year: August-July.

TABLE 20 *(continued)*. EXPORTS OF NITROGENOUS FERTILIZERS IN THE ECAFE REGION
(Metric tons N)

Country	*1956/57*	*1957/58*	*1958/59*	*1959/60*	*1960/61*	*1961/62*
Australia	3,174	124	2,590	2,600	3,294	414
China (Taiwan)	143	—	—	—	7,387	7,820
Japan	191,820	255,284	306,340	339,450	286,090	395,840
New Zealand	—	—	426	1,040	—	--
TOTAL	195,137	255,408	309,356	343,090	296,771	404,074

TABLE 21. ANTICIPATED IMPORTS OF NITROGENOUS FERTILIZERS IN THE ECAFE REGION
(Metric tons N)

Country	*1962/63*	*1963/64*	*1964/65*	*1965/66*	*1966/67*
Afghanistan	2,475	4,950	6,105	13,530	8,580
Brunei	300	350	400	450	500
Burma	5,000	6,000	8,000	10,000[*]	12,000[*]
Ceylon	29,810	31,630	33,460	37,000[*]	40,000[*]
China (Taiwan)	42,000	26,300	—	—	—
Hong Kong	2,600	2,610	2,620	2,630	2,640
India	272,400	245,000	200,000	230,000	225,000
Indonesia	220,000	250,000	300,000	300,000[*]	300,000[*]
Korea, Republic of	180,126	155,085	129,313	107,786	32,483
Pakistan	48,600	20,000	3,000	—	—
Philippines	40,401	50,000	60,000	65,000	70,000
Thailand	11,944	15,110	18,808	22,833	28,355
Viet-Nam, Republic of	17,300	18,900	20,700	22,400	24,100
TOTAL	872,956	825,935	782,406	811,629	743,658

SOURCE: Report of the United Nations Conference on the Development of Fertilizer Industry in Asia and the Far East, 1963.

[*] FAO tentative estimates.

TABLE 21 *(continued)*. ANTICIPATED EXPORTS OF NITROGENOUS FERTILIZERS IN THE ECAFE REGION
(Metric tons N)

Country	*1962/63*	*1963/64*	*1964/65*	*1965/66*	*1966/67*
China (Taiwan)	—	—	29,600	32,200	29,800
Japan	440,000	450,000	460,000	470,000	480,000

Owing to non-availability of statistical data on the import of individual plastics and synthetic resins for many countries, no attempt has been made to estimate their relative shares in the region's total. From available information for some countries, it is estimated that, in 1963, the relative shares of individual plastics and synthetic resins in these countries, were: for *China (Taiwan)*, polyethylene 88 per cent, polystyrene 12 per cent; for *Hong Kong*, polyethylene 54 per cent, polystyrene 25 per cent, polyvinyl chloride 13 per cent, phenolics 2 per cent and urea resins above 1 per cent; for *India*, polyvinyl chloride 40 per cent, urea resins 27 per cent, polyethylene 23 per cent, phenolics 9 per cent; for *Japan*, polystyrene 58 per cent, polyethylene 22 per cent, polyvinyl chloride 11 per cent, and phenolics 5 per cent.

In 1963, polyvinyl chloride constituted the major export item in the region, representing about 63 per cent of the region's total exports of plastics and synthetic resins, followed by polyethylene with nearly 28 per cent.

Non-cellulosic man-made fibres

Although Japan was the sole exporter, her exports were of such magnitude that, when taken as a whole, the region became a net exporter, with exports increasing from nearly 10,000 metric tons in 1960 to over 27,000 metric tons in 1963 and imports rising from about 9,600 metric tons to over 20,000 metric tons during the same period (table 24).

In 1963, major importers were the Republic of Korea with imports of 5,123 metric tons, China (Taiwan), 3,560 metric tons, Australia, an estimated 3,550 metric tons, and India, an estimated 2,000 metric tons.

The available statistical data for a few countries of the region on the imports of individual fibres and yarns between 1960 and 1963 show that the share of polyamides in China (Taiwan) decreased from 95 per cent to 62 per cent; in Hong Kong from 57 per cent to 5 per cent; in the Republic of Korea from 92 per cent to 73 per cent; almost all imports into Burma were in the form of nylon yarn, which increased from 603 metric tons in 1960 to 1,055 metric tons in 1962. Polyesters increased from 5 per cent to 14 per cent in China (Taiwan) and from almost nil to 46 per cent in Hong Kong. Acrylics expanded its share from almost nil to 24 per cent in China (Taiwan) and from an insignificant share to 17 per cent in the Republic of Korea.

Synthetic rubber

Despite a hundred per cent increase in consumption in the ECAFE region between 1960 and 1963, the imports registered only a small increase. While the consumption increased from about 117,000 metric tons to over 210,000 metric tons, imports increased from about

94,000 metric tons to over 100,000 metric tons during this period (table 25).

The ECAFE region has been a net importer of synthetic rubber, its exports being only about 600 metric tons in 1960 which increased to over 8,700 metric tons in 1963.

Major importers were Japan, acccunting for about 55 per cent, Australia 24 per cent, and India about 10 per cent, respectively, of the region's total in 1960. This position remained almost the same in 1963, with Japan sharing about 55 per cent, Australia about 20 per cent, and India 9 per cent of the region's total imports.

SBR constituted the bulk of the imports of synthetic rubber into the ECAFE countries, although its share has declined in recent years. In *Japan*, its share has decreased from 67 per cent in 1960 to 54 per cent in 1963.

VI. PLANS FOR EXPANSION IN THE PETROCHEMICAL INDUSTRY

With the exception of Japan and Australia, the development of the petrochemical industry in the ECAFE countries is still in its infancy. Nevertheless, on account of the great importance attached to the development of the fertilizer industry in most countries of the region, ten countries produce ammonia, while six others have plans for establishing plants for its production. Although production of ammonia in the initial stages was based upon electrolysis and solid fuels in many countries of the region, the present trend is towards liquid and gaseous petroleum feedstocks. Among those countries that are planning to produce it, Thailand and the Republic of Viet-Nam will base the production of ammonia upon solid fuels and the remaining four will base their plants upon liquid and gaseous petroleum feedstocks.

In the ammonia producing countries of the ECAFE region, it is anticipated that the domestic production of ammonia will progressively increase and that new facilities will be required for this increased production. In *China (Taiwan)* it will be increased by 32,500 metric tons between 1963 and 1966 and petroleum feedstocks will be used to effect this increase; in *India*, an increase of 1,207,300 metric tons is expected between 1963 and 1970, out of which an output of 487,000 metric tons will be based upon petroleum feedstocks and that of the remaining 720,300 will be based upon other sources; in *Indonesia*, the first ammonia plant established at Palembang, South Sumatra, came on stream in late 1963. It is based upon natural gas and has an annual capacity of 46,000 metric tons N. Another ammonia plant is being planned and will be located at Gresik near Surabaya in East Java. It will have a capacity of 52,200 metric tons N per year and will be based upon fuel oil. For *Japan*, it is estimated that there will be an increase of only 41,000 metric tons in 1964 over 1963. This increased output will be realized by using petroleum feedstocks for an additional output of 57,000 metric tons, while simultaneously reducing the output based upon other

TABLE 22. IMPORTS OF PLASTICS AND SYNTHETIC RESINS IN THE ECAFE REGION

(Metric tons)

Country	*1960*	*1961*	*1962*	*1963*
Burma	1,320 [a]	1,940 [a]	2,470 [a]	3,380 [b]
Ceylon	792	1,580	2,020	1,860
China (Taiwan)	1,013	1,920	3,709	5,994
Malaysia: Malaya	1,461	1,734	2,669	3,630 [b]
North Borneo	—	13 [c]	14 [c]	
Sarawak	—	85 [c]	71 [c]	—
Singapore	—	—	1,279	—
Hong Kong	34,050	51,650	58,600	68,600
India	6,737	11,822	8,411	3,892
Indonesia	2,060 [c]	4,537 [c]	6,240 [b]	8,540 [b]
Iran	1,979	3,397	3,851	5,400 [b]
Japan	32,300	55,200	24,800	22,200
Korea, Republic of	5,844	6,679	7,861	5,540
Pakistan	—	2,050 [a]	5,130 [a]	5,130 [d]
Philippines	—	3,625	3,170	—
Thailand	4,609 [c]	6,523 [a]	6,191 [a]	7,140 [b]
Viet-Nam, Republic of	—	1,749	4,300	2,956
New Zealand [e]	10,950	12,850	—	16,292
Australia [e]	22,400 [f]	26,730 [f]	21,620 [f]	31,000 [a]
TOTAL	125,606	194,084	162,406	191,554

SOURCE: Information provided by Governments.

[a] Estimates from value in the national customs returns.

[b] Estimates.

[c] National customs returns.

[d] Imports in 1962.

[e] Year ending 30 June.

[f] *Manufacturing Industries*, Commonwealth Bureau of Census and Statistics, Australia.

sources by 16,000 metric tons, in the *Republic of Korea*, the increase in planned output is 222,000 metric tons in 1970 over 1963; petroleum feedstocks will be used to produce an additional 205,000 metric tons and other sources will be utilized to produce the remaining additional 17,000 metric tons; in the *Philippines*, the Esso Standard Fertilizer Chemical Co. Inc. (Philippines) is planning for the establishment of a new ammonia plant with an annual capacity of 103,000 metric tons, to be based upon petroleum feedstocks. It is expected that the plant will be completed in 1965; in *Pakistan*, it is planned to increase the production by 29,990 metric tons between 1963 and 1970, by an increased production of 18,560 metric tons based upon natural gas and of 11,430 metric tons based on coal.

For the remaining countries of the region which are not yet producing ammonia, in *Afghanistan* the discovery of natural gas offers an attractive proposition for the establishment of an ammonia plant. It is anticipated that by 1967 the country will be able to establish an ammonia plant with an annual capacity of 8,250 metric tons N, which will be increased to 18,150 metric tons N in 1970. *Burma* is planning to establish an ammonia plant with an annual capacity of 40,000 metric tons. It will be based upon natural gas reserves which are estimated at 100,000 million cu ft or 2,800 million cubic metres; *Ceylon* will base its projected ammonia plant on refinery gases and naphtha, its annual capacity is 63,000 metric tons N; in *Malaysia*, the Standard-Vacuum Oil Co., Ltd. is planning an ammonia-fertilizer plant at an estimated cost of $30 million, as part of a planned refinery-petrochemical installation; in *Thailand*, the projected ammonia plant has reached the engineering stage. In terms of nitrogen, the plant will have a capacity of 26,400 metric tons per year, the raw material used will be lignite and it is expected that the plant will be completed in 1966; in the Republic of *Viet-Nam*, an anthracite based ammonia plant with an annual capacity of 36,000 metric tons has reached the engineering stage and is expected to be on stream in 1966.

Although Japan and Australia are the only countries in the region which have developed petrochemical industries, some countries are now actively planning for the establishment of petrochemical complexes.

In *Australia*, the most recent petrochemical complex to come on stream is a 50,000-ton per year ammonia-methanol plant established by Imperial Chemical Industries of Australia and New Zealand, Ltd. at Botany, New South Wales. There are also plans for expansion of the existing polyethylene capacity to 5,000 tons per year. Union Carbide has a polyethylene plant with an annual production capacity of 15 million lbs or 6,825 metric tons under construction at Melbourne. Farbwerke Hoechst AG is planning to establish a $10 million, 10,000-ton per year polyethylene (high density) plant in early 1965. Shell Chemicals (Australia) Ltd. has plans for the establishment of a 25,000-ton per year solvents unit.

TABLE 23. EXPORTS OF PLASTICS AND SYNTHETIC RESINS IN THE ECAFE REGION

(Metric tons)

Country	*1960*	*1961*	*1962*	*1963*
China (Taiwan)	392	2,767	4,010	7,200
Hong Kong	1,500	4,200	5,640	6,020
India			30.6	
Japan	44,900	46,700	74,600	91,900
Australia [a]	1,960	1,986	3,700	
TOTAL	48,752	55,653	87,980.6	105,120

SOURCE: Information provided by Governments.

[a] *Manufacturing Industries*, Commonwealth Bureau of Census and Statistics, Australia.

In *China (Taiwan)*, although there is no plan for the production of ethylene or acetylene from petroleum sources, the Government has plans for the establishment of new facilities to increase the estimated output of 20,000 metric tons of polyvinyl chloride in 1964 to 50,000 metric tons in 1967. It is assumed that acetylene will be generated from calcium carbide.

Up to 1964 *India* had not established any petrochemical complex. Nitrogenous fertilizer industry was the only one utilizing petroleum feedstocks in producing synthesis gas for ammonia manufacture. With the establishment of the first naphtha cracker near Bombay, which will be able to process 225,000 tons of naphtha per year to produce 60,000 tons of ethylene, 36,000 tons of propylene, 7,200 tons of butadiene, etc., all of which will be converted into various petrochemical products, the country will have embarked upon the creation of a petrochemical industry for which it has drawn up a comprehensive development plan. It is reported that the technical and engineering contracts and financial proposals for this project are now before the Government for approval. Targets for production in India of intermediates in 1970 are 500,000 metric tons of ammonia, 60,000 metric

TABLE 24. IMPORTS OF NON-CELLULOSIC MAN-MADE FIBRES AND YARNS IN THE ECAFE REGION

(Metric tons)

Country	*1960*	*1961*	*1962*	*1963*
Australia [a]	3,180	4,500	3,550	3,500 [b]
Burma [c]	603	720	1,095	1,095 [b]
Ceylon	42	50	99	40
China (Taiwan)	740	2,970	2,800	3,500
Hong Kong	256	50	310	445
India	1,500	2,000	2,500	2,000
Korea, Republic of	1,979	2,200	5,364	5,123
Pakistan [d]	—	205	400	400 [b]
Thailand	702	1,376	1,365	1,365 [b]
Viet-Nam, Republic of	40	134	273	1,100
New Zealand	535	727		1,266
TOTAL	9,586	14,907	17,815	20,134

SOURCE: Information provided by Governments.

[a] *Industrial Fibres*, 1964, Commonwealth Economic Committee.

[b] Figure for 1962.

[c] National Customs Returns.

[d] Estimates based upon values in the national customs returns.

TABLE 24 (*continued*). EXPORTS OF NON-CELLULOSIC MAN-MADE FIBRES AND YARNS IN THE ECAFE REGION
(*Metric tons*)

Country	*1960*	*1961*	*1962*	*1963*
Hong Kong	65	55	6	10
Japan	9,900	14,500	22,000	27,200
TOTAL	9,965	14,555	22,006	27,210

tons of methanol, 30,000 metric tons of acetylene, 200,000 metric tons of ethylene, 100,000 metric tons of propylene, 60,000 metric tons of butadiene, 120,000 metric tons of benzene, 13,000 metric tons of toluene, 30,000 metric tons of xylenes, 40,000 metric tons of ethyl benzene and 3,000 metric tons of hydrogen cyanide. For plastics and synthetic resins, it is planned to achieve production targets of 50,000 metric tons of polystyrene, 115,000 metric tons of polyethylene, 110,000 metric tons of polyvinyl chloride resins, 12,000 metric tons of phenol formaldehyde moulding powder, 6,000 metric tons of urea formaldehyde moulding powder and 20,000 metric tons of urea formaldehyde resins. For non-cellulosic man-made fibres and yarns, the production in 1970 will reach 20,000 metric tons of nylon yarn, 20,000 metric tons of polyester fibre, 20,000 metric tons of acrylic fibre and 20,000 metric tons of polyvinyl alcohol, polypropylene and other fibres combined. Targets for synthetic rubbers in 1970 are: 30,000 metric tons of SBR type rubbers and 90,000 metric tons of stereo specific rubbers.

TABLE 25. IMPORTS OF SYNTHETIC RUBBERS IN THE ECAFE REGION
(*Metric tons*)

Country	*1960*	*1961*	*1962*	*1963*
Australia [a]	22,800 [b]	28,400 [b]	7,200 [b]	19,800 [b]
Burma	4			
China (Taiwan)		516	678	678
Malaysia				
Malaya and Singapore [c]		110		
Hong Kong	1,272	580	1,574	1,530
India [a]	8,985	10,[illegible] [d]	10,475 [d]	9,696 [d]
Indonesia [c]	10	200	200	
Japan	51,000	44,000	40,900	54,500
Korea, Republic of	1,070	1,005	2,160	2,970
New Zealand [a]	4,200	5,720		4,300
Pakistan	—	600 [b]	575 [b]	575 [e]
Philippines	3,600	4,000	4,000	5,000
Thailand [c]	30	100	170	77
Viet-Nam, Republic of	8	5	10	10
TOTAL	[illegible]	97,[illegible]	77,713	[illegible]

SOURCE: Information provided by Governments.

[a] Year ending 30 June.

[b] Estimates based on national customs returns.

[c] National customs returns.

[d] Year beginning 1 April.

[e] 1962 figure.

TABLE 25 (*continued*). EXPORTS OF SYNTHETIC RUBBERS IN THE ECAFE REGION
(*Metric tons*)

Country	*1960*	*1961*	*1962*	*1963*
Hong Kong	590	323	254	323
Japan		5,400	6,300	8,400
TOTAL	590	5,723	6,554	8,723

Iran is planning to establish a petrochemical complex which is expected to come on stream in 1968 to produce 18,000 metric tons of polyethylene, 6,500 metric tons of polybutadiene, 5,000 metric tons of polyacrylonitrile, 2,000 metric tons of polystyrene, 5,000 metric tons of nylon 6 fibres, 11,500 metric tons of SBR and 5,000 metric tons of dodecyl benzene.

The total cost of establishing this complex is estimated at $100 million.

In *Indonesia*, in accordance with the over-all national development plan, the Government will undertake the construction of a petrochemical industry at Gresik near Surabaya in East Java. In the first stage of development, an ammonia-fertilizer complex will be established and the plants will be designed so as to permit the production of plastics and other allied chemicals when the need should arise. It was reported that P. T. Permina, a government organization, is planning to establish a carbon black plant at Rantau at a cost of $4 million.

In *Japan*, the only country in the region that has reached international level in the development of the petrochemical industry, the demand for products from the petrochemical industry necessitated the planned increase of new facilities and expansion of existing ones to facilitate the output of various intermediates, plastics and synthetic resins and non-cellulosic man-made fibres and synthetic rubber.

For intermediates it is planned to increase the 1964 level of output of ethylene from 520,000 tons to 1,031,000 tons in 1967, propylene from 232,000 tons to 405,000 tons, acetylene from 370,100 tons to 435,400 tons, butadiene from 84,000 tons to 181,000 tons, benzene from 303,700 tons to 408,500 tons, toluene from 151,400 tons to 232,700 tons, xylenes from 97,000 tons to 135,300 tons and methanol from 302,500 tons to 528,500 tons during the same period. For plastics and synthetic resins, planned expansion between 1964 and 1967 aims at achieving increased production of polyvinyl chloride from 436,900 tons to 595,000 tons, polyethylene from 283,800 tons to 497,100 tons, polystyrene from 106,100 tons to 189,600 tons, polypropylene from 37,000 tons to 72,000 tons, urea resins from 222,600 tons to 271,700 tons, phenolic resins from 72,800 tons to 111,100 tons and melamine resins from 32,800 tons to 46,900 tons.

For non-cellulosic man-made fibres, it is planned to increase production of nylon from 88,100 tons in 1963 to 137,700 tons in 1964, vinylon from 37,400 tons to 40,000 tons, acrylic from 36,000 tons to 71,900 tons, polyester from 62,300 tons to 114,400 tons, polypropylene from 6,000 tons to 21,600 tons, polyvinyl chloride from 8,100 tons to 10,000 tons, vinyliden chloride from 3,700 tons to 4,000 tons and polyethylene from 5,800 tons to 13,800 tons during the same period.

For synthetic rubbers between 1964 and 1967 output of SBR will be increased from 131,200 tons to 162,000 tons, NBR from 6,700 tons to 7,800 tons, CR from 10,200 tons to 13,200 tons and PB from nil to 60,900 tons.

It is felt that separate treatment of the development of the petrochemical industry in Japan is desirable in view of the phenomenal growth of this industry in that country and also because it is the only country in this region which has reached a stage of development comparable to those of advanced countries of the world. A detailed description of this development is contained in the document appended to this paper.

In the *Republic of Korea* it is planned to establish new plants to increase the 1964 production of 2,990 metric tons of polyvinyl chloride to 13,000 metric tons in 1970. It is presumed that acetylene generated from calcium carbide will be used for the purpose. Also, it is planned to establish plants for the production of methanol based upon petroleum feedstocks, starting with an annual production of 15,000 metric tons in 1966, and for increased production of filament nylon yarn from the present estimated production of 1,091 metric tons in 1964 to 4,066 metric tons in 1970.

In *Pakistan*, the development of the petrochemical industry is considered as a land mark in the industrial development of the country. An acetylene plant, with a capacity of 16 tons per day, has been sanctioned at a total cost of $6.72 million. This plant will feed a polyvinyl chloride plant with an annual production capacity of 4,950 tons and a polyacrylonitrile plant with a capacity of 4,950 tons per year. Both these plants have been sanctioned by the Government at a cost of $5.65 million and $26.1 million respectively. In addition, a urea formaldehyde plant with an annual production capacity of 2,400 tons has been sanctioned by the Government, at a total cost of $2.44 million, and a polyethylene plant with a capacity of 5,000 tons per year is being established at an estimated cost of $15.86 million.

It is reported that Futehally Chemicals Ltd., of Karachi is planning a 1,800 ton per year alkyl benzene sulphonate detergent plant and that Pakistan Petroleum, Ltd., and Comstock International Methane, Ltd., are planning to establish a 100,000 tons per year carbon black plant in West Pakistan to be based upon natural gas from the Sui field.

In *the Philippines*, it is reported that the Philippines Industrial Chemical Co. is planning to establish a 6,000 tons per year polyvinyl chloride plant in Rizal province.

New Zealand has plans for the establishment of two nylon spinning plants which are expected to be in operation at the beginning of 1965. The initial planned production is 3.5 million lbs, or 1,590 metric tons, which should be increased to 4.5 million lbs, or about 2,000 metric tons, in 1967. It is planned that Terylene, a polyester fibre may become a possible product of one of these plants after 1967.

Singapore plans to establish a polyvinyl chloride plant capable of producing 5,000 metric tons per year. The plant is planned to be on stream in 1968. In addition, the establishment of an ammonia plant based upon petroleum feedstocks is in the planning stage. The plant would be able to produce 25,000 metric tons per year and it should be in full production by 1969.

VII. SPECIAL FEATURES AND PROBLEMS IN THE DEVELOPMENT OF THE PETROCHEMICAL INDUSTRY

The ECAFE region is characterized by a low level of consumption of the major end-products of the petrochemical industry. In 1961 the *per capita* consumption of nitrogenous fertilizers in the region was 1.4 kg N, compared with 14.9 kg N in the United States, 10.8 kg N in the European Economic Community (EEC), 8.7 kg N in the European Free Trade Association (EFTA) and 3.5 kg N in the Soviet Union. For plastics and synthetic resins, it was 0.96 kg in the ECAFE region, as against 14.4 kg in the United States, 9.7 kg in EEC and 8.86 kg in EFTA. For non-cellulosic man-made fibres, it was only 0.16 kg in the ECAFE region, compared with 1.7 kg in the United States, 1.04 kg in EFTA and 0.9 kg in EEC.

Japan is the only country in the region comparable with the industrially advanced countries in its *per capita* consumption, with 8 kg N of nitrogenous fertilizers, 7.25 kg of plastics and synthetic resins and 1.48 kg of non-cellulosic man-made fibres in 1961.

Despite the low-level of consumption, the *per capita* production is still lower in nitrogenous fertilizers, plastics and synthetic resins and synthetic rubber, thereby making the ECAFE region dependent on imports. In 1961 the *per capita* production in the region was 1.3 kg N for nitrogenous fertilizers, compared with about 14.9 kg N in the United States, 18.7 kg N in EEC and 11.7 kg N in EFTA. For plastics and synthetic resins also, it was only 0.81 kg in the ECAFE region, compared with 11.5 kg in EEC and 9.4 kg in EFTA, which made these countries net exporters, while the ECAFE region remained a net importer. For non-cellulosic man-made fibres, the ECAFE region was a net exporter, despite its low-level of production. *Per capita* production was 0.17 kg in the ECAFE region, compared with 1.86 kg in the United States, 1.03 kg in EEC and 0.87 kg in EFTA. EFTA was the only net importer in the above groups of countries.

Here again, Japan is the only country in the region with a *per capita* level of production comparable with those of the industrially advanced countries, with 11 kg N of nitrogenous fertilizers, 7.15 kg of plastics and synthetic resins and 1.63 kg of non-cellulosic man-made fibres.

There are various factors which impede the growth of petrochemical industry in countries of the region. Factors responsible for the slow growth of the fertilizer industry were brought out at the recent United Nations Conference on the Development of the Fertilizer Industry in Asia and the Far East. Price relationship between crops and fertilizers, non-availability of credit, lack of adequate distribution facilities and inadequate measures for promotion of fertilizer use were the factors responsible for the low level of consumption in most countries of the region. The slow growth of the industry was due to the shortage of foreign exchange, lack of capital, lack of know-how, shortage of trained personnel, paucity of suitable raw materials and under-developed infrastructure.

The basic obstacle to the development of an integrated petrochemical industry is the limited market in most countries of the region for the major petrochemical end products, such as plastics and synthetic resins non-cellulosic man-made fibres and synthetic rubbers. The present demand for these products is so low that it could not support a plant of minimum economic size.

The low-level of consumption in plastics and synthetic resins in most countries of the region may be due to the absence or to the low-level of development of consuming industries. Plastics and synthetic resins go into making various products such as plastic products made by moulding, extrusion and calendering, paints, lacquers and other coating material, adhesives and bonding material, and they are also used for textile and paper treatment. The automobile industry may be considered an important user of plastics and synthetic resins. An average passenger car requires 3 gallons of paint and 25 to 30 pounds of plastics. It may be of interest to note that, in the ECAFE region, Japan and Australia have high levels of consumption in plastics and synthetic resins in 1961. Japan consumed 681,000 tons and Australia 79,000 tons. In the same year Japan produced 1,038,500 passenger cars and commercial vehicles, and Australia produced 217,800 and assembled 292,700. These are the only two countries which have developed automobile industries both for domestic and overseas markets. The low-level of consumption of non-cellulosic man-made fibres and yarns in most countries of the region may be attributed to the lower price of natural fibres and cellulosic man-made fibres over the non-cellulosic man-made fibres. Low-level of consumption of synthetic rubbers, is attributable to the large exportable surplus of natural rubber in this region. In 1962, total exports of natural rubber amounted to 2.65 million metric tons, while the total imports came to only 1 million metric tons.

Nevertheless, judging by the rapid growth of consumption of the above petrochemical products, there are possibilities for the development of this industry, at least in some countries of the region. Based upon future demand of these products, India, Iran and Pakistan are planning to establish petrochemical complexes in their respective countries.

The demand for gasoline in the region averages about 20 per cent of the total products demand (table 26). Since the naphtha portion of the average crude is higher than 20 per cent, there would be a surplus of naphtha in the region and it would form the most important petrochemical feedstock. India would base its petrochemical industry primarily on its surplus naphtha whereas Pakistan would utilize its huge reserves of natural gas. For Iran, where the percentage of gasolene demand is much lower than that of India, it would either use surplus naphtha or surplus natural gas, which is being flared at the rate of about 672 million cubic feet or over 19 million cubic metres a day in the southern fields of Iran.

TABLE 26. DEMAND FOR PETROLEUM PRODUCTS IN THE ECAFE REGION
(*1,000 barrels*)

Country	*Gasolene demand*	*Total products demand*	*Gasolene per cent*
Australia	40,888	90,212	45
Afghanistan	807	1,100	73
Burma	1,310	4,278	30
Ceylon	1,292	4,899	26
China (Taiwan)	1,772	9,154	19
Hong Kong	620	10,837	6
India	9,002	66,349	14
Indonesia	8,298	40,007	21
Iran	4,218	53,422	8
Japan	48,243	326,139	15
Korea, Republic of	680	7,007	10
Laos	185	239	77
Malaysia	9,746	63,607	15
New Zealand	8,635	15,152	57
Pakistan	2,344	20,021	12
Philippines	8,110	24,783	33
Thailand	3,404	12,034	28
Viet-Nam, Republic of	2,279	6,769	34
ECAFE REGION	151,833	756,009	20

SOURCE: World Petrochemical Report, 1964 (Noyes Research Company)

With the exception of Pakistan and Iran, where there are large reserves of natural gas, the petrochemical industry in most countries of this region is likely to be built around naphtha crackers. It might, therefore, be of interest to note that out of 23 countries in the region, thirteen already have refineries and two are planning to establish them, one to be on stream in 1966 and the other in 1967. Table 27 shows that all the above countries will have sufficient refining capacities by 1967 to meet the total demand of petroleum products in their own countries.

In the ECAFE region, there are at present only two countries which have a developed petrochemical industry. Japan has reached an international level, whereas Australia is still confined to her domestic market. Japan has built its petrochemical industry based upon naphtha, whereas Australia's is based on refinery gases and gas oil. Neither of them have significant reserves of oil or gas in terms of their requirements and they have to import large quantities of crude oil. This places them at a disadvantage when competing with the industrially advanced countries, such as the United States, which has large reserves of oil and gas, and Europe, where the price of naphtha has been lower than that in Japan.

The major problem faced by these two countries is the keen competition from overseas suppliers which have surplus capacity. In Australia, it is reported that, with the elimination of import licensing, the local chemical industry, including the petrochemical industry, became vulnerable to dumping by overseas suppliers who sell at marginal prices to the detriment of the local industry.

TABLE 27. ECAFE COUNTRIES: REFINING CAPACITIES AND TOTAL DEMAND FOR PETROLEUM PRODUCTS

Country	*Total products demand (b/d)*		*Refining capacity (b/d)*	
	1964	*1967*	*1964*	*1967*
Australia	250,000	392,000 [a]	375,000	490,000 [b]
Burma	12,000	—	26,000	—
Ceylon	20,000	—		34,000
China (Taiwan)	30,000	—	40,000	—
India		340,000 [b]	168,000	288,000 [c]
Indonesia	100,000	—	275,000	—
Iran	150,000	—	492,100 [d]	—
Japan	1,000,000	1,840,000	1,200,000	2,700,000
Korea, Republic of	20,000	—	35,000	—
Malaysia	175,000	—	120,000	145,000 [c]
New Zealand	42,000	—	50,000	—
Pakistan	60,000	—	40,000	80,000 [c]
Philippines	64,000	—	90,000	—
Thailand	35,000	—	42,000	
Viet-Nam, Republic of	—	—	—	24,000 [b]

SOURCE: *World Petrochemical Report*, 1964; *Petroleum Refiner*, January 1964.

[a] 1972.

[b] 1966.

[c] 1965.

[d] 1962. "World Oil Statistics", October, 1963.

As one of the measures to protect local industry, the Federal Parliament has passed the Vinyl Resin Bounty Act 1963 under, which a bounty of 4d per lb, or about $0.08 per kg, will be paid on vinyl resins produced and sold for use in Australia or used by the producer in the production of other goods. The bounty will operate for three years as from 15 August 1963 and will be subject to the usual reduction or elimination if and when profits exceed 10 per cent before tax.

Japan, which has attained international level in the petrochemical industry, has its own problems. The small size of production units and the high price of naphtha, which is the basic material for the petrochemical industry, were listed as major problems. Japan's maximum unit capacity of ethylene in 1964 was 120,000 tons per year as against 250,000 tons in the United States, 200,000 tons in the United Kingdom, 150,000 tons in the Federal Republic of Germany, and 80,000 tons in France.

The United States counterparts have the solid advantages of size, technology and access to cheap materials in the form of natural gas and petroleum by-products. Even compared with its European counterparts, which have to rely mainly on naphtha as the raw material, the higher price of naphtha in Japan becomes a big handicap. The price of naphtha in Europe was about $11.9 per kilolitre ex refinery, whereas, in Japan, it ranged from $16.4 to $16.7 delivered.

Price comparison of selected petrochemical products showed that, owing to the foregoing reasons, in 1962 the domestic price per kilogramme of polyethylene was about $0.58 compared with the imported price of about $0.51, that of polystyrene about $0.69 as against $0.36, and that of SBR about $0.53 compared with about $0.48 for the imported product.

VIII. SCOPE FOR REGIONAL OR INTERNATIONAL CO-OPERATION

From the foregoing paragraphs, a few facts emerge which merit serious consideration. First very few countries in this region have levels of consumption high enough to warrant the establishment of petrochemical plants with capacities large enough to be competitive with the industrially advanced countries. Secondly, even in Japan, which has attained an international level, economies of scale and natural endowment factor are still crucial, especially in the face of strong competition from overseas suppliers of petrochemical products.

Viewed against this background, there appears to be scope for regional or international co-operation in the development of the petrochemical industry. There are some countries in this region with large reserves of oil and gas. Petrochemical plants with large capacities may be built in these countries jointly by countries both within and outside this region through financial, commercial and technological collaboration.

APPENDIX A

The petrochemical industry in Japan

I. Introduction

The development of the Japanese petrochemical industry has been very spectacular indeed. In about ten years it has reached an international scale of operations, equal to or even higher than that of some west European countries. It produces varieties of synthetic fibres, rubber, plastics, fertilizers, and industrial chemicals derived from natural gas or petroleum.

Beginning from 1952, methanol was the first chemical product made commercially from natural gas. Today, all methanol and more than 70 per cent of ammonia produced in Japan are manufactured from natural gas or petroleum. Six years ago, Japan was only able to produce a few petrochemicals, such as isopropyl alcohol, secondary butanol, acetone and methyl ethyl ketone by the use of refinery gases as raw materials.

It was in July 1955 that the Ministry of International Trade and Industry (MITI) drew up a development plan for the production of petrochemicals, and took measures to encourage investments in petrochemical industry from private enterprises. These measures aimed at: (1) an abundant supply of low-cost raw materials for petrochemical industry, and (2) minimizing imports to economize on foreign exchange and to encourage domestic production.

In fact, the large-scale development of Japanese petrochemical industry only started in 1958, when naphtha cracking plants began to produce olefinic hydrocarbons for making varieties of petrochemical products. The production of ethylene, the basic petrochemical intermediate, was only 14,000 tons a year in 1958. It rose to 107,000 tons a year in 1961, and it is expected to reach 520,000 tons a year in 1964. In the beginning four companies, Nippon Petrochemical Co., Mitsui Petrochemical Co., Mitsubishi Petrochemical Co. and Sumitomo Chemical Co., were engaged in naphtha cracking. Now there are nine companies, of which the total capacity of ethylene production will reach about 900,000 tons a year by 1966.

In terms of production value, the petrochemical output in 1957 was valued at only 1,700 million yen. It reached 129,000 million yen in 1962, accounted for 11.6 per cent of the total production value of the Japanese chemical industry. It was estimated that the production value of petrochemicals in 1970 will be 1,600,000 million yen, which will represent about 50 per cent of the value of total chemical products in Japan.

In view of the above, it is most desirable to make a case study on the development of Japanese petrochemical industry which will serve as reference material especially for the developing countries of the ECAFE region.

II. A brief description of leading Japanese petrochemical companies

In Japan, chemical companies are making metals and metal companies are making chemicals. Both chemical and artificial fibre producers are pushing into petrochemicals, as are oil companies. Therefore the structure of the Japanese chemical industry cannot be clearly defined. Each major product has its own manufacturers' association and one company may belong to as many as a dozen of these associations.

Petrochemical companies have been formed in Japan either by the pooling of financial resources within a major industrial group or as joint ventures involving independent companies. The parent companies finance the construction of the complex and buy its products. Investments of foreign capital are also prominent in the petrochemical industry.

Sumitomo Chemical has the largest sales, but this includes sales of its petrochemical division. In Mitsubishi and Mitsui, petrochemicals are handled by separate companies. The Mitsui group of companies reportedly has the largest combined annual sales. Ube Industries makes not only chemicals but also cement and other non-chemical products, sales of which are not reported separately.

Sumitomo

Sumitomo Chemical is claimed to be the largest all-around chemical company in Japan. It manufactures chemical fertilizers, industrial chemicals, electrochemicals, synthetic resins, dyestuffs, insecticides, pharmaceuticals and petrochemicals. Sumitomo is the only leading chemical producer in Japan that has set up its petrochemical plants within the parent company. The following companies are closely related to Sumitomo Chemical:

(1) Sumitomo Bakelite Co. Sumitomo supplies most of the raw materials to the company, which has the largest resin processing capacity in Japan.

(2) Japan Exlan Co., Ltd., which is a joint venture with Toyo Spinning Co., for producing acrylic fibre. Sumitomo Chemical supplies acrylonitrile monomer and the fibre produced by the company is shipped to Toyo Spinning for conversion into textiles.

(3) Akita Petrochemical Co., which is a joint venture with Teikoku Oil Co. The company produces ammonia and methanol from natural gas.

(4) Nihon Catalytic Chemical Co., which produces phthalic anhydride and other chemicals.

(5) Sumitomo Naugatuck Co., Ltd., which is a joint venture with U.S. Rubber Co. to manufacture ABS resins.

Mitsui

The Mitsui group, unlike Sumitomo Chemical, has four chemical companies:

(1) Mitsui Chemical, which manufactures chemicals from acetylene and petroleum. Its mainstays are high-density polyethylene, polypropylene, and raw materials for urethane.

(2) Mitsui Petrochemical, which is a leading company in the production of terephthalic acid, phenol and ethylene glycol, which are intermediates for synthetic fibres.

(3) Mitsui Polychemicals, which is a joint venture of Mitsui Petrochemical and Du Pont, each of which have a half interest in the company. It manufactures high-pressure polyethylene.

(4) Toyo Koatsu Industries, Inc. Toyo Koatsu manufactures ammonia, urea, ammonium sulphate, methanol, formaldehyde and other organic chemicals from natural gas produced in the Mobara gas field, Chiha prefecture. It has the biggest urea plant, producing about 38 per cent of total urea production in Japan. The Toyo Koatsu process for making urea by total recycle system is one of the most efficient processes in the world.

Mitsubishi

The chemical companies belonging to the Mitsubishi group are:

(1) Mitsubishi Chemical, which is the leading company of the group. It is one of the largest producers of coke, carbon black, dyestuffs, nitric acid, fertilizers and agricultural chemicals. It is also a main producer of raw materials for synthetic fibres and resins, such as acrylonitrile, acetone cyanohydrin, 2-ethyl hexanol, and maleic anhydride.

(2) Mitsubishi Petrochemical, which is a joint venture of nine Mitsubishi companies with the Royal Dutch/Shell Group. It has the largest naphtha-cracking capacity in Japan, supplying other Mitsubishi companies with various raw materials. The company has three subsidiaries of its own:

Yokkaichi Chemical Co., Ltd, which manufactures nonionic surface-active detergents.

Yuka Badische Co, which is a joint venture with a subsidiary of Germany's Badische Anilin & Soda-Fabrik AG to produce expandable polystyrene.

Sansho Plastics Co., Ltd, which manufactures biaxially oriented polypropylene film.

(3) Mitsubishi Monsanto Chemical Co, which is a joint venture with Monsanto producing polyvinyl chloride, polystyrene, and plasticizers.

(4) Mitsubishi Vonnel Co. Ltd. It is a joint venture with Chemistrand Corp. to make acrylic fibre, vonnel.

Nippon Petrochemical Co.

Nippon Petrochemical is an independent company not associated with major industrial groups. It is a fully owned subsidiary of Nippon Oil Co. In turn, Nippon Oil Co. is associated with California Texas Oil Corp. (Caltex) as a partner in Nippon Petroleum Refining Co., Ltd, which supplies Nippon Petrochemical with naphtha and propane-propylene. Nippon Petrochemical produces isopropanol, acetone, ethylene, butadiene, benzene, toluene and xylenes. It supplies its products to Furukawa Chemical Industry Co., Japan Catalytic Industry Co., and Asahi-Dow Co. for the manufacture of various petrochemicals.

Showa Denko KK

Showa Denko KK is one of the leading independent chemical enterprises in Japan, having about twenty subsidiaries and affiliates that make a range of products including fertilizers, resins, adhesives, phthalic anhydride, explosives, and phosphates.

Showa Denko and Du Pont have jointly established Showa Neoprene Co. for the manufacture of synthetic rubber, neoprene. It started production in 1963.

Ube Industries, Ltd.

Ube Industries, Ltd. is also an independent company having diversified ventures including chemical, machinery, cement and coal. Its chemical division produces chemical fertilizers, urea, polyethylene and caprolactam. It is moving into petrochemicals in a joint venture with Maruzen Oil Co. Ube also has 31 subsidiaries involved in the manufacture of chemical products.

Synthetic fibre companies

Toyo Rayon Co. ranks third in the world in the production of synthetic fibres, after Du Pont and Chemstrand. It has recently stopped making rayon and now produces nylon, polyester, polyacrylic, and polypropylene fibres. It shares 70 per cent of the Japanese market for nylon and 50 per cent for polyester. Next to Toyo Rayon in capacity is Teijin, Ltd. (Teikoku Rayon), which manufactures rayon, acetate fibre and polyester fibre. Polyvinyl alcohol fibre, known as vinylon, is made by Kurashiki Rayon Co. and Dai Nippon Spinning Co. The former has 80 per cent of the market in vinylon and the latter has only 20 per cent. Acrylic fibres are manufactured by Asahi Chemical, Mitsuhishi Chemical, Japan Exlan and Kanegafuchi Chemical Co., each sharing about one-fourth of the market.

Japan Gas Chemical Co.

Japan Gas Chemical Co., located in Niigata, is the pioneering petrochemical company in Japan; it has been producing methanol from natural gas since 1952, and ammonia since 1957. It also produces urea, ammonium sulphate, formaldehyde, hydrogen cyanide, and methyl methacrylate.

III. Raw materials

1. NATURAL GAS

There are three types of natural gas accumulations in Japan.

(1) Dissolved-in-water type. The proven and probable reserves are about 19,000 million cubic metres by volumetric calculation. This figure does not mean the actual recoverable reserves, which must be substantially subjected to withdrawal rates of water.

The gas composition in the Yamagata field is (vol. per cent):

CH_4	C_2 +	CO_2	N_2	Ar	O_2	Gas-water ratio
84.5	none	5.22	10.1	0.20	0.01	0.19

(2) Oil-free type. The proven and probable reserves may be slightly over 10,000 million cubic metres.

The gas composition in the deep wells of the Higashi-Niigata field is:

CH_4	C_2H_4	C_3H_8	C_4H_{10} +	$N_2 + CO_2$
83.71	8.15	4.35	2.93	0.69

(3) Associate with oil type. The proven and probable reserves are about 3,000 million cubic metres.

The gas composition in the Barato field is:

CH_4	C_2H_6	C_3H_8	C_4H_{10}+	$N_2 + CO_2$
66.98	9.93	12.51	8.97	1.59

The total natural gas reserves in Japan are about 32,000 million cubic metres, of which the proven reserves are estimated to be 15,000 million cubic metres.

The discovery of new gas reserves and the development of petrochemical industry have resulted in almost a tenfold increase in the production of natural gas in Japan since 1956. The yearly production is shown in table A.

The production in 1964 will probably reach about 2,000 million cubic metres.

There are two big gas producers in Japan, Teikoku Oil Co. and Japan Petroleum Exploration Co. The gas is sold directly to gas consumers except for residential use. The well-head price is about 6 yen per cubic metre, which is equivalent to US$ 0.48 per 1,000 cubic feet.

TABLE A. NATURAL GAS PRODUCTION IN JAPAN

Year	*Quantity (1,000 m³)*	*Index*
1956	176,800	100.0
1957	243,540	137.8
1958	367,280	208.1
1959	506,770	286.6
1960	731,440	413.7
1961	950,280	537.5
1962	1,209,060	683.9
1963	1,694,621	952.0

About 80 per cent of the total consumption of natural gas is used by chemical industry. The breakdown of the end-use in 1962 is shown in table B.

TABLE B. END-USE PATTERN OF NATURAL GAS IN 1962

End-use	*Quantity in cubic metres*	*Index*
Mining industry	46,094,000	3.92
Food industry	804,000	0.07
Fibre industry	486,000	0.04
Chemical fertiliser industry	376,101,000	32.02
Organic chemical industry	334,391,000	28.46
Pulp and paper industry	51,863,000	4.41
Other chemicals	170,530,000	14.51
Iron and steel industry	25,383,000	2.16
Power generation	151,105,000	12.86
Others	18,157,000	1.55
TOTAL	1,174,914,000	100.00

2. CRUDE OIL

The crude oil supply in Japan depends mainly upon imports, more than 80 per cent from the Middle East. The proven petroleum reserves are very small, being less than 7 million tons. The domestic production is only enough to meet 1.5 per cent of the total requirement. The production and import data are shown in table C.

TABLE C. CRUDE OIL PRODUCTION AND IMPORT
(Unit: thousand metric tons)

Year	*Production*	*Import*
1960	593	32,955
1961	738	39,163
1962	858	47,261
1963	898	61,976
1964 (estimate)	900	76,104

3. LIQUEFIED PETROLEUM GAS (LPG)

Production of LPG is limited because most of the natural gas is very dry. The main source is the oil refineries. The production and import data are shown in table D.

In the United States, LPG is one of the most important raw materials for making petrochemicals and synthetic rubber. But in Japan, as well as in some European countries, the supply of LPG is

TABLE D. PRODUCTION AND IMPORT OF LPG
(Unit: thousand metric tons)

Year	*Production*		*Import*
	From natural gas	*From refineries*	
1960	9	454	—
1961	11	716	28
1962	13	939	129
1963	13	1,336	226
1964 (estimate)	13	1,686	368
1965 (estimate)	13	2,017	463

The end-use pattern of LPG in 1963 was as follows:

Use	*Quantity (metric tons)*	*Percentage*
Residential fuel	1,030,000	74.8
Municipal use	39,000	13.8
Engineering industrial use	189,000	2.8
Chemical industries use	120,000	8.6
TOTAL	1,378,000	100.0

SOURCE: Asahi Evening, 5 Oct. 1963.

inadequate for chemical use. Instead, naphtha is used as a principal raw material.

In 1962, the consumption of naphtha in Japan for the production of petrochemicals was 2,006,276 kilolitres, representing 86.3 per cent of total consumption. In 1964 the annual requirement for naphtha is estimated to be about 3.5 million kilolitres, which requires about 14 million kilolitres of crude oil to produce. The supply of naphtha is tight owing to the rapid development of steam-cracking plants. The price is also high, ranging from yen 5,900 to yen 6,000 per kilolitre ($16.40 to 16.70 per kl). Comparing with European countries, it is only about $12 per kl.

IV. Production

1. AMMONIA

Ammonia is the basic raw material for the manufacture of various nitrogen fertilizers, and for making acrylonitrile, which is used for the manufacture of synthetic fibre of acrylic type, synthetic rubber of nitrile type, and plastics.

Japan is the third biggest producer of ammonia in the world after the United States and West Germany. Ammonia began to be produced in large scale from natural gas in 1957, when the Matsuhama Plant of the Japan Gas Chemical Company started in operation.

By 1963, more than 70 per cent of ammonia produced in Japan had been manufactured from natural gas and petroleum. Table E shows the production of ammonia in Japan:

TABLE E. PRODUCTION OF AMMONIA
(Unit: metric tons)

Year	*From natural gas and petroleum*		*From coal and others*		*Total*
	Quantity	*Percentage*	*Quantity*	*Percentage*	
1960	606,000	47.0	678,000	53.0	1,284,000
1961	830,000	58.0	596,000	42.0	1,426,000
1962	1,003,000	65.6	525,000	34.4	1,528,000
1963	1,243,000	72.8	466,000	27.2	1,709,000
1964 (estimate)	1,300,000	74.2	450,000	25.8	1,750,000

It is interesting to note that the production of ammonia from natural gas and petroleum was more than doubled within a period of four years from 1960.

Since 1953, considerable changes in the feedstocks for ammonia production can be clearly seen in table F.

TABLE F. PERCENTAGES OF AMMONIA PRODUCTION FROM DIFFERENT SOURCES

Source	*1953*	*1959*	*1963*
Electrolysis of water	26.0	12.6	5.2
Coal:			
Coal and coke	69.0	45.8	6.8
Coke-oven gas	—	10.3	15.4
Natural gas		13.5	20.8
Crude oil	5.0	12.0	42.4
Refinery and waste gases		4.7	8.4
Others		1.1	1.0
TOTAL	100.0	100.0	100.0

It is estimated that, by 1970, only 2 per cent of ammonia will still be produced from electrolysis; coke will not be used at all, and coal will represent only 4 per cent of the total feedstock.

The production of nitrogen fertilizers in terms of nitrogen is shown in table G.

TABLE G. PRODUCTION OF NITROGEN FERTILIZERS
(Unit: thousands tons N)

Year	*Ammonium sulphate*	*Urea*	*Ammonium chloride*	*Others*	*Total*
1960	509	280	59	64	912
1961	526	308	92	88	1,013
1962	527	346	84	114	1,071
1963	475	438	112	149	1,184
1964 (estimate)	473	468	130	177	1,228

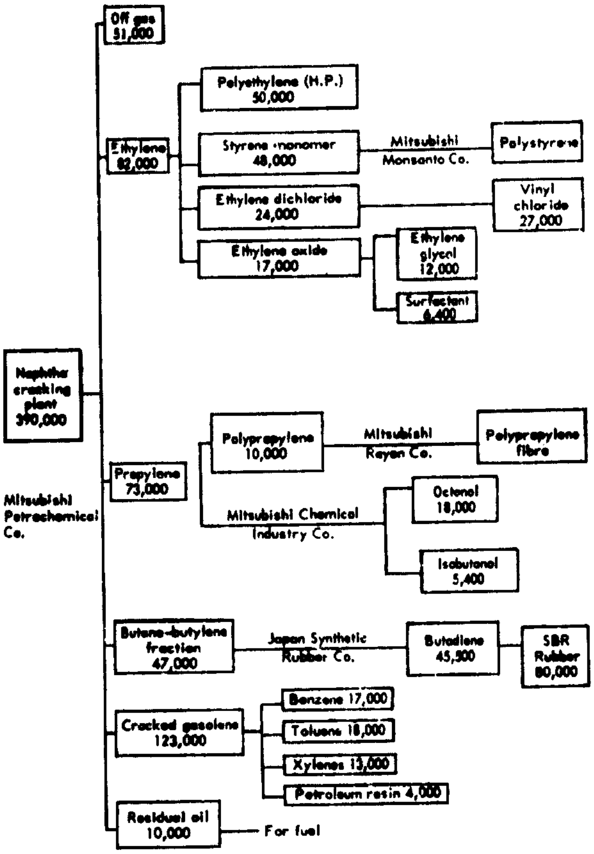
2. PETROCHEMICALS DERIVED FROM NAPHTHA CRACKING

By steam cracking of naphtha, a typical plant produces the following products simultaneously with some variation in compositions depending upon the characteristics of the feedstock and processing conditions:

	Per cent by weight of naphtha
Off gas	22
Ethylene	19
Propylene	17
Butane-butylene	15
Cracked gasolene	21
Residual oil	4
Loss	2

In order to utilize all these products, a petrochemical complex is established. The naphtha cracking plant acts as a centre, around which manufacturing plants of plastics, synthetic rubber, synthetic fibre and industrial chemicals are established.

The operations of a petrochemical complex may be better described by means of diagrams. The following diagrams of the complexes, Mitsubishi Petrochemical Company and Mitsubishi Chemical Industry Company, are made for illustration:



Unit: Tons/year

Mitsubishi Petrochemical Complex, Yokkaichi Japan

TABLE H. ETHYLENE PRODUCTION CAPACITY

(Unit: tons/year)

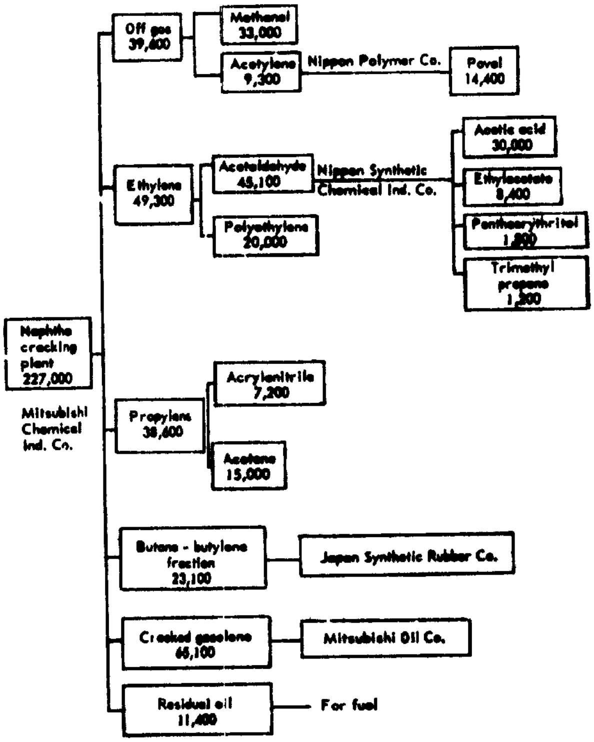
Complex	*1962*	*1963*	*1964*	*1965*
Mitsui Petrochemical	80,000	80,000	160,000	160,000
Mitsubishi Petrochemical . .	82,000	82,000	142,000	142,000
Sumitomo Chemical	55,000	55,000	87,000	87,000
Nippon Petrochemical . . .	50,000	75,000	100,000	160,000
Tonen Petrochemical	40,000	60,000	84,500	143,000
Maruzen Petrochemical . . .	—	44,000	44,000	44,000
Daikyowa Petrochemical . .	—	41,000	41,300	41,300
Mitsubishi Chemical Industry	—	—	49,300	49,300
Indemitsu Kosan	—	—	73,000	73,000
TOTAL	307,000	437,000	781,100	899,600

In Japan there are nine such petrochemical complexes and some more in the planning stages. Since ethylene is the most important intermediate product of all, the capacity of the cracking plant is always expressed in terms of ethylene production. The development of naphtha cracking capacity in Japan by the end of each year is shown in table H.

The expansion of cracking capacity in Japan is phenomenal; it will be tripled in a period of four years from 1962. Total planned production capacities of ethylene to be completed in 1966 will be about 370,000 tons.

TABLE I. ETHYLENE PRODUCTION CAPACITY

Country	*Year*	*Total capacity (metric tons)*
United States	1963	3,600,000
	1964	3,900,000
United Kingdom	1962	571,000
West Germany	1963	747,000
France	1962	139,000
	1964	171,000



Unit: Tons/year.

Mitsubishi Petrochemical Complex Mitzushima Japan

TABLE J. PRODUCTION OF PETROCHEMICAL INTERMEDIATES

(Unit: thousand tons)

Intermediate	*1960*	*1961*	*1962*	*1963*	*1964*	*1965*	*1966*	*1967*
Ethylene . . .	78.0	107.2	231.5	345.8	520	710	869	1,031
Propylene . .	—	—	160.5	180.0	232	302	352	405
Butadiene . .	16.4	35.2	47.6	63.8	84	134	158	181
Benzene . . .	14.8	27.3	55.9	83.6	120	200	240	270
Toluene . . .	34.6	55.9	74.4	96.0	113	136	160	190
Xylenes . . .	26.1	42.3	53.1	63.6	88	100	110	125
Acetylene . .	—	1.3	8.0	22.4	—	—	—	—

For comparison, the annual production capacities of ethylene for four countries are listed in table I.

The production of petrochemical intermediates in Japan with estimates from 1964 to 1967 is shown in table J.

Benzene, toluene and xylenes are also produced from coal. Acetylene is mainly produced from calcium carbide Their production figures are shown in table K.

The production of plastics, synthetic rubbers, synthetic fibres and industrial chemicals derived from petrochemical intermediates with estimates from 1964 to 1967 is shown in table L. The production value of petrochemicals is shown in table M.

TABLE K. PRODUCTION OF BENZENE, TOLUENE, XYLENES, ACETYLENE FROM COAL

(Unit: thousand tons)

	1960	*1961*	*1962*	*1963*
Benzene	118.7	136.7	141.5	167.8
Toluene	26.5	32.1	34.8	37.6
Xylenes	5.8	6.3	7.5	8.2
Acetylene	293.5	302.9	301.3	352.7

TABLE L. PRODUCTION OF PLASTICS, SYNTHETIC RUBBERS, SYNTHETIC FIBRES AND INDUSTRIAL CHEMICALS

(Unit: thousand tons)

	1960	*1961*	*1962*	*1963*	*1964*	*1965*	*1966*	*1967*
Plastics								
PVC resins *	258.1	308.9	303.5	348.1	436.9	494.0	544.5	959.0
Polyethylene	41.2	58.1	142.5	223.4	283.8	350.2	419.8	497.1
Polypropylene	—	—	2.5	21.2	37.0	54.5	62.0	72.0
Polypropylene	21.9	29.0	43.1	61.4	105.1	131.0	158.1	189.6
Synthetic rubbers								
Styrene butadiene rubber	21.4	48.5	65.8	9.3	131.2	141.7	151.5	162.0
Nitrile rubber	2.1	2.6	3.6	4.2	6.7	7.0	7.4	7.8
Neoprene	—	—	—	3.6	10.2	11.3	12.3	13.2
Polyethylene	—	—	—	—	—	35.4	47.0	60.9
Synthetic fibres								
Nylon	40.3	49.5	57.7	80.1	118.6	137.7		
Vinylon	22.6	30.0	35.4	37.4	45.8	48.8		
Acrylics	22.0	23.0	27.4	36.0	54.0	71.8		
Polyester	22.4	37.3	46.8	62.3	84.0	114.4		
Polypropylene	—	—	1.9	6.0	13.6	21.6		
PVC	6.5	7.3	7.2	8.1	8.9	10.0		
Vinylidene chloride	3.2	3.1	3.1	3.7	3.8	4.0		
Polyethylene	1.2	2.7	3.2	5.8	9.7	13.8		
Chemicals								
Ethylene oxide	16.2	22.7	27.5	31.9	56.0	64.5	74.4	83.2
Ethylene glycol	14.0	20.4	23.1	27.1	56.4	69.9	81.9	94.4
Styrene	33.9	46.8	70.6	105.3	142.7	185.4	218.6	257.6
Propylene oxide	2.7	6.7	13.3	25.0	26.3	34.2	42.7	51.2
Acetone	11.2	13.8	17.5	26.1	58.3	74.8	86.6	98.7
Butanol	8.8	10.2	14.2	30.8	60.5	67.9	75.4	82.4
2-Ethyl hexanol	3.9	6.2	11.6	21.3	43.8	49.0	55.0	60.5
Dioctyl phthalate	28.3	31.5	39.3	47.0	—	—	—	—

* Including from calcium carbide.

TABLE M. PRODUCTION VALUE OF PETROCHEMICALS

Year	*Value in yen*[a]	*$US equivalent*	*Index*
1957	1,739,000,000	4,810,000	100.0
1958	11,096,000,000	30,900,000	638.1
1959	29,527,000,000	82,000,000	1,697.9
1960	62,863,000,000	174,000,000	3,616.0
1961	84,067,000,000	234,000,000	4,832.4
1962	128,926,000,000	359,000,000	7,413.8

SOURCE: MITI.

[a] Yen 360 = $US1

The breakdown of the production value in 1962 is:

	Per cent
Polyethylene	23.25
Synthetic rubbers	11.08
Polystyrene	8.28
Styrene monomer	7.86
Phthalic anhydride	7.12
Ethylene oxide	3.22
Others	39.19
TOTAL	100.00

V. Pattern of consumption and trade

1. NITROGEN FERTILIZERS

As shown in table N, the amount of export of Japanese nitrogen fertilizers has more than doubled within a period of four years since 1960, and currently 50 per cent of the production in terms of nitrogen is for export.

The export prices of fertilizer have gone steadily downward in the past ten years. In 1963, the average export price of urea, f.o.b. Japan, was only about $US 70 per ton, and that of ammonium

TABLE N. EXPORT OF NITROGEN FERTILIZERS
(Unit: thousand tons N)

Year	*Ammonium sulphate*	*Urea*	*Ammonium chloride*	*Others*	*Total*
1960	186	89	1	4	280
1961	169	123	15	7	314
1962	188	212	15	11	426
1963	260	279	81	13	633
1964 (estimate) .	195	321	69	13	598

sulphate was $US 36. Owing to the increasing demand in the world market, the price rose more than 20 per cent early in 1964, which was the first time that the fertilizer supply was not sufficient to meet the export demand. By 1964 Japan had become the largest exporter of nitrogenous fertilizers in the world contributing about 16 per cent of total world exports.

2. PETROCHEMICALS

(1) *Consumption*

The domestic consumption of petrochemicals has been increasing very rapidly in recent years. Although strenuous efforts have been made to boost production capacities, the supply is still unable to keep pace with the demand. Imports are necessary to fill up the deficiency. However, starting from 1962, imports of petrochemicals began to fall off for the first time, mainly because domestic polyethylene production increased. They are expected to drop further in coming years with increasing production of synthetic rubbers, ethylene glycol, polystyrene and other petrochemicals.

The domestic demand for ethylene, the principal petrochemical intermediate, was estimated by MITI as in table O.

TABLE O. DOMESTIC DEMAND FOR ETHYLENE

Year	*Quantity in metric tons*	*Index*
1962	250,000	100
1963	350,000	140
1964	520,000	208
1965	700,000	280
1966	840,000	366

The domestic demands for some important petrochemical products in 1963 and 1964 are shown in table P.

TABLE P. DOMESTIC DEMAND FOR PETROCHEMICALS

Products	*1963 (metric tons)*	*1964 (estimate) (metric tons)*
Polyethylene	215,000	276,000
Styrene	100,000	123,000
Polystyrene	67,000	83,000
Ethylene oxide	46,000	56,000
Polypropylene	20,000	37,000
Acetaldehyde	176,000	212,000
Styrene-butadiene resin	121,000	131,000

Imports of some important petrochemical products from 1960 to 1963 are shown in table Q.

TABLE Q. IMPORTS OF PETROCHEMICALS
(Unit: metric tons)

	1960	*1961*	*1962*	*1963*
Polyethylene	23,400	42,600	12,800	4,900
Polystyrene	6,700	10,000	9,800	12,900
Ethylene glycol	5,800	8,300	13,900	23,500
2-ethylene hexanol. . . .	1,200	2,300	8,500	4,300
Butanol	200	300	400	7,800
Acetone	—	600	300	7,200
Styrene-butadiene rubber .	34,700	22,200	27,100	29,500
Neoprene	6,300	9,400	7,100	6,100
Nitrile rubber	1,300	2,400	1,700	2,000
Other synthetic rubbers .	4,100	5,300	8,100	11,900

The total values of imports of petrochemicals from 1957 to 1962 are as follows (unit: million yen):

1957	*1958*	*1959*	*1960*	*1961*	*1962*
16,261	16,039	24,998	27,439	30,703	26,936

(2) *Export*

Although the domestic demand of petrochemical products is very heavy, efforts to promote the export drive are not slackening. Exports of polyethylene, synthetic fibres and methanol are increasing very rapidly as shown in table R.

TABLE R. EXPORTS OF PETROCHEMICAL PRODUCTS
(Unit: metric tons)

	1960	*1961*	*1962*	*1963*	*1964 (estimate)*
Polyethylene	1,172	509	11,833	25,500	—
Polystyrene	173	96	1,600	2,500	—
Methanol	1,700	7,000	16,500	26,500	—
Styrene-butadiene rubber . .	—	5,400	6,300	8,400	—
Polyester resin	3,800	2,900	2,400	1,900	—
Synthetic fibre yarn and fabrics	14,800	21,900	35,600	46,500	62,500

The total export values of polyethylene, polystyrene and synthetic rubber are yen 582 million in 1960, yen 988 million in 1961, and yen 2,740 million in 1962.

Japan has relied heavily upon foreign technology for the development of petrochemical industry. Most of the Japanese manufacturers of petrochemical products are licensees of patents held by foreign companies. Owing to the limitations in the contracts, the Japanese are usually prohibited from exporting their products to European countries or the Americas where similar licensees are in production.

It can be seen from table S that the Japanese prices of petrochemical intermediates are generally higher than those of the United States and European countries. This is mainly due to two factors: smaller size of plants and higher cost of raw materials, especially naphtha.

However, the Japanese export prices of petrochemical products are generally cheaper than the domestic prices and the prices of imported goods. It is evident that export sales are subsidized by domestic sales. Table T shows the comparison of average domestic price, import price, and export price of some principal petrochemical products in 1962:

The export prices as shown in table T are competitive in the world market. That of polyethylene is only 56 per cent of the domestic price, and that of polystyrene is about 50 per cent. However, the export price of polyvinyl chloride (PVC) is only 10 per cent lower than the domestic price. This is because PVC is a well-established industry in Japan and has the strongest competitive strength among all chemical products for export. Of the total value, yen 17,000 million, of synthetic resins and products exported in 1962, 58 per cent was PVC. The Japanese domestic price compared with those of other countries in US dollars per lb of PVC is as follows: United States, 0.139-0.151; Germany, Fed. Rep. of, 0.160; France, 0.175; UK, 0.159; Italy, 0.153; Belgium, 0.142; Japan, 0.120-0.126.

(3) *Price*

TABLE S. PRICE COMPARISONS OF PETROCHEMICAL INTERMEDIATES IN 1962
(Unit: $US/lb)

	Japan	*USA*	*UK*	*France*	*Germany Fed. Rep. of*	*Italy*
Ethylene	0.073	0.050	0.082	—	0.060	—
Ethylene oxide	0.164	0.155	0.180	0.169	0.226	0.188
Styrene	0.182	0.108	0.117	0.125	0.130	0.120
Propylene oxide	0.258	0.145	0.193	0.166	—	0.174
Isopropanol	0.164	0.064	0.079	0.074	0.065	0.087
Acetone	0.117	0.070	0.088	0.071	0.070	0.051
Butadiene	0.139	0.127	0.134	0.135	0.119	0.148
Benzene	0.049	0.030	0.043	—	0.025	0.032

TABLE T. PRICE COMPARISON

	Domestic price		*Import price*		*Export price*	
	Yen/kg	*$ US/lb*	*Yen/kg*	*$US/lb*	*Yen/kg*	*$US/lb*
Polyethylene (high pressure)	229	0.289	197	0.248	139	0.175
Polystyrene (high impact)	265	0.335	140	0.177	131	0.165
Styrene	144	0.182	—	—	128	0.161
Polypropylene	370	0.468	316	0.398	—	—
Polyvinyl chloride	100	0.126	—	—	90	0.113
Styrene-butadiene rubber.	190	0.240	171	0.215	145	0.182
Ethylene glycol	130	0.165	76	0.096	—	—

Following the world tendency, the domestic and export prices of petrochemical products are decreasing every year. The price trend of polyethylene, for example, is shown in table U.

TABLE U. PRICE TREND

Year	*Domestic price*		*Export price*	
	Yen/kg	*$US/lb*	*Yen/kg*	*$US/lb*
1959	326	0.404	278	0.350
1960	313	0.395	275	0.348
1961	275	0.347	230	0.286
1962	229	0.289	139	0.175
1963	180	0.227	—	—

The price of ethylene, raw material for polyethylene, was about yen 70 per kg in 1959, and by 1964 it has been reduced to about yen 45 per kg ($US 0.057 per lb.). Likewise, the prices of most petrochemicals have come down by about 40 per cent.

VI. Economic aspects

1. INVESTMENT

The establishment of petrochemical industry needs very heavy capital investment. It has been estimated that the total investment in petrochemical industry in Japan from 1958 to 1962 amounted to about $600 million. More than $200 million will be invested each year starting from 1963 in order to make the petrochemical industry fully competitive on an international scale. Sources of money are loans from the Development Bank of Japan, commercial bank loans, foreign capital, companies' own capital, stocks and bonds.

The actual investment in 1962 and planned investment in 1963 and 1964 on different petrochemical projects are itemized in table V.

The total investment was equivalent to $125 million in 1962, $215 million in 1963, and $232 million in 1964. About one-third of the total investment was for the manufacture of products derived from ethylene.

The investment required to establish a naphtha cracking plant of medium size and its cost of production in Japan may be of interest

TABLE V. PETROCHEMICAL INVESTMENTS

Item	1962 (actual)		1963 (planned)		1964 (planned)	
	Yen million	Percentage	Yen million	Percentage	Yen million	Percentage
Naphtha cracking	*7,900*	*17.6*	*12,200*	*15.7*	*6,200*	*7.4*
Products from ethylene:						
Polyethylene	7,300		9,000		6,500	
Acetaldehyde	1,300		2,800		2,000	
Polystyrene	400		900		1,400	
Ethylene oxide and glycol	300		2,100		2,500	
Ethylene dichloride	0		1,200		400	
Others	3,300		10,100		16,200	
Sub-total	*12,600*	*28.0*	*26,100*	*33.6*	*29,000*	*34.9*
Products from propylene:						
Polypropylene	5,100		5,600		4,300	
Alkane	1,200		900		3,700	
Acrylonitrile	200		2,400		3,500	
Acetone	200		700		1,000	
Propylene oxide and glycol	500		1,200		1,900	
Phenol	600		1,100		1,000	
Methyl isobutyl ketone	0		400		200	
Others	3,500		1,900		3,200	
Sub-total	*11,300*	*25.0*	*14,200*	*18.2*	*18,800*	*22.5*
Products from butylene:						
Styrene - butadiene rubber	300		500		—	
Acrylonitrile-butadiene-styrene resin	400		700		400	
Polybutylene	0		2,200		8,100	
Others	1,500		2,500		3,400	
Sub-total	*2,200*	*4.9*	*5,900*	*7.6*	*11,900*	*14.2*
Products from aromatics:						
Benzene, toluene and xylenes	3,400		300		1,300	
Phthalic acids	200		600		1,600	
Others	200		2,900		2,700	
Sub-total	*3,800*	*8.4*	*3,800*	*4.9*	*5,600*	*6.7*
Products from acetylene	*800*	*1.8*	*2,500*		*2,200*	*2.6*
Others	*2,400*	*5.3*	*5,300*	*6.8*	*3,300*	*3.9*
Accessory items	*4,100*	*9.0*	*7,700*	*10.0*	*6,500*	*7.8*
TOTAL	45,100	100.0	77,700	96.8	83,500	100.0

to the developing countries planning to develop petrochemical industry. This plant has a capacity to produce 15,000 tons per year, or 45.2 tons per day, of ethylene with a purity of 99.9 per cent by weight. It was with about that size of petrochemical centre that Japan started to develop this industry in 1958. The raw material used is naphtha having a boiling range from 124° to 313°F. The total cost of the plant was $6,050,000. The breakdown is as follows:

	United States dollars
Equipment	5,100,000
Design, engineering and installation	830,000
Technical "know-how"	120,000
TOTAL	6,050,000

The cost of production of ethylene is estimated in table W based on the present conditions in Japan.

The cost of ethylene per kg is yen 50.92 ($US 0.064 per lb).

It has been mentioned before that the current selling price of ethylene in Japan is only about yen 45 per kg., or $US 0.057 per lb: therefore a plant of this size can hardly be operated nowadays.

In order to reduce the cost of production, the Japanese petrochemical industry is expanding the naphtha cracking units to several times the size of the original ones installed in 1958. Currently, the optimum size for a petrochemical centre capable of efficient and economic operation in Japan is one with a production capacity of from 100,000 to 150,000 tons of ethylene per year.

The data on the investment required for the manufacture of some important petrochemical products by Japanese companies are listed in table X.

2. FINANCIAL STRUCTURE OF PETROCHEMICAL INDUSTRY

Its financial structure is the weakest point of the Japanese petrochemical industry. Inherently, Japan is short of capital. Industrial companies have to apply to the banks, not only for operating funds but also for new investment capital. With the tremendous investment made in petrochemical industry in recent years, many Japanese companies have acquired long-term debts which bring their debt-equity ratio to 70-30, or approximately the reverse of the ratio of most American companies. Financial operations are generally

TABLE W. COST OF PRODUCTION OF ETHYLENE IN A 15,000 TONS PER YEAR NAPHTHA CRACKING PLANT

Item	*Unit price (yen)*	*Quantity*	*Yen per day*
Naphtha	6,000/kl	266 kl /day	1,596,000
Electricity	3.5/kWh	3,648 kWh/day	12,770
Water	5/kl	6,270 gal/min	170,860
Steam			
570 psig	1,000/ton	357.5 tons/day	357,500
30 psig	1,000/ton	2.9 tons/day	2,900
Catalyst and chemicals			16,000
Laboratory control			12,530
Labour, 5 workers per shift			23,080
Maintenance, 4 per cent of plant cost			238,680
Insurance and tax, 2.5 per cent of plant cost			149,180
Depreciation, 10 per cent of plant cost			596,700
Interest 10 per cent of plant cost			596,700
		TOTAL	3,772,900

From the amount of 3,772,900 yen the value of by-products obtained should be deducted, the breakdown of which is as follows:

Item	*Unit price (yen)*	*Quantity*	*Yen per day*
Steam, 200 psig	1,000/ton	9.8 tons/day	9,800
Propane-propylene	18,000/ton	31.3 tons/day	563,400
Butylene-butadiene	20,000/ton	24.1 tons/day	482,000
C_5 to 400° F distillates	6,000/kl	51.8 kl/day	310,710
Residual oil (above 400° F)	3,000/kl	13.2 kl/day	39,550
Off-gas	0.8/1,000 kcal	10.3 million BTU/hr	49,850
		TOTAL	1,455,310
Cost of ethylene		45.2 tons/day	2,301,590

TABLE X. INVESTMENT ON PETROCHEMICAL PRODUCTS

Company	*Capacity, MT/yr*	*Investment, $US*	*Process*
A. *Polyethylene from ethylene:*			
Mitsubishi Petrochemical	50,000	11,000,000	BASF, high pressure
Mitsui Chemical	24,500	6,950,000	Du Pont, high pressure
Furu-Kawa Chemical	9,700	2,500,000	Standard, medium pressure
Japan Olefin	22,000	6,950,000	Phillips, medium pressure
B. *Styrene and polymers:*			
Asahi-Dow	15,000	2,600,000	Dow, Benzene to styrene
	3,200	930,000	ABS resin
Mitsubishi-Monsanto	3,300	560,000	Monsanto, ABS resin
Japan Olefin	19,000 7,000	5,600,000	UOP, benzene to styrene Koppers, polystyrene
C. *Polypropylene from propylene:*			
Shin-Nippon Nitrogen	13,000	6,300,000	Bechtel International Corp.
Tokuyama Petrochemical	20,000	11,100,000	Own process
D. *Terephthalic acid (for making dacron) from p-xylene:*			
Mitsui Chemical	7,200	2,200,000	Scientific design
Teijin-Hercules	13,000	4,200,000	Hercules. Including DMT manufacturing

difficult, with high interest rates caused by the demand for funds. Profits on total capital are very low, but paying high dividends is a matter of prestige in Japan; this weakens the cash position of companies even when they have solid earnings. However, the Japanese Government recognizes the facts and is helping out with financing, giving tax breaks and providing other assistance. Most companies are finding new sources of financing from the money markets in the United States, Canada, and western European countries.

Table Y, a comparison of financial ratios, and table Z, a comparison of business ratios in 1966, made by the Industrial Structure Research Committee of Japan, give a clear picture of the financial structure of petrochemical industry in Japan:

Table Y. Comparison of financial ratios 1961

(Percentages)

	Sumitomo Chemical	*Du Pont*	*ICI*	*Bayer*	*Montecatini*
Profit on total capital	3.0	25.6	7.0	14.1	4.8
Turnover ratio of total liabilities and net worth (fold)	0.58	0.71	0.62	0.84	0.32
Profit on sales	5.2	36.1	11.2	16.7	13.6
Profit on paid-in capital	12.2	112.8	11.3	28.0	8.8
Equity capital *vs* borrowings	30.4	96.1	69.1	61.1	93.3

Table Z. Comparison of business ratios, 1961

	U.S.A. (11 firms) (percentage)	*West Europe (9 firms) (percentage)*	*General Chemical Mfg. Japan (4 firms) (percentage)*	*Petrochemical Mfg. Japan (5 firms) (percentage)*
Liabilities ratio	36.4	60.0	284.6	480.3
Current ratio	209.7	150.6	96.8	100.0
Equity to borrowings	74.0	63.0	30.0	17.6
Fixed assets turnover (times)	1.1	1.2	1.3	0.6
Total capital turnover (fold)	0.8	0.7	0.8	0.5
Profit on sales	19.2	14.8	6.4	8.6
Profit on total capital	14.6	10.8	4.8	4.0
Interest burden *vs* sales	0.6	1.3	6.4	13.3
Financing cost ratio	3.4	6.3	11.8	8.8
Productivity (value added: yen million)	9.6	4.7	4.1	9.9

VIII. Research and development

Japan has long been accustomed to adapting foreign technology for industrial development. The petrochemical industry forms no exception. Nearly all new techniques are foreign developments brought into Japan under licence. Every year a large sum of money has been spent by the petrochemical industry to obtain technical know-how from abroad, as shown in the following table

Year	*1957*	*1958*	*1959*	*1960*	*1961*	*1962*
Technical know-how fee in $	4,086,000	5,286,000	3,347,000	11,719,000	16,908,000	19,000,000

It is obvious that the introduction of foreign technology will accelerate the establishment of a modern petrochemical industry. However, Japan has to do its own research and development work in order to improve its international competitive power. It was reported that in 1960 Japan sold $4.8 million worth of its own technology to foreign countries.

The Statistics Bureau of the Prime Minister's office estimated that $930 million was spent on all research and development in 1962, approximately $600 million by industry, $200 million by universities and $130 million by other public and private research groups. This is about 2 per cent of the gross national product of Japan.

Petrochemical companies in Japan have led the move to construct big modern research laboratories. The following is an outline of their activities.

Sumitomo Chemical spends roughly 2 per cent of its annual $400 million sales on research. Besides having a plastic research laboratory at Niihama and a pharmaceutical laboratory in Nagoya, it plans to build a new laboratory in the Osaka area in 1965 for new polymer research and will employ 200 research workers.

Mitsubishi Chemical will open a new $US8.7 million central laboratory at Kawasaki early 1965. It will concentrate on chemical and petrochemical research, having a staff of 300 research workers and 450 technicians.

Toyo Rayon spent 3 per cent of sales, $16.6 million, on research in 1963. It has a central laboratory at Otsu and eleven others throughout the country. It has completed a basic research laboratory for polymer studies at Kamakura in 1962, costing $8.3 million.

Teijin spent 1.8 to 2.6 per cent of its sales for research in the past years. It plans to boost this to 3 per cent of its sales. A new central laboratory at Toyoda was established recently, having 385 research workers and 180 technicians. Another central laboratory for applied textile research will be completed in October 1964. It will have a basic polymer research laboratory in Tokyo with 30 research workers and 50 technicians.

Mitsui Chemical has a research laboratory in Tokyo with 150 research workers for developing new plastics, polypropylene and urethane, and for doing basic research on dyestuffs.

Showa Denko spent 1.3 per cent of its $180 million sales on research and development. It has a central laboratory in Tokyo with 366 research workers working on petrochemicals, fertilizers and metals.

Toyo Koatsu. This company spent about 3 per cent of its annual sales ($80 million in 1963) on research. It has a central laboratory at Yokohama, staffed by 100 research workers, and a plastic laboratory at Ofuna.

Major achievements in Japanese research on and development of the petrochemical industry are as follows:

(1) Toyo Rayon has developed a commercial process for the manufacture of caprolactam which is a raw material for making nylon-6.

It is known as the photochemical process. Cyclohexane is diffused with nitrosyl chloride and is treated with light energy in the 3,000 to 6,000 Angstrom range. The product is cyclohexanone oxime which is then converted to caprolactam by the conventional procedure. This is claimed to be more economical than the usual method.

(2) Toyo Koatsu completed the development of a total recycle urea process in 1958. This process employs the use of water as a means of recycling carbamate. Excess ammonia is used. Two stages of decomposition and absorption are used to produce concentrated carbamate solution for recycle. A major portion of the excess ammonia is removed at the first stage of absorption to reduce the amount of water returned to the autoclave. The ammonia is condensed and recycled for reaction. This process has not yet been employed by other producers.

(3) Professor Ichiro Sakurada of Kyoto University produced a synthetic fibre with properties nearly similar to those of cotton. It is polyvinyl alcohol fibre known commercially as vinylon. Kurashiki Rayon started to develop this process for commercial production in 1952. The starting raw material is acetylene which is converted into vinyl acetate and then polymerized. Polyvinyl acetate is hydrolyzed into polyvinyl alcohol, which is dissolved in solution and extruded through nozzles to form fibre. This fibre is treated with formalin or other aldehydes to form vinylon.

(4) Glutamic acid was formerly made by the hydrolysis of gluten from wheat flour. Kyowa Hakko Kogyo has been producing glutamic acid by the fermentation of starch since 1955 at a great reduction of cost. Ajinomoto invented in 1960 a synthetic method of manufacturing glutamic acid which uses acrylonitrile, a petrochemical product, as raw material. This process will be commercialized in the near future. It is the first petrochemical product to be used for food purposes. Recently, Tokyo University has been carrying out research to produce glutamic acid by the fermentation of kerosene using a strain of bacteria isolated from soil.

APPENDIX [illegible]

New refineries in the ECAFE countries

Company	Plant site	Project	Daily capacity	Estimated cost	Status	Probable completion	Licensor	Engineering	Contractor
Australia									
Amoco, Australia	Brisbane	Refinery	25,000 b/d	..	Engineering	1966	..	Kellogg	Kellogg
British Petroleum	Westernport	Refinery	30,000 b/d	..	Planning	Late 1965	..		
Burma									
Burmah Oil	Syriam	Crude distillation	350,000 gals	..	Under construction	Early 1966	..	Foster Wheeler	Foster Wheeler
India									
Indian Refineries	Barauni	Refinery	44,000 b/d	$55,000,000	Under construction	1966	Indian Govt.	Rumanian Govt.	Rumanian Govt.
	(Gujarat) Koyali	Crude distillation	40,000 b/d	..	Under construction	1966		Russian Govt.	
Oil and Natural Gas Commission (Indian Govt.) . . .	Near Baroda Gujarat	Refinery	40,000 b/d	..	Engineering	Late 1966	Indian Govt.	Giproneftezavod	Tyazhprom-Export
Iran									
National Iranian Oil	Tehran	Refinery	100,000 b/d	$115,000,000	Engineering	..	Cal Research	Cal Research Fluor/Snell	Fluor
Japan									
Toa Oil	Kawasaki	Crude distillation	40,000 b/d	$5,000,000	Engineering	Late 1966	..	JGC	JGC
Maruzen Oil	Sakai	Crude expansion	100,000 b/d	..	Planning	1966	..	Chiyoda	Chiyoda
Mitsubishi	Mizushima	Crude expansion	20,000 b/d	$700,000	Engineering	June 1966	.	Chiyoda	Chiyoda
Fuji Asia Oil	Yokohama	Topping	20,000 b/d	$2,540,000	Engineering	..	..	JGC	JGC
Nippon Petroleum Refining .	Negishi	Crude	110,000 b/d		Under construction	March 1966	..	Chiyoda	Chiyoda
Osaka Gas	Osaka	Hydrofining	5,071 tons/month	..	Under construction	...	BASF/Scholven	Heinrich Koppers	Heinrich Koppers
		Crude distillation	5,071 tons/month	...	Under construction	..	Heinrich Koppers	Heinrich Koppers	Heinrich Koppers

Showa Oil	Niigata	Crude	40,000 bbls	…	Complete	…	[illegible]	[illegible]/Staff Chiyoda	Chiyoda
Showa Yokkaichi Sekiyu	Yokkaichi	Crude distillation	12,000 bbls	…	Under construction				
Showa Yokkaichi Sekiyu	Niigata	Exp. refinery: crude distillation	35,000 bbls	…	Complete	…	…	…	…
Toa Nenryo	Wakayama	Distillation	70,000 bbls	…	Planning	July 1966	…	Staff	…
Korea, Republic of									
Korean Oil	Near Ulsan City	Refinery	35,000 bbls	$16,000,000	Complete	…	…	Fluor	Fluor
Malaysia									
Esso Standard	Port Dickson	Refinery	24,500 bbls	$13,000,000	Under construction	…	Esso	Parsons	Parsons
[illegible] refining	Singapore	Refinery	[illegible] bbls	$12,000,000	Engineering	Early 1966	…	…	…
Shell refining (Malaya)	Port Dickson	Refinery	[illegible] bbls	…	Under construction	…	…	[illegible]	[illegible]
New Zealand									
New Zealand Refining (BP, Caltex, Europa, Shell, Mobil)	Whangarei	Crude distillation, cat reforming, gas-oil desulfurization, bitumen	35,000 bbls	…	Under construction	Mid 1964	…	Bechtel	Bechtel
Thailand									
Thai Oil Refinery	Sriracha, near Bangkok	Refinery	35,000 bbls	$30,000,000	Under construction	Aug. 1964	Shell/UOP	Procon	Procon
Viet-Nam, Republic of									
Viet-Nam Refining	Nha Trang	Refinery	24,400 bbls	$16,000,000	Engineering	Oct. 1965	Esso	…	…

APPENDIX C

New petrochemical plants in the ECAFE region

TYPE OF PLANT							
Company	*Plant site*	*Annual capacity (tons)*	*Estimated cost*	*Status*	*Probable completion*	*Licenser*	*Remarks*
			Ammonia				
Australia							
ICIANZ	Botany, NSW	50,000	...	Engineering	Early 1964	ICI	
Burma	Chauk	60,000	...	Planning	...	...	
Ceylon	...	63,000 N	...	Planning	...	...	Ammonium sulphate
China (Taiwan)							
1. China National Technical Import	...	...	$20.4 mn	Engineering	...	...	
2. Mobil China Allied Chemical Industries Ltd	Miao Li	106,000	$24 mn	Complete		Allied Chemical	With 100,000 ton/yr urea
India							
1. Fertilisers and Chemicals Travancore	Alwaye, Kerala State	154 t/d	$20 mn	Engineering	Dec. 1964	Power Gas/British Oxygen/Dorr-Oliver	With ammonium sulphate 330 ton/d, ammonium phosphate 300 ton/d
2. Fertilizer Corp. of India	Rourkela	514 t/d		Under construction		Uhde	
3. E. I. D. Parry with (California Chem. Co., International Minerals and Chem. Corp.)	Madras	50,000	$30 mn	Approved by Government	1963	...	Fertilizer
4. Fertilizer Corp. of India	Alwaye, Kerala State	66,000 N	...	Planning	End 1963	...	
	Ankleshwar Gujarat State	90,000 N	...	Planning	End 1963	...	
	Gorakhpur U. P.	80,000 N	...	Under construction	End 1963	...	
	Namrup,	80,000 N	...	Under construction	End 1963	...	Urea
	Assam State	30,000 N	...	Under construction	End 1963	...	Ammonium phosphate
	Trombay	90,000 N	...	Under construction	End 1963	...	
5. Gujarat State Fertilizer Co., Ltd.	Koyali, near Baroda	80,000 N	...	Under construction	Aug. 1966	...	
Indonesia							
Indonesian Government	Palembang, Sumatra	46,000 N	$30 mn	Complete	1963	...	Urea
	Surabaja	31,500 N	...	Planning	...	...	
		20,700 N	...		...	...	
Iran		150,000	...	Under construction	...	...	
Korea, Republic of							
Korean Government	Naju	95,000	...	Under construction	...	Inventa	Urea
Malaysia							
Standard-Vacuum Oil Co., Ltd	...	...	$30 mn	Planning	...	...	As part of a planned refining - petrochemical installation

PAKISTAN	...	300 t/d	...	Approved by Government	...		...	
PHILIPPINES								
1. Esso Standard Fertilizer and Chemicals Inc. (Philippines)	Bataan	100,000	$30 mn	Planning	1965		...	Together with urea — 67,500 and mixed fertilizer — 320,500 tons per year
2. Marinduque Iron Mines Agents, Inc	Mindanao	...	$23 mn	Planning	...		...	Urea and ammonium sulphate
THAILAND								
Government of Thailand	...	12,400 N 13,000 N	...	Engineering	1966		...	Ammonium sulphate/urea
VIET-NAM (REPUBLIC OF)								
Industrial Komplex An-Hoa Nong Son	Anhoa	36,000	...	Engineering	Mid-1966		Uhde	...

Company	*Plant site*	*Annual capacity (tons)*	*Estimated cost*	*Status*	*Probable completion*	*Licensor*	*Engineering*	*Contractor*
				Ethylene				
INDIA								
1. Esso Standard Eastern	Trombay	100,000	...	Government approved	...	...	...	Ethylene, propylene, butylene, butadiene, benzene, etc.
2. Mafatlal Group (National Organic Chem. Ind.)	Trombay	60,000	...	Planning	...	...	...	
JAPAN								
1. Idemitsu	Tokuyama	100,000	...	Engineering	Sept. 1964	...	...	
2. [illegible] Petrochemical	[illegible]	...	...	Under construction	...	...	...	
3. Maruzen Oil	Goi	44,000	...	Planning	...	...	...	
4. Mitsubishi	Mizushima	43,100	...	Planning	Mar. 1964	...	...	
5. Mitsubishi Chem. Ind.	Mizushima	30,000	...	Under construction	1964	...	...	
6. Mitsubishi Petrochemical	Yokkaichi	...	...	Engineering	1964	...	S & W	
7. Mitsui Petrochemical Industries	Near Tokyo	200,000	...	Planning	1971	...	...	
8. Nippon Petrochemicals	Kawasaki	60,000	...	Engineering	1965	S & W	JGC	JGC
	Kawasaki	30,000	...	Under construction	Early 1964	S & W	JGC	JGC
9. Nippon Soda	Chiba Prefecture	13,000 to 26,000	...	Planning	...	SD	SD	...
				Planning	...	...	...	...
10. Sumitomo Chem. Co. Ltd.	[illegible] District	120,000	...	Planning	...	...	...	...
11. Tonen Petrochemicals	Kawasaki	40,000	...		...	...	...	...
12. Ube Kosan	Goi	21,000	...	Planning		Rexall	...	...

APPENDIX C (*continued*)

New petrochemical plants in the ECAFE region (*continued*)

TYPE OF PLANT

Company	*Plant site*	*Annual capacity (tons)*	*Estimated cost*	*Status*	*Probable completion*	*Licensor*	*Engineering*	*Contractor*
				Propylene				
Japan								
1. Idemitsu Kosan Co. Ltd.	Tokuyama	56,000	...	Planning	Mar. 1964	...	...	...
2. Maruzen Oil Co. Ltd.	Goi	22,000	...	Planning	...	...	...	...
3. Mitsubishi Kasei Co. Ltd.	Mizushima	33,200	...	Planning	Mar. 1964	...	...	...
4. Mitsui Petrochemical Industries Ltd.	Near Tokyo	160,000	...	Planning	1971	...	...	...

Company	*Plant site*	*Annual capacity (tons)*	*Estimated cost*	*Status*	*Probable completion*	*Licensor*	*Remarks*
				Acetylene			
Japan							
1. Kureha Petrochemical	Nishiki	...	...	Under construction	...	Research Association of Polymer Raw Materials	
2. Mitsubishi Chem. Ind	Niigata	11,000	...	Under construction	1964	BASF	
3. Mitsubishi Kasei Co. Ltd	Mizushima	—	...	Planning	1963	BASF	
4. Shin-etsu Petrochemical	...	15,000	...	Planning	...	Montecatini	
				Butadiene			
India							
1. Firestone Tire and Rubber	Bareilly	23,000	$30 mn	Under construction	...	Union Carbide	
Japan							
1. Idemitsu Kosan	Tokuyama	19,000	$2 mn	Engineering	End 1964	UOP	
2. Japan Synthetic Rubber	Yokkaichi	5,000	...	Under construction	...	ESSO	
3. Nippon Petrochemicals	Negishi	...	...	Engineering	...	Pan American	
4. Tonen Petrochemicals	Kawasaki	7,000	$25 mn	Under construction	...	ESSO	
Japan							
Idemitsu Kosan Co., Ltd.	Tokuyama	*Benzene* 13,900 tons/yr *Toluene* 10,600 tons/yr *Xylenes* 9,800 tons/yr		Planning	Mar. 1964	...	

Ethyl benzene

Japan								
Kohgo Chem. Ind.	Kawasaki	21,000	...	Engineering	...	UOP		

Vinyl chloride

India								
1. Chemical and Plastics India Ltd.	Mettur	6,000 PVC	$7 mn	Planning	Late 1964	...	...	B.F. Goodrich will provide technical and financial assistance
2. Dharangadhra Chemicals Ltd .	Tuticorin	16,000	...	Planning	...	...	...	
3. Mafatlal Group (National Organic Chem. Ind.)	Trombay	6,000 PVC	...	Planning	...	...	...	
Japan								
1. Kureha Petrochemical	Nakoso City	30,000	$7.778 mn	Under construction	Feb. 1964	Research	Chiyoda	Chiyoda
2. Mitsui Chemical Co.	Nagoya	...	...	Engineering	1964	Hoechst/Goodrich	Uhde	Uhde
3. Nippon Carbide	...	...	...	Planning	...	Hoechst/Goodrich	Uhde	Uhde
4. Sumitomo Chemical Co. Ltd. .	Shizuoka Pref.	18,000	...	Planning	...	...	...	...
Korea, Republic of								
Lucky Chem. Co. and Dae Han Life Insurance Co	...	4,000 PVC	...	Planning	1964	...	...	Blaw-Knox to design and engineer
Pakistan								
Hyesons Commercial and Industrial Corp. with Rino-G.D. Khalid and Co	...	4,950 PVC	...	Planning	...	...	...	...
Philippines								
Philippines Industrial Chemical Co	Rizal province	8,000 PVC	...	Planning	...	B.F. Goodrich Chemical Co process	...	...

Polyethylene

Australia								
1. Union Carbide	Melbourne	15 mn lb	$6.5 mn	Under construction	...	...	...	...
2. Farbwerke Hoechst A.G. .	...	10,000	$10 mn	Planning	1965	...	...	...
3. Imperial Chem. Ind. of Australia and New Zealand Ltd	Near Clyde	5,000	$5 mn	Planning	1963		Expansion to 5,000	...
India								
1. A.C.C.I.	Rishra	10,000	$6.5 mn	Under construction	...	...	...	...
2. Union Carbide of India Ltd. .	Trombay	11.5 mn lb.	...	Planning	...	...	Expansion	...
3. National Carbon Co. of India .	Bombay	5,500	...	Planning	1966	...	Expansion	...
4. Mafatlal Group (National Organic Chem. Ind.).	Trombay	15,000	...	Planning	...	...	...	...
Japan								
1. Asahi-Dow	Kawasaki	25,000	...		Oct. 1963	SD	SD	SD
2. Furukawa Chem. Ind. Co. Ltd.	Kawasaki	7,000	...	Expansion	Early 1964	Standard Indiana	..	...

APPENDIX C *(continued)*

New petrochemical plants in the ECAFE region *(continued)*

TYPE OF PLANT

Company	*Plant site*	*Annual capacity (tons)*	*Estimated cost*	*Status*	*Probable completion*	*Licensor*	*Engineering*	*Contractor*
			Polyethylene (continued)					
3. Mitsubishi Petrochemical . . .	Yokkaichi	30,000	...	Under construction	...	BASF	BASF Mitsubishi Chemical Machinery	Mitsubishi
4. Nippon Olefin Chem. Co. . . .	Kawasaki	12,000	...	Planning	Sept 1963	...	...	...
5. Sumitomo Chem. Co. Ltd. . . .	Shizuoka Prefecture	46,000	...	Planning	...	...	...	...
6. Ube Kosan	Goi	20,000	...	Planning	...	Rexall	...	...
PAKISTAN								
Mansoor Chem. & General Industries	...	5,000	...	Planning	1965	...	...	...

Company	*Plant site*	*Annual capacity (tons)*	*Estimated cost*	*Status*	*Probable completion*	*Licensor*	*Remarks*
			Polystyrene				
AUSTRALIA							
H. H. York & Co. Pty. Ltd. (BASF)	Altona, Victoria	...	...	Planning	...	...	
INDIA							
Shree Ram Mills Ltd	...	...	...	Planning	...	...	Technical assistance to be provided by Distillers Co. Ltd. and UOP
JAPAN							
1. Denki Kagaku	Chiba	12,000	$2.8 mn	Engineering	1964	...	
2. Dai Nippon [illegible] Co. Ltd . .	Osaka	12,500	...	Planning	...	...	
3. Furukawa Chem. Ind.	Kawasaki	7,000	...	Under construction	...	...	
4. [illegible] Kagaku	Chidoricho	...	...	Under construction	...	...	
5. Sekisui Chem. Co.	[illegible]	20,000	...	Planning	End. 1965	...	
6. Sumitomo Chem. Co. Ltd. . .	Shizuoka Pref.	10,000	...	Planning	Jan. 1965	...	
			Polypropylene				
INDIA							
West Polymers Work	Trombay	21 mn lb.	...	Planning	...	...	
JAPAN							
1. Ube Kosan	Goi	5,000	...	Planning	...	...	
2. Shin Nippon Nitrogen Co. Ltd. .	Goi	13,000	...	Planning	...	...	Avisun Coys will provide technical assistance
3. Sumitomo Chem. Co. Ltd. . . .	Shizuoka Pref.	20,000	...	Planning	...	...	

				Synthetic rubber			
INDIA							
Firestone Tire & Rubber	Bareilly	30,000	...	Under construction	...	Staff	
JAPAN							
1. Japan Synthetic Rubber	Yokkaichi	5,000 SBR	...	Engineering	...	...	Expansion
		20,000 butyl rubber	...	Planning	...	...	
		20,000 cis-polybutadiene	...	Engineering	...	...	
2. Nippon Geon Co. Ltd	Kawasaki	Stereo rubbers	...	Planning	...	...	
3. Sumitomo Chemical Co. Ltd . .	Shimane Pref.	15,000 ethylene-propylene rubber	...	Planning	...	...	
4. Ube Kosan	Ube	6,000 t/yr. ABS resin	...	Planning	...	Marbon Chem.	
				Carbon black			
INDIA							
1. Phillips Carbon Black	Durgapur	30 mn lb.	...	Under construction	...	Phillips Petroleum	
2. United Carbon	Bombay	30 mn lb.	$3.5 mn	Planning	Late 1965	United Carbon	
3. P.I.B. Ind	Naharkatiya	10,000	...	Planning	1963	...	Technical assistance from Continental Carbon
INDONESIA							
P. T. Permina	Rantau	...	$4 mn	Planning	...	...	
JAPAN							
1. Japan Synthetic Rubber	Yokkaichi	13,000	...	Planning	Mar. 1964	...	
2. Showa Denko Co. Ltd.	Kawasaki	6,000	...	Planning	...	...	Expansion
3. Toyo Continental Carbon Ltd .	Yokoshiba	9,000	...	Planning	...	...	Expansion
PAKISTAN							
Pakistan Petroleum Ltd.& Commack International Methane Ltd. (Sui Carbon Co. Ltd.)	West Pakistan	300,000	$5 mn	Planning	...	...	
				Methyl methacrylate			
JAPAN							
Delta Plastics	Kawasaki	6,000	...	Engineering	July 1964	Kyowa Gas Chem.	
				Sulphur recovery			
JAPAN							
1. Koa Oil	Marifu	10 t/d	$320,000	Under construction	Early 1964	...	
2. Nippon Petroleum Refining . .	Negishi	11 t/d	...	Engineering	April 1964	...	
3. Toa Nenryo	Shimizu	10 t/d	...	Under construction	...	...	
4. Mitsubishi Oil	Mizushima	70.5 t/d	$692,000	Planning	1965	...	

SOURCES: 1. *World Petroleum* (15 July 1963); 2. *Petroleum Refiner* (January 1964); 3. *European Chemical News Ethylene Supplement* (19 June 1964).

2. DEVELOPMENT OF THE PETROCHEMICAL INDUSTRY IN EUROPE: ITS PROBLEMS AND POTENTIALITIES

Secretariat of the Economic Commission for Europe

BRIEF REVIEW OF THE ORIGIN OF THE PETROCHEMICAL INDUSTRY IN EUROPE

Petrochemistry developed much later in Europe than in the United States. The most important reasons for this slower development are: in the reconstruction problems which arose immediately after the Second World War; the time-lag in technological progress, the policy of the oil companies of locating the refineries near oil or natural gas reserves in order to avoid adding transport costs to the heavy capital costs; and the well-developed chemicals-from-coal industry which was then less expensive because of the existence of rich coal resources. Consequently, during the inter-war period the production of chemicals from petroleum and natural gas in Europe was negligible, serving chiefly the needs of the automobile industry with new surface coatings, paint, anti-freeze compounds and anti-knock additives.

In fact, the development of a significant petrochemical industry depends on the availability of low-cost hydrocarbons accompanied by an industrial environment capable of supplying the other raw materials required (such as chlorine, sulphuric acid, etc.), technical knowledge and large chemical processing industries, which are the primary markets for petrochemical products. Moreover, being pre-eminently an industry of synthetics, it reflects in the highest degree the country's scientific and technological progress, its industrial potential and its availability of investment funds.

At the end of the Second World War nearly all European countries were still dependent for their organic chemical products on coal and vegetable matter. Just before the war 90 per cent of German organic chemicals were derived from tars and gases, obtained mainly as a by-product of coke produced for industrial uses. The United Kingdom was still dependent on coal carbonization for its aromatics; on fermentation (mainly of molasses) for aliphatics; on coke for synthesis gas; and on calcium carbide for acetylene. The Italian chemical industry derived its chemical products from air, water, salt and pyrites, and Sweden produced a limited range of inorganic and organic chemicals from her natural resources of iron ore, water power and timber.

Up to 1949, the United Kingdom was the only country in western Europe producing its chemical products from oil, only subsequently increasing its activity with the installation of three units of carbon black. At about the same period, a certain activity in this field was to be observed in France, Italy, the Netherlands, and, a little later, in the Federal Republic of Germany.

Thus, before the 1950s, most of the refineries were located outside western Europe but afterwards it became the policy for most western European countries to locate oil-refining capacity in the major consuming areas. This resulted in a vast expansion of western Europe's capacity and drew attention to the possibility of domestic chemical production, chiefly to meet the tremendous increase in demand for synthetic rubbers and plastics.

Organic chemical production spread all over western Europe, while the availability of raw materials from coal grew less rapidly, mostly owing to difficulties of exploitation and to the consequent very high cost of production. This shortcoming in most countries was mitigated by the petroleum industry. From 1955 to the end of 1960, 80 per cent of the organics capacity of the Federal Republic of Germany was based on oil and natural gas which in 1960 fed 50 per cent of the entire organic production of the Federal Republic compared with only 18 per cent in 1955. In the United Kingdom, petroleum was responsible for most of the increased production of organic chemicals, furnishing almost 50 per cent of total raw material requirements in 1959. In France, the successful prospecting and development of the Lacq natural gas field and the exploitation of Sahara oil and gas lent extraordinary impetus to the petrochemical industry. In 1959 petrochemicals accounted for 50 per cent of French organics production. In Italy, ever since the discovery and development of natural gas in the Po Valley region in 1953, this raw material has played an important role in this country's chemical production. Indeed, by 1960, natural gas provided 36 per cent of the industry's feedstocks, and production of petroleum chemicals based on natural gas amounted to 60 per cent of total organics production. In the Netherlands, gas was first discovered in 1948 but it was only in 1959, with the exploitation of substantial deposits at Slochteren, that petrochemical production began to increase so rapidly, soaring from 1,000 tons in 1948 to 325,000 tons in 1962.

Each of the foregoing countries constitutes a large consumer market, and reserves of some of them are such as to enable a wider development of the petrochemical industry. In addition, their economic conditions — the rate of economic expansion, the level of technology and skill, the financial resources — have facilitated the petrochemical boom of recent years.

Sweden may be cited as an interesting example of a country which has developed a petrochemical industry despite a lack of domestic raw materials and the smallness of the home market. After the war, the demand for organic chemical products called for more organic raw materials than could be supplied from cellulose-derived sources. This resulted in a great increase in imports of many basic petrochemicals. By 1963, however, Sweden's first petrochemical complex went into operation, with a capacity of about 25,000 tons of ethylene.

It was towards the end of the 1950s that the socialist countries of eastern Europe became actively interested in developing a petrochemical industry. The USSR, rich in oil and natural gas resources, went into production in early 1950. The cracking capacity of the refining units showed a fourfold increase between 1951 and 1956, thus providing an important basis for expanded petrochemical production. Romania, with larger hydrocarbon resources than the other eastern European countries, set up its petrochemical industry as early as in 1949; real progress took place, however, only after 1955. So far, owing to a lack of petroleum and natural gas resources, Czechoslovakia, Eastern Germany, Hungary and Poland have continued to develop their chemicals-from-coal industry. At the same time, thanks to supplies of oil from the USSR, and the construction of the CMEA (Council for Mutual Economic Assistance) pipeline, they are rapidly developing their petrochemical industry, especially to meet their requirements in fertilizers.

The rapid switch from coal to oil and natural gas, which took place in Europe's chemical industry during the last decade, resulted partly from the fact that coal had become too expensive to compete with the growing petrochemical industry of the United States, and partly from the more abundant and regular supply, and hence more stable prices, of hydrocarbons.

STRUCTURE OF THE PETROCHEMICAL INDUSTRY IN EUROPE

The close interrelation between development of the petrochemical industry, industrial development and technological progress is clearly apparent in the experience of the European countries.

The most rapid strides in the petrochemical industry have taken place in the highly industrialized countries, it being only now that the developing countries, such as Spain, Portugal and Greece, are beginning to build their petrochemical plants. Table 1 gives the status of plants existing, under construction or planned in western Europe in 1963.

For this industry, raw materials are not the most important problem; these are abundant and less expensive and of less economic significance than in the chemical industry based on coal. In fact, petrochemical units, which are highly capital intensive on account of the technical complexity of the processes and the high level of automation and chemical engineering, are largely governed by the consideration of "minimum economic size", which assumes particular importance for the capital cost of, for example, maintenance and depreciation. This, in turn, is a substantial factor in the cost of the finished product.

TABLE 1. PLANTS EXISTING, UNDER CONSTRUCTION OR PLANNED IN WESTERN EUROPE, 1963

Country	*Existing plants*	*Plants under construction or planned*
Austria	5	—
Belgium	7	3
Denmark	4	1
Finland	1	—
France	67	7
Germany, Fed. Rep. of	29	9
Greece	1	2
Italy	31	9
Netherlands	19	8
Portugal	6	—
Spain	5	6
Sweden	3	1
Switzerland		1
United Kingdom	41	12
Yugoslavia	8	1
TOTAL	227	60

SOURCE: *Oil and Gas Journal*, Tulsa (Okla.), (2 September 1963), p. 100.

In determining a plant's optimum size, the consideration to take into account is whether or not the plant is likely to operate at maximum capacity. By way of an example, table 2 lists the costs for the production of hydrogen from naphtha in three units of different capacity.

From these calculations it appears clear that the cost of production is relatively unaffected by the cost of raw materials. The largest unit, spending five times more than the smallest, has a production cost per unit of one-

TABLE 2. COSTS FOR THE PRODUCTION OF HYDROGEN IN THREE UNITS OF DIFFERENT CAPACITY

Item	*Unit 1 (50,000 tons p.a.)*	*Unit 2 (25,000 tons p.a.)*	*Unit 3 (10,000 tons p.a.)*
Investments	$US 6,700,000	$US 4,560,000	$US 2,880,000
Raw materials	683,000	341,000	136,000
Utilities	1,075,000	537,500	215,000
Labour	240,000	209,500	160,100
Fixed charges ᵃ	1,339,500	865,000	554,600
TOTAL	3,337,500	1,953,000	1,065,700
Production cost ($US/ton)	66.8	78.2	106.6

SOURCE: Lapinas: "The Petrochemical Industry", Seminar paper No. 21, United Nations Interregional Seminar on Techniques of Petroleum Development, United Nations, N.Y., 23 January to 21 February 1962.

ᵃ 10 per cent annual depreciation.

TABLE 3. COSTS FOR THE PRODUCTION OF HYDROGEN CYANIDE (FROM AMMONIA AND NATURAL GAS)

Capacity (tons p.a.)	*Investment costs (thousand $US)*	*Investment costs p.a per ton produced ($US)*
4,539	780	171.8
9,070	1,300	143.3
11,337	1,500	132.3
22,675	2,440	107.6
45,400	3,900	85.9

SOURCE: Isard, Schooler *and* Victorisz, "Industrial Complex Analysis and Regional Development," M.I.T., Wiley, 1959.

third less. It will also be seen from table 3 that in order to be competitive, petrochemical units must obtain a considerable capacity.

It is believed, in fact, that the minimum production capacity should be 50,000 tons for synthetic rubbers, 20,000 tons for butadiene rubber and 20,000 to 25,000 tons for carbon black.

As may be seen from the petrochemical complexes of Ravenna (Italy), Lacq (France) and the Rhineland (Federal Republic of Germany), a characteristic of this industry is its high degree of geographical concentration near sources of raw materials and power (iron and steel, electrochemical complex), or water for transportation, processing and cooling uses, or major consuming centres.

There is also considerable concentration of capital. In countries other than the Socialist countries of eastern Europe a very great impact was made on the development of petrochemical industry in the form of investments by the petroleum industry. Originally, in fact, petroleum-based chemicals were derived from the waste products of the petroleum industry which, at the time, was the sole supplier of raw materials for chemical manufacturing. Even now, petroleum companies are often active in the field of chemical research; they provide chemical companies with much of their raw materials, sometimes operating jointly with them. Indeed, there is a strong tendency towards vertical integration from production to marketing in order to eliminate the losses entailed by separate operations and to gain economies of scale. Investments and the rate of obsolescence being extremely high, strong vertical integration is essential as a protection against competition, both domestic and foreign. It provides for a more rapid and economic diversification and it ensures adequate sources of raw materials as well as outlets for sales. This concentration of capital is to be found in fact in the most important producer countries of western Europe. In the Federal Republic of Germany, 75 per cent of petrochemical production comes from only five companies, two of them combined with oil companies. In the United Kingdom, about 25 per cent is in the hands of the Imperial Chemical Industries. In Italy, the industry is largely controlled by three firms, Montecatini, Anic and Edison, and their subsidiaries and joint ventures. Even in France, where the most striking feature of the petrochemical industry is its apparent dispersal, most of the basic feedstocks are supplied by five firms only.

Heavy investments are necessary not only for fixed assets but also for the research required to keep pace with technological progress.

Within the context of world capital expenditures in the domain of oil for the period 1953-1962, the chemical sector showed the highest increase (341 per cent), while still accounting for a relatively small proportion (3 per cent) of the total. It should be noted that China (mainland), the USSR and the socialist countries of eastern Europe are not included.

TABLE 4. WORLD[a] CAPITAL EXPENDITURES IN THE DOMAIN OF OIL FOR THE PERIOD 1953-1962
(Millions US dollars)

Item	*Production*	*Refinery*	*Marketing*	*Marine*	*Pipelines*	*Chemical plants*	*Other*	*Total*
United States								
United States dollars	42,135	6,175	4,755	785	2,660	1,540	1,225	59,275
Percentage	71	10	8	1	5	3	2	100
Rest of the world								
United States dollars	17,310	8,145	7,585	8,740	2,655	1,420	1,045	46,900
Percentage	37	17	16	19	6	3	2	100
World total								
United States dollars	59,445	14,320	12,340	9,525	5,315	2,960	2,270	106,175
Percentage	56	13	12	9	5	3	2	100
Rate of increase in annual expenditures over the decade	27 %	2 %	145 %	57 %	71 %	341 %	66 %	47 %

SOURCE: *Oil Today (1964)* OECD, Paris 1964, page 91.

[a] Excluding China (mainland), the USSR and the socialist countries of eastern Europe.

At the end of 1962, chemical plants accounted for 3 per cent investments in gross fixed assets in countries other than the United States, and, in the latter country, 4 per cent, as is illustrated in table 5.

TABLE 5. WORLD[a] INVESTMENTS IN THE DOMAIN OF OIL IN GROSS FIXED ASSETS AT THE END OF 1962
(Million US dollars)

Item	*United States*	*Per cent*	*Other countries*	*Per cent*	*World*	*Per cent*
Production	39,225	61	17,075	31	56,300	47
Pipelines	4,170	6	3,360	6	7,530	6
Marine	1,135	2	10,830	20	11,965	10
Refineries	8,895	14	10,610	19	19,505	17
Chemical plants	2,340	4	1,745	3	4,085	3
Marketing	6,900	11	10,190	19	17,090	15
Other	1,620	2	1,325	2	2,945	2
TOTAL	64,285	100	55,135	100	119,420	100

SOURCE: *Oil Today (1964)*, OECD, Paris 1964, page 90.

[a] Excluding China (mainland), the USSR and the Socialist countries of eastern Europe.

Specific investments in petrochemicals have increased considerably in some European countries but do not yet constitute an appreciable proportion of total industrial investments.

In France, for instance, at the end of 1954, total investments amounted to $US 33 million and, at the end of 1961, to $US 251 million, i.e., they increased almost eightfold. In Italy and the Federal Republic of Germany, petrochemical investments rose during the same period from $US 44 million to $US 348 million and from $US 68 million to $US 523 million, respectively, again an almost eightfold increase. In Italy, the proportion of the petrochemical sector from 1955 to 1960 in total chemical investments rose from 11.3 per cent to 30.7 per cent, while the proportion of chemicals investments in total industrial investments changed very slightly from 12.3 per cent to 14.5 per cent. In the United Kingdom, investments jumped from $US 122 million to $US 461 million — almost four times as high.[1] For the other western European countries, the investments have been less significant. At the end of 1960, they amounted to only $US 23 million in the Netherlands, and to $US 17 million in Belgium.[2]

It is estimated that in western Europe these investments will increase substantially — to about $US 3 billion — when the sixty new projects under construction or planned are completed.

So far as eastern Europe is concerned, the relevant data are available for Eastern Germany only, where a marked increase was reported for the period 1958 to 1962. At the end of 1958, the petrochemical sector accounted for $US 177 million (14 per cent of total industrial investments) and, at the end of 1962, for $US 395 million (about 22 per cent).[3]

The breakdown by country is as follows:

TABLE 5 A. ESTIMATES OF PETROCHEMICAL INVESTMENTS, END OF 1964
(Million US dollars)

Country	*1964*	*Percentage increase over 1961*
Austria	10	—
Belgium	49	40.0
France	430	69.3
Germany, Fed. Rep. of	723	38.2
Italy	925	165.8
Netherlands	103	415.0
Spain	20	—
Sweden	48	—
United Kingdom	632	37.1
TOTAL	2,940	

SOURCES: Peter W. Sherwood; "Petrochemicals" *World Petroleum*, New York, June 1963; *Oil and Gas Journal*, Tulsa (Okla.), 2 September 1963.

But it can be affirmed that, in these countries also, investments in the petrochemical industry will increase. The national economic development plans place great emphasis on the development of the chemical industry, concentrating mainly on fertilizers, pharmaceuticals and plastics and synthetic rubber production.

RAW MATERIALS

The original basis for petroleum chemical manufacture was the streams of olefin-rich gas from refinery cracking operations. Indeed, petrochemicals have always depended closely on the waste products of oil refineries.

The wider use of natural gas as a chemical raw material, and in particular its application to the manufacture of

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[1] Data assembled from the various numbers of the annual report, Chemical Industry in Europe, OECD, Paris.

[2] *Petrochimie Paris*, 1960.

[3] *Wochenbericht Deutscher Institut für Wirtschaftsforschung*, 1963, vol. 30, No. 25, pp. 115 and 116.

ammonia, followed closely upon the utilization of refinery gases. But while these two sources supply an overwhelming proportion of raw materials for the petrochemical industry in the United States, the European pattern has evolved somewhat differently.

Both natural gas and refinery gases lack flexibility as raw materials. Since the production of refinery gases is geared to the requirements of petroleum products, the producers of chemicals from these sources can never be sure that it will expand as fast as the market for chemicals. Natural gas, on the other hand, has so far been available in very limited quantities only. Therefore, the recent discovery of important natural gas fields in Italy, France and the Netherlands gave to this source major commercial significance. Table 6 shows the different costs of producing acetylene from calcium carbide (its traditional raw material) and from hydrocarbons.

A more recent but important development in natural gas processing is the SBA-Kellogg process. This is attracting a lot of attention because it may be adapted to the co-production of acetylene and ethylene which offers many economic advantages. In the Socialist countries of eastern Europe there is a trend to build acetylene-from-natural gas plants and to utilize the by-product tail gases for ammonia production. A third source of petroleum chemical raw materials in western Europe has been developed in the cracking units; these are separate from the refineries and are especially designed to procure high proportions of olefinic gas streams from liquid hydrocarbon fractions in the range of naphtha to gas oil.

Since in western Europe petrol consumption averages about 20 per cent of the total demand for petroleum products, there is a substantial surplus of naphtha available. This fact has stimulated its use as a petrochemical feedstock and as a raw material for town-gas production. Table 7 shows the demand for petrol as a percentage of total demand for petroleum products.

From these figures, it is evident why in many countries the cracking of naphtha has become the most common process for obtaining the basic petrochemical materials.

The cracking of naphtha results in ethylene and higher olefins. Pyrolysis of naphtha is of interest to firms able to use propylene and butylene by-products. The new ICI process for producing synthesis gas from naphtha for ammonia production is one of the most outstanding petrochemical developments of recent years, because it does not require an oxygen plant. This process is of interest to those countries disposing of large quantities of naphtha and little natural gas, or able to obtain natural gas only at a high price.

There are also processes whereby acetylene can be obtained from naphtha, for example, in the Imperial Chemical Industries (ICI) plant being built in the United Kingdom, and the plants in the Federal Republic of Germany, which at the same time produce ethylene. In order to produce acetic acid, the Distillers Corporation in the United Kingdom has developed a process for the direct oxidation of naphtha. The naphtha steam-reforming process has, in addition, accelerated the trend away from coal in the production of town gas. This trend is most apparent in the United Kingdom but is also seen in the Federal Republic of Germany where the plants for this purpose are under construction.

TABLE 6. COSTS OF PRODUCING ACETYLENE
($US per ton)

Capacity of the plant (tons/year)	*Cost per ton (from calcium carbide)*	*Cost per ton (from hydrocarbons)*
9,000	297.08	[illegible]
20,000	286.08	[illegible]
40,000	275.97	197.00

SOURCE: *Chemical Engineering Progress*, New York No. 11,20 (1964).

TABLE 7. CONSUMPTION OF PETROL IN WESTERN EUROPE 1962
(Thousands of barrels)

Country	*Petrol*	*Total products*	*Petrol per cent*
Austria	6,368	27,642	23
Belgium-Luxembourg	13,510	77,801	17
Denmark	11,096	52,395	21
Finland	3,790	25,395	15
France	56,134	268,962	21
Germany, Fed. Rep. of	60,661	298,325	20
Greece	[illegible]	34,310	10
Iceland	2,297	2,478	12
Ireland	3,006	13,107	23
Italy	37,282	243,673	15
Netherlands	10,892	141,331	8
Norway	5,368	29,263	18
Portugal	2,102	14,964	14
Spain	6,529	43,080	15
Sweden	19,092	107,763	18
Switzerland	8,904	35,480	25
Turkey	4,373	16,764	26
United Kingdom	86,175	413,305	21
Yugoslavia	2,702	12,080	23

SOURCE: *World Petrochemical Report*, Noyes Research Company, New York, 1964.

SOME PETROCHEMICAL INTERMEDIATES AND THEIR MOST IMPORTANT INDUSTRIAL APPLICATIONS

It is proposed here to give only an indication of the influence of petroleum raw materials on an already flourishing chemical industry based mainly on coal.

Ethylene is the most important of lower olefins from the point of view of scale of operation and variety of products. Capacity in western Europe, at present around 2 million tons, should reach almost 4 million tons by 1966. Consumption will continue its rapid growth owing to the demand for polyethylene, styrene monomer and vinyl chloride, its most important outlets. Table 8 shows the consumption of ethylene according to end-use in these countries.

TABLE 8. CONSUMPTION OF ETHYLENE ACCORDING TO END-USE, 1960

Product	United Kingdom		France		Germany, Fed. Rep. of	
	Tons	Per cent	Tons	Per cent	Tons	Per cent
Ethyl alcohol	47,000	21.4				
Ethylene oxide	52,000	23.6	15,000	30.6	55,000	33.3
Polyethylene	101,000	46.0	18,000	36.9	60,600	36.7
Styrene	12,000	5.5	9,500	19.4	29,400	17.8
Others	8,000	3.5	6,400	13.1	20,000	12.2
TOTAL	220,000	100.0	48,900	100.0	165,000	100.0

SOURCE: A. L. Waddams, *Chemicals from Petroleum*, Shell Chemical Co. Ltd, London 1962, page 10.

So far as ethylene production is concerned, there are no official data for the United Kingdom, whose capacity attained 576,200 tons in 1963. Table 9 covers France, Italy and the Federal Republic of Germany.

It is evident that the future development of ethylene production is keyed chiefly to plastics and elastomers. Polyethylene, which in its various forms (high or low pressure) is one of the major achievements in petroleum chemicals, has brought a revolution in the fields of packaging and flexible containers. Styrene is one of the most important petroleum chemical products whose biggest single use is still the manufacture of polystyrene. Another important application is in the production of styrene-butadiene rubber (SBR), derived from the co-polymerization of butadiene and styrene. Ethyl alcohol is still obtained by fermentation processes in many European countries. In fact, where there is an unquestioned surplus of fermentable material such as molasses, grain, starch, etc., the fermentation process remains still competitive. Only when conditions of low and stable prices for raw materials are in doubt does the whole economic basis of the fermentation processes come into question.

Amongst the propylene derivatives whose current capacity in western Europe is 1.4 million tons, glycerine constitutes another great achievement. Glycerine was for a long time a by-product of the soap and fat-splitting industries, and, as such, was subject to wide fluctuations in price. Its availability in the form of a synthetic product, derived from the "hot chlorination" of propylene, has introduced a major stability in its market position. Glycerine is mostly used for alkyd resins, cellophane, drugs and cosmetics.

TABLE 9. ETHYLENE PRODUCTION IN SELECTED COUNTRIES OF WESTERN EUROPE, 1958 TO 1960
(Thousands of tons)

Country	1958	1959	1960
France	120	165	204
Germany, Fed. Rep. of	80	135	150
Italy	375	400	407

SOURCE: Bureau central de statistiques industrielles, Paris; Chemische Werke Hüls, Marl; Istituto Centrale di Statistica, Rome.

As a raw material, petroleum has had considerable influence on the production of ammonia and fertilizers for a number of essentially economic reasons (*a*) owing to the ease of handling raw materials in fluid form, the capital costs of ammonia plants can be reduced, (*b*) the economics of synthesis gas production from hydrocarbons are generally more favourable than those of such production from coke, partly owing to the higher concentration of hydrogen — this factor tends to reduce the load on the purification units treating the hydrogen stream (*c*) the development of processes based on natural gas has enabled ammonia to be economically produced in countries which have no coal resources — Italy, for example, (*d*) the availability of processes based on heavy fuel oil has made the economic production of fertilizers possible almost everywhere.

In 1958-1959 the world breakdown of synthetic ammonia facilities was as follows (the USSR is excluded):

Total capacity approximately 8 million metric tons N

	Percentage
Based on petroleum	55
Based on coal and coke	40
Other	5

Aromatics are the most recent of the basic large-volume organics to be produced petrochemically. Until fairly recently, supplies of major aromatic compounds derived from coal carbonization were sufficient to meet all chemical needs. Moreover, the separating of individual aromatic compounds from petroleum concentrates was often uneconomic, so that outside the United States the trend towards petroleum-based aromatics is not yet so marked, but it is growing. The most important aromatic is benzene whose major applications are for styrene, phenol and synthetic detergents production.

Only recently have petroleum feedstocks been used for carbon black production in western Europe. A few years ago, the entire carbon black industry was still centred in the United States. Now, 30 to 35 per cent of the "rubber" in tyres consists of carbon black. Indeed, 90 to 95 per cent of total carbon black consumption goes into some form of synthetic rubber.

At this point it is interesting to note the extent to which petroleum materials have replaced traditional sources.

TABLE 10. CONSUMPTION OF PRIMARY RAW MATERIALS IN SELECTED COUNTRIES OF EUROPE[a] 1962

Raw materials	Thousand tons of carbon content	Percentage obtained from: Coal	Oil and natural gas	Other sources
Carbon monoxide	241	61.0	39.0	
Aliphatic hydrocarbons	2,928	16.5[b]	80.5[b]	3.0
Aromatic hydrocarbons	1,244	61.5	33.0	5.5
TOTAL	4,413[d]	34.0	63.0	3.0

SOURCE: *The Chemical Industry 1962-63*, OECD, Paris, 1963.

[a] Austria, the Federal Republic Germany, France, Italy, the Netherlands, Spain, Sweden, the United Kingdom.

[b] Excluding the United Kingdom.

[c] Excluding Sweden and the United Kingdom.

[d] Excluding the Netherlands.

According to the last OECD report on the chemical industry, nearly two-thirds of the raw materials utilized in 1962 for organic synthesis in western Europe were obtained from oil and natural gas.

In the United Kingdom the use of petroleum for organic chemicals manufacture rose at a remarkable rate between 1950 and 1962, by which year it constituted 61 per cent of the industry's raw materials (Table 11).

In the Federal Republic of Germany, petroleum represents just over one-half of the industry's total raw materials, but a considerable increase in this proportion is forecast.

In the USSR, oil and natural gas are very little used in chemical production, but they are expected to assume far greater importance by 1980, as will be seen by table 13.

According to the national economic development flow for the Hungarian chemical industry the share of production from hydrocarbons in value terms will be 14 per cent in 1965 and 70 per cent in 1980.

PATTERN OF PRODUCTION OF SOME PETROCHEMICAL PRODUCTS

As mentioned earlier, one of the main determinant factors in Europe's development of petrochemicals has been the increase in refining capacity. Indeed, this increase continues all over Europe and promises much for the petrochemicals sector.

According to the *World Petroleum Report* of 1964, the total refining capacity in Europe amounted to 436 million tons in 1963, to which the socialist countries of eastern Europe contributed 175 million tons, or 45 per cent. In western Europe, 50 per cent (215 million

TABLE 11. ORGANIC CHEMICALS FROM ALL SOURCES IN THE UNITED KINGDOM, 1950 TO 1962

Source	1950	1953	1955	1960	1962
Coal tar	105	230	275	360	670
Acetylene (carbide)	70	80	110	135	180
Synthesis gas (coke)	60	70	80	95	80
Fermentation	160	170	140	80	30
Petroleum	45	195	290	595	1,180
TOTAL	520	745	895	1,270	2,146
Percentage from petroleum	9	26	32	47	61

SOURCE: *World Petroleum*, New York, June 1963.

TABLE 12. INPUT OF PRIMARY MATERIALS FOR THE PRODUCTION OF ORGANIC CHEMICAL PRODUCTS

(*Thousands of tons*)

Product	1957 T[a]	1957 Percentage of oil and natural gas	1958 T[a]	1958 Percentage of oil and natural gas	1959 T[a]	1959 Percentage of oil and natural gas	1960 T[a]	1960 Percentage of oil and natural gas	1961 T[a]	1961 Percentage of oil and natural gas	1962 T[a]	1962 Percentage of oil and natural gas
Carbon monoxide	287	11	290	27	305	29	309	30	398	30	442	32
Methane	13	100	16	100	13	100	24	100	22	90	19	100
Acetylene	108	20	240	26	247	32	201	33	280	36	280	42
Ethylene, ethane	75	50	99	60	166	70	288	87	273	91	307	95
Propane, propylene	40	100	60	100	84	100	115	100	141	100	175	100
Butane, butylene, butadiene	10	100	40	100	94	100	75	100	124	100	140	100
C_5 and the aliphatics	16	12	8	45	48	88	89	84	105	84	136	60
Benzene	108	0	220	0	305	0	316	1	304	4	380	17
Toluene	20	15	18	20	28	91	38	80	37	88	40	94
Xylene	6	0	7	0.2	9	78	17	76	10	95	34	77
Naphthalene	67	0	76	0	88	0	102		160		110	
TOTAL	874	20	1,074	30	1,340	40	[illegible]	44	[illegible]	50	2,075	50
TOTAL (carbon content)	687		[illegible]		1,084		[illegible]		[illegible]		[illegible]	

Source: [illegible], Chemische Industrie, Düsseldorf, vol. [illegible], No. 14, April [illegible], p. [illegible]

[a] T = tonnage.

TABLE 13. PROPORTION OF THE RAW MATERIALS UTILIZED FOR CHEMICAL PRODUCTION IN USSR, 1958 TO 1980

(Percentages)

Raw material	*1958*	*1965* [a]	*1980* [a]
Oil and natural gas	2.2	12.9	20
Synthesis gas (coke)	42.6	26.4	20
Gas from non-ferrous minerals	9.0	8.1	10
Apatite, salt, sulphur	25.9	26.8	25
Coal	0.8	0.8	10
Fermentation	19.5	25.0	15

SOURCE: *Referativni Sbornic Economica promichlemosti*, Academy of Science, Moscow, 1963.

[a] Forecasts.

tons) of the European total is concentrated in France, Italy, the Netherlands, the United Kingdom and the Federal Republic of Germany. It is estimated that by 1966 the refining capacity in Europe will have reached 596 million tons — an increase over 1963 of 36.7 per cent.

Petrochemicals are used in many fields, including fertilizers, solvents, plastics, synthetic fibres and synthetic rubbers, but much of the petrochemical growth of western Europe can be identified with the rapid increase of two sectors — synthetic rubbers and plastics, chiefly thermoplastics whose most important group is that of olefins, which includes polyvinyl chloride (PVC), polyethylene, polystyrene and acrylics — which can be taken as significant examples of the trend in the petrochemical production.[4]

Western Europe's petrochemical production registered an almost eightfold increase during the period 1953-1960, from 219,000 of carbon content to 1,697,000 tons. Table 14 gives absolute figures for all western European countries and their share in the total during this period.

TABLE 14. PRODUCTION OF PETROCHEMICALS IN WESTERN EUROPE, 1953 AND 1960

(Thousands of tons of carbon content)

Country	*1953*		*1960*	
	Total	*Percentage of western Europe total*	*Total*	*Percentage of western Europe total*
France	16	7	230	14
Germany, Fed. Rep. of	55	25	504	30
Italy	12	5	243	14
United Kingdom	124	57	567	33
Others	12	6	153	9
TOTAL	219	100	1,697	100

SOURCE: For 1953, *Chemische Industrie*, Dusseldorf, December, 1961; for 1960, *The Chemical Industry in Europe*, 1960-61, OECD, Paris, 1961.

It will be seen that in 1953 the United Kingdom was the main producer, with Italy ranking fourth. By 1960, production was more evenly distributed. Table 15 shows a completely changed situation by 1961: the Federal Republic of Germany has displaced the United Kingdom as leading producer, Italy has moved rapidly ahead of France, and the Netherlands has made immense strides.

TABLE 15. WESTERN EUROPEAN PETROCHEMICALS PRODUCTION

(Thousands of tons of carbon content)

Country	*1961*	*1962* [a]	*1963* [a]
Austria		6	13
Belgium	25	42	80
France	278	397 [b]	646
Germany, Rep. Fed. of	666	810	1,100
Italy	355	469 [b]	1,037
Netherlands	95	136	322
Spain	3	3	100
United Kingdom	579	759	1,069
TOTAL	2,001	2,622	4,367

SOURCE: *The Chemical Industry in Europe*, 1961-62 and 1962-63, OECD, Paris, 1962 and 1963, respectively.

[a] Estimates.

[b] According to the *European Chemical News* (London, July 17, 1964, page 18) production of petrochemicals in 1962 reached 478,000 tons in France and 464,000 tons in Italy.

The plastics sector in 1963 reached a new world record of 9 million tons, the countries of western Europe accounting for 27 per cent and the socialist countries of eastern Europe 10 per cent. Europe's rate of expansion over the last ten years has been 21 per cent annually. Trade sources predict an average world growth rate of 7 per cent a year over the next ten years, bringing total production up to over 13 million tons by 1968 and to 18.5 million tons by 1973. The petrochemical industry has a major stake in the plastics industry, being the sole supplier of ethylene for the production of polyethylene, styrene and PVC.

Per capita production figures for the leading producer countries of western Europe are given in table 16.

TABLE 16. COMPARATIVE PRODUCTION RATIO FOR PLASTIC MATERIALS, 1960

Country	*Kg/person*
Belgium/Luxembourg	7.4
France	7.5
Germany, Fed. Rep. of	14.4
Italy	4.9
Netherlands	8.7
United Kingdom	9.2

SOURCE: E. P. Learned, F. J. Aguilar and R.C.K. Valtz, *European Problems in General Management*, Homewood, Illinois, [illegible], page [illegible].

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[4] In the leading producing countries of western Europe, ethylene and propylene — the most important basic materials for plastics manufacturing — are derived entirely from the cracking of light naphtha. No precise information is available on the sources of these products in eastern Europe; the data given here must therefore be taken as a rough indication only.

TABLE 17. PRODUCTION OF MAJOR PLASTIC MATERIALS IN THE FEDERAL REPUBLIC OF GERMANY, 1961 TO 1963

(Thousands of tons)

Product	*1961*	*1962*	*1963*
Polyethylene	98	148	165
Ethylene oxide	89	102	113
Acetaldehyde	236	259	253
PVC	196	225	273

SOURCE: *Verband der Chemischen Industrie*, Chemische Werke Huels.

In the Federal Republic of Germany, production of plastics in 1962 reached 1,250,000 tons, the greatest shares being those of polymers (668,000 tons) and thermoplastics (465,000). The most important products are listed in table 17.

In the United Kingdom, production almost doubled in seven years. The greatest increase occurred in thermoplastics, from 140,000 tons to 346,000 tons. The different rates of expansion will be seen from table 18, where the indexes of production are divided into thermosetting and thermoplastic groups.[5]

TABLE 18. INDEXES OF PRODUCTION OF PLASTIC MATERIALS IN THE UNITED KINGDOM, 1961 TO 1963

(1958 = 100)

Group	*1961*	*1962*	*1963*
Thermosetting	116	125	129
Thermoplastic	156	165	197
TOTAL	139	148	168

SOURCE: *Industry and Technology*, April, 1964, page 21.

Table 19 gives the production of olefins — the most important item of the thermoplastics group. The greatest increase is that of PVC, which in 1963 rose almost 32 per cent above the level of the previous year, followed by unsaturated polyesters (around 19 per cent).

TABLE 19. PRODUCTION OF OLEFINS IN THE UNITED KINGDOM, 1955 TO 1963

(Tons)

Year	*Polyolefins*	*Polyvinyl chloride*	*Polyvinyl acetate*	*Polystyrene*	*Polyesters (unsaturated)*
1955	29,200	49,000	10,600	22,800	1,000
1960	125,700	107,800	15,200	49,600	8,900
1961	129,000	108,600	16,800	52,500	10,000
1962	174,700	116,800	18,500	68,800	11,700
1963	201,000	153,900	21,000	77,000	13,900

SOURCE: Board of Trade statistics.

In Italy, plastics production reached 623,000 tons in 1963 — 19 per cent more than the previous year (542,000 tons), whereas in 1962 the increase was as high as 35 per cent. The thermoplastic sector, which constitutes 70 per cent of the country's plastic production, showed the most rapid progress; within that sector, PVC rose by 39 per cent in 1962 and 13 per cent in 1963, and polyethylene by 48 per cent and 26 per cent respectively (see table 20).

TABLE 20. PRODUCTION OF SOME PLASTIC MATERIALS IN ITALY, 1961 TO 1963

(Tons)

Year	*Polyethylene*[a]	*Polystyrene*	*Polyvinyl chloride*
1961	53,617	44,667	151,000
1962	79,562	65,000	195,000
1963	100,000	n.a.	220,000

SOURCES: Instituto Centrale di Statistica, Rome; Associazione Nazionale de l'Industria Chimica, Rome; OECD reports, Paris.

[a] Including a small amount of polyisobutylene.

France produced 451,000 tons of plastic material in 1963, an increase of only 3 per cent over the 1962 figure of 440,000 tons. Production of thermoplastics as a whole was stable, but while PVC production rose by nearly 25 per cent, the rhythm of expansion of other materials — polyethylene for instance — slowed down considerably.

In the Socialist countries of eastern Europe, the industry of petroleum-based chemicals is progressing very rapidly and the national plans provide for an intensive development over the next ten years. The few data available show that, even if so far the greatest emphasis has been on the production of fertilizers, much progress has been made also in the plastics sector.

Indeed, plastics production is at present increasing at a much higher rate than chemical production in general. In 1962 it rose by 17 per cent in the USSR, 20 per cent in Czechoslovakia, and 38 per cent in Romania; in Bulgaria there was a thirty-two fold increase during the period 1959-1962. The national plan figures for plastics output are: 950,000 tons in the USSR by

TABLE 21. PRODUCTION OF SOME PLASTIC MATERIALS IN FRANCE, 1961 TO 1963

(Tons)

Material	*1961*	*1962*	*1963*
Polyethylene	39,010	63,100	66,200
Ethylene oxide	30,500	44,800	47,000
Polystyrene	42,400	48,400	58,000
PVC	119,370	136,000	172,300

SOURCE: Bureau central de statistique industrielle, Paris.

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[5] Thermosetting includes: phenolics, alkyds, polyester and polyether urethanes; thermoplastic includes, *inter alia*: olefins (polyethylene, propylene, etc.) and vinyls (polystyrene, styrene copolymers, PVC, etc.).

TABLE 22. PRODUCTION OF PVC IN SELECTED SOCIALIST COUNTRIES, OF EASTERN EUROPE 1957 TO 1965

(Tons)

Country	*1957*	*1958*	*1959*	*1960*	*1965* [a]
Czechoslovakia	4,000	...	5,700	...	45,000
Eastern Germany		54,500		58,600	125,000
Romania			5,500		36,000
Yugoslavia		4,700	6,300		10-12,000

SOURCE: *Referativini Sbornik Economika promyshlennosti*, Academy of Science, No. 8, Moscow, 1963.

[a] According to national plan forecasts.

1965 and 3.5-4 million tons by 1970; 70,000 tons in Bulgaria by 1970; and 200,000 and 95,000 tons in Poland and Romania, respectively, by 1965.[6] Table 22 shows the trend of PVC production in selected countries of eastern Europe.

Hungary produced 4,000 tons of plastics in 1958, thrice as much in 1960, and the planned figure for 1965 is 50,000. Till now, as the following figures show, the greatest share came from thermosetting (in tons):[7]

	1960	*1961*
Thermoplastic	193	375
Thermosetting	4,214	4,366

The future pattern of production for 1965 is planned as follows (in tons):[8]

PVC	16,000
Polyethylene	10,000
Phenolic resins	9,000
Aminoplastics	7,500
Alkyds	5,000
Others	2,500

TABLE 23. PRODUCTION OF PLASTIC MATERIALS IN POLAND, 1958 TO 1965

(Thousands of tons)

Product	*1958*	*1959*	*1960*	*1965* [a]
Plastics — total	27.1	37.6	55.1	200
Of which:				
Phenolic resins	10.7	13.4	14.7	29.5
Amino plastics	4.6	5.9	10.6	39.3
PVC	4.2	7.5	13.4	60.0
Polystyrene	—	—	3.6	10.0

SOURCE: *Revista de Chimie*, Bucarest, vol. 14, November-December 1963, page 698.

[a] Planned amounts.

The Polish plastics industry, in full process of development, is centred chiefly in two units utilizing natural gas, in Tarnow and Kedzierzyn. As shown in table 23, total production doubled during the years 1958 to 1960. The most significant increase was in PVC, the production of which rose by more than 200 per cent.

As recently as 1955 western Europe's synthetic rubber output totalled only 11,000 tons, the Federal Republic of Germany being the sole producer. By 1963, however, this figure had mounted to 508,000 tons, from plants in the Federal Republic of Germany, France, Italy, the Netherlands and the United Kingdom.

TABLE 24. PRODUCTION OF SYNTHETIC RUBBER IN WESTERN EUROPE, 1960 TO 1963

(Thousands of long tons)

Country	*1960*	*1961*	*1962*	*1963*
France	17	40	63	97
Germany, Fed. Rep. of	80	86	88	106
Italy	66	82	86	95
Netherlands	12	40	45	85
United Kingdom	90	106	117	125
TOTAL	265	354	399	508

SOURCE: *Statistical Rubber Bulletin*, London, July 1964.

It would appear from table 25 that in the last two years the rate of expansion of this sector slackened in comparison to 1961. In fact, in 1961 this rate was 33.5 per cent while in 1962 it was only 12.7 per cent; in 1963, while recovering as much as 27.3 per cent, it was still below the 1961 peak. Few data are available for the major synthetic rubber groups, except for styrene-butadiene rubber (SBR) production of which is given in table 25.

This brief review would be incomplete if it did not mention petrochemical prices. Since 1959, these have been falling considerably for plastics and synthetic rubbers, owing both to the strong competition exerted

TABLE 25. SBR PRODUCTION IN SELECTED EUROPEAN COUNTRIES, 1960 TO 1963

(Tons)

Country	*1960*	*1961*	*1962*	*1963*
Eastern Germany	...		86,000	90,000
France	3,200	23,300	35,000	46,500
Germany, Fed. Rep. of	73,000	78,000	79,000	90,000
Italy	71,000	88,000	91,000	...
Romania	—	—	..	50,000 [a]
United Kingdom	...	—	..	122,000 [a]

SOURCES: *Chemical and Engineering News*, Washington, 3 and 31 August 1964; for Eastern Germany: *European Chemical News*, London, 17 July 1964, page 8; and, for Romania: *Revista de Chimie*, Bucarest, vol. 14, 1963.

[a] Production capacity.

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[6] *Közgazdasági Szemle*, Budapest, September 1963.

[7] All the statistical data have been drawn from: *Iparstatisztikai zsebkönyv*, Budapest, 1960 and 1963; *Statisztikai évkönyv*, Budapest, 1962, *Statisztikai havi közlemények*, Budapest, 1964, No. 6.

[8] *Usine Nouvelle*, Paris, January 1964.

on the international market and to over-capacity in many western European countries as well as in the United States. While, previously, under the pressure of sustained demand the industry was working at almost full capacity, the present position is one of slackened demand so that many European countries find themselves confronted with the problem of finding not only new markets but also new fields of application.

SUMMARY CONCLUSIONS

The scope of the present report has been to describe briefly the development of the petrochemical industry in Europe as well as the economic impact on the chemical industry of the utilization of new materials derived from petroleum.

Before summarizing the conclusions arising from the foregoing analysis it would be advisable to draw attention to the limitations of the data on which they are based. In fact, apart from the few data selected from the reports on the chemical industry in western Europe prepared by the OECD, all figures have been taken from technical reviews and should therefore be considered as informed judgements rather than factual information. Similarly, for want of detailed data, the subject of demand and prices could not be adequately examined.

After modest and halting beginnings, this branch of the chemical industry has been very buoyant in the last decade, as is apparent from the high rates of production and investments.

It should be noted that, while the countries concerned, encouraged by the decrease in costs per unit of product, are trying to substitute oil or natural gas for coal, petroleum feedstocks are not yet seriously competing with coal since, so far, the chemical field has resorted to these mostly in an attempt to fill the gap in coal supply.

The degree of this substitution has certainly been quite extensive in certain countries, including France, the Federal Republic of Germany, Italy and the United Kingdom, and continues to assume considerable proportions wherever possible. Nevertheless, petrochemicals should still be considered largely as a complement of those chemicals which can still be derived economically from coal.

This brisk development of petrochemicals is not only due to the development of the oil industry in general, and the increase of European refining capacity in particular. It results also from the considerable increase in demand for those products which are now overwhelmingly dependent on petroleum-based materials, such as plastics, synthetic rubbers, synthetic fibres, carbon black, etc.

Nevertheless, as the report clearly shows, the development of the industry differed from country to country, depending on the general economic environment, the degree of industrialization achieved, the availability of investment funds, as well as on the importance of the chemical industry and its range of production.

The United States still maintains its lead, owing to its earlier shift away from coal based feedstocks. In 1962, 92 per cent of its organic chemicals was based on oil, the corresponding figure for western European countries was 58 per cent, with the sole exception of Italy, which has little coal and thus derives about 91 per cent of its organic chemicals from oil sources.

The petrochemical sector is considered the most promising within the chemical industry and, in spite of current over-capacity in some areas, construction activity is rising sharply in Europe.

An immediate consequence of over-capacity was a certain fall in prices; this was due on the one hand to a reduction in world raw material prices because of technological improvements and the increasing size of plants, and, on the other hand, price cutting in face of competition for products where demand had not yet caught up with increased capacity.

Since Europe's petrochemical industry is not yet fully developed, investments continue to be high, chiefly in research and development.

It has been emphasized that the petrochemical industry is highly capital-intensive and automated, tied up with units of very great capacity. But heightened competition in this sector also lends particular importance to research expenditure.

It is well known, in fact, that the petrochemical industry depends to a great extent on technological progress but at the same time it gives rise to the invention of new materials which can better correspond to the needs of this "technical era".

This has brought about a change in the direction of competition competition in volume is being succeeded by competition in quality, which makes it very difficult, at least on the international market, for latecomers; these may certainly take advantage of the latest technical discoveries but will have a hard time competing with the "sophistication" of the well-established producers.

The present paucity of information makes it difficult to forecast the future development of petrochemicals in western Europe. It can only be affirmed that the industry's activity will continue to increase as a result of the added continuity and permanence provided by new products. For the socialist countries of eastern Europe also, it would appear from the forecasts on the production of plastics that petrochemicals will progress at a very swift pace.

3. THE PETROCHEMICAL INDUSTRY IN LATIN AMERICA

Secretariat of the Economic Commission for Latin America

1. INTRODUCTION

In Latin America, the manufacture of chemical products based on petroleum derivatives began in Argentina in 1944 with the production of isopropyl alcohol by the Yacimientos Petrolíferos Fiscales (YPF) refinery at San Lorenzo, Santa Fé, using a sulphation-hydrolysis process developed at its Florencio Valera research laboratories.

Later in 1951, a synthetic-ammonia plant owned by Guanos Fertilizantes de Mexico, S.A., situated at Cuatitlan, D.F., started operation. In order to supply this plant with raw material, operations were begun at the same time at a number of installations belonging to Petróleos Mexicanos (PEMEX), which extract sulphur from sour natural gas at Poza Rica, Veracruz, and pump the sweet natural gas to the Cuatitlan plant.

In the same year, the Argentina Directorate-General of Military Equipment began to produce toluene and benzene from a naphtha fraction at its plants situated at Campana, Buenos Aires, using a catalytic dehydrogenation (hydroforming) process.

The installation of these production plants marks the beginning of the development of the petrochemical industries in Latin America, and interest in the establishment of new industries of this type has continued to spread in the Latin American countries since the nineteen-fifties. This is due to the process of industrialization which has been gathering momentum since the end of the Second World War. The steadily mounting demand for various chemical products needed by industry used to be met by imports and national manufactures based on other raw materials. At present, the demand for many of these products has risen to, or is approaching, a level sufficiently high to make their production by petrochemical processes economic in those countries which have a vigorously expanding modern petroleum industry.

The widespread interest in petrochemicals is due chiefly to the enormous opportunities offered by the actual composition of petroleum and natural gas, which provide the chemical industry with many of the hydrocarbon compounds it requires. It is estimated that in the United States in 1965 the output of petrochemical products will represent 40 per cent of the volume and 70 per cent of the value of all United States chemical production. At the same time, the basic petrochemical raw materials obtained from petroleum and natural gas will absorb some 3.3 per cent of the output of the United States petroleum industry. The same thing has happened in the United Kingdom and the Federal Republic of Germany, whose chemical industries have developed to a considerable extent on the basis of by-products of coal distillation. In the United Kingdom only 9 per cent of all organic products were obtained from petroleum in 1949, whereas in 1962 the proportion was 65 per cent. In the Federal Republic of Germany, the figure for the output of organic products based on petrochemical raw materials was 60 per cent in 1963 as against 15 per cent in 1950.

In most Latin American countries the production of natural gas is associated with that of petroleum, it is extracted but not utilized immediately. Adequate utilization of this gas for the improvement of agriculture through the production of fertilizers and, in general, for the economic development of the various countries is one of the problems which the Latin American Governments are now tackling.

On the other hand, the ease with which petroleum can be transported by means of pipelines and tankers and, first and foremost, its low cost are other factors favouring the development of petrochemical industries in those countries which have no large areas producing petroleum or natural gas but do have a reasonably sized consumer market for fuels which has justified the construction of large-capacity petroleum refineries (Brazil, Japan and the European countries).

The great possibilities of development in the petrochemical industry in Latin America make investment in this field attractive. The substantial reserves of petroleum and natural gas which exist in Venezuela, Mexico, Argentina and Colombia, and the potential demand of the Latin American market as a whole are good reasons for establishing a number of petrochemical industries.

2. CHARACTERISTICS OF THE INDUSTRY

Within the chemical industry as a whole, the petrochemical industry may be regarded as a branch particularly representative of the present phase of development in this industrial sector, not only because the technology it uses is modern but also because its economic characteristics make it very much more similar to the petroleum industry than to the traditional chemical industry in that it requires relatively large investments whose profitability increases with expanding capacity.

Technically speaking, the petrochemical industry, which is in fact the modern chemical industry, consists primarily of the production of synthetics. It enables certain natural products to be replaced by higher-quality and less expensive synthetic materials, and entirely new products with hitherto unknown properties to be developed.

The petrochemical industry is characterized by extensive automation, which enables the labour force to achieve a very high level of productivity.

With the introduction of modern techniques for the manufacture of new products, the technological advances observed in the petrochemical industry have made it possible to undertake chemical synthesis more directly, with a resultant greater economy of energy than was possible with the older manufacturing techniques.

Thus, acetylene, which up to 1945 was produced almost exclusively from calcium carbide or by the electric-arc process, is being produced by the petrochemical industry through the partial combustion of natural gas or naphtha in special burners. Similarly, ethylene oxide is produced by petrochemical processes involving the direct oxidation of ethylene, which eliminates the intermediate monochlorohydrin stage. It has also been possible to synthesize ammonia more cheaply because petrochemical processes could be used to obtain hydrogen from natural gas at a lower cost. The synthesis of methanol through the synthetic gas obtained from natural gas or by partial combustion of fuel oil is another characteristic petrochemical operation, which has helped to reduce the market price of this alcohol.

The manufacture of acrylonitrile by a more direct process based on propylene is one of the latest developments in the petrochemical industry and indicative of the extraordinary technological progress achieved.

Generally speaking, the numerous petrochemical products require a high degree of precision in controlling the conditions under which the synthesis takes place; it has been possible to meet this requirement thanks to the immense advances made in automation, particularly as regards control and measuring instruments.

On the other hand, the equipment of petrochemical plants, particularly reactors, are made of materials which resist corrosion by the various products and high pressures and temperatures. Furthermore, the catalysts, which have a very well-defined composition, are almost always expensive. Consequently, petrochemical plants usually require a relatively high level of investment, which in order to be profitable, will have to be high enough to ensure the minimum output capacity appropriate for each case.

One trend observed in the petrochemical industry is that of grouping into industrial complexes the maximum possible number of production plants which use the same raw material source for their basic input. One reason for this grouping is that the output of one plant may be used as the raw material for another; a second reason is the economy achieved by the installation of large generating plants for electric services or for the production and processing of the basic raw materials. Among the many examples of such complexes, mention may be made of Imperial Chemical Industries in the United Kingdom, the Ente Nazionale Idrocarburi in Italy, and the United States industries in the Gulf of Mexico area. As may be supposed, the construction of such petrochemical complexes requires large investments.

The need to immobilize large amounts of capital has, to a certain extent, determined the financial structure of the Latin American petrochemical industry, which is characterized by the existence of State enterprises or the predominance of foreign investment. Up to the present time the private national sector has participated very little in the petrochemical activities of Latin American countries.

In compensation for the large investments it requires, the petrochemical industry usually emerges in the industrially more developed countries as a highly profitable activity and therefore holds a great attraction for the national entrepreneurs of Latin America. Since it is, however, a young industry which originated and expanded during a period when great technological strides were being made in all other industrial sectors, it employs modern techniques in its continuous processes and in the automatic control of reactions. For this reason, small and even medium-sized national enterprises have been unable to compete freely with the traditional chemical enterprises, since most of the technical know-how is still protected by patents held by the latter.

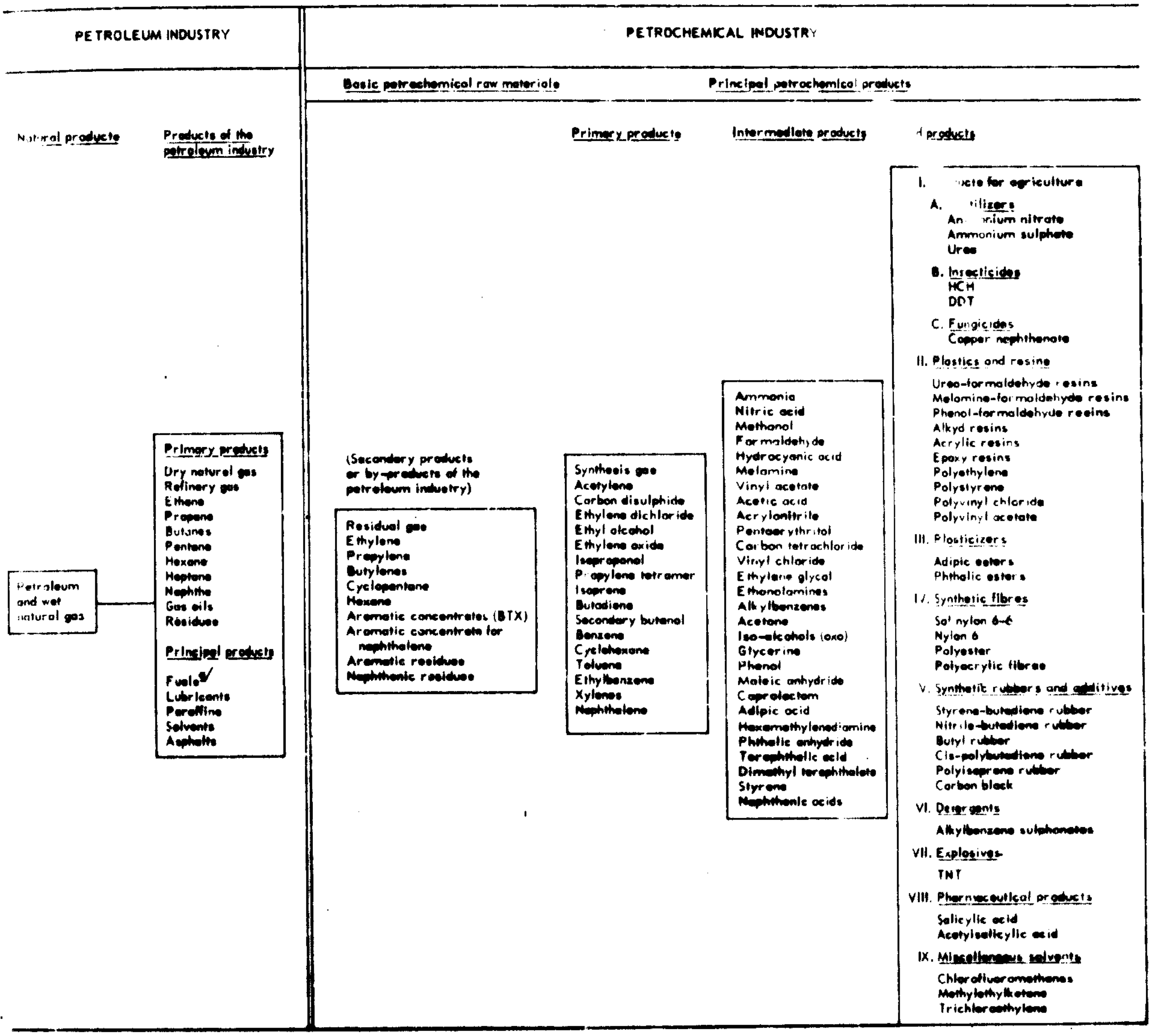
One feature of the petrochemical industry is the rapid development of its technology through the intensive scientific and technological research conducted by the large enterprises in this sector.

In the traditional chemical industry, research in the conventional processes that have been in use for many years is chiefly concerned with technical advances which will make it possible to cut production costs without changing the basic procedures. In the petrochemical industry, on the other hand, more economical production processes (olefin direct-oxidation techniques, polyethylene at low pressure, etc.) are often discovered or completely new products are developed which often make petrochemical plants obsolete in a very short time.

Latin America does not yet offer the conditions which would permit such technological research at a level consistent with the advances that have been made by the petrochemical industry in the industrially more developed countries.

Another feature of the petrochemical industry is the opportunity it offers of using different raw materials and different technological processes for the manufacture of a single product. The selection is usually based in each case on the cost of the available raw materials and the other manufacturing costs for each technological process. The minimum economic capacity may vary in the various plants depending on the different technological processes used for manufacturing a single product. Thus, for example, it is a well-known fact that the production of ethylene glycol by direct oxidation is more economical in plants with capacities of more than twenty tons per day, while the old process involving the intermediate chlorohydrin stage is preferable for lower-capacity plants.

Given the various possibilities which petroleum and its derivatives and natural gas offer as a starting point



[a] Liquid and gaseous.

Latin America: diagram of the petrochemical industry and its links with the petroleum industry

for the development of petrochemical industries, and in view of the different processes that may be used, depending on the various economic schemes, the petrochemical industry is a relatively complex activity. A number of difficulties have, therefore, arisen in studying and interpreting the opportunities for development in this field which are offered by each country. In order to define the scope of this report, a diagram of the petrochemical industry is given above indicating the products that have already become important in the Latin American market and the links between the petroleum and petrochemical industries.

By *end-products* is meant the petrochemical products used directly as consumer goods or as raw materials in manufacturing industries. *Primary products* and *intermediate products* are those obtained by chemical processes which use basic raw materials, products derived from them, or other chemical products, such as oxygen, chlorine, nitrogen, etc. *Basic petrochemical raw materials* are the hydrocarbons or fractions obtained in the fundamental processes or operations of refining petroleum or natural gas.

3. THE RAW MATERIALS OF PETROCHEMISTRY

In the last few years, the domestic consumption of natural gas as a fuel has increased in Argentina and Mexico, countries where many kilometres of gas pipelines have recently been laid to transport it to the urban centres. In the other countries of Latin America, on the other hand, the situation is different as regards both the transport and the industrial and domestic consumption of natural gas.

In Venezuela, where almost all gas production is associated with the production of petroleum, despite the fact that gas is reinjected in the oilfields to lessen wastage, 45 per cent of the gas produced continues to be burned, constituting a petroleum equivalent of more than 250,000 barrels per day.

In Mexico, only 25 per cent of the natural gas produced is burned for lack of demand, and over 50 per cent is consumed as fuel, some being exported to the United States through an international gas pipeline.

In Colombia, 60 per cent of the gas produced is burnt, while in Argentina the proportion is 42 per cent and consists of gas which is not used either as fuel or for reinjection in the oilfields. On the other hand, Chile, which has natural gas in Magallanes in the extreme south of the continent, is giving close study to the possibility of transporting it to the north of the country, in special vessels equipped with a sub-zero refrigeration system, for use in copper mines. In view of the distance involved (2,040 nautical miles), it is possible that this system may also be used for exporting liquefied natural gas from one country of the area to another, just as the transport of natural gas was recently initiated in Europe from Algeria to the United Kingdom.

Again, in Peru and Bolivia, considerable quantities of natural gas have been discovered whose use would require the construction of gas pipelines to carry it to the centres of consumption.

The situation in Brazil is different, as far as its supplies of natural gas are concerned, since the associated gas produced in the oilfields is used largely in the reinjection programme for the secondary recovery of petroleum deposits.

This being the case, in the next five years Brazil may eventually import natural gas from other Latin American countries for consumption as fuel, for which it should perhaps consider the possibility of making part of the propane and butane from its refineries available for use in larger quantities as a basic petrochemical raw material. The high proportion of the hydrocarbon methane contained in natural gas (85 per cent or more) and its relative inertness restrict the use of natural gas, in most cases, for the supply of energy as a fuel or as a raw material for a very small number of chemical products (principally ammonia, methanol, acetylene, hydrocyanic acid and acrylic resins).

Table I shows the present situation of seven Latin American countries in regard to petroleum and natural gas reserves. The figures on the various countries' reserves are collected from different sources and are based on different criteria; for this reason the values in the table indicate only the magnitude of the declared reserves in the countries concerned and do not permit an evaluation of each country's capacity to develop petroleum and petrochemical activities.

The results obtained hitherto, and the general knowledge of each country's potentialities, enable us to predict a moderate expansion of the proved reserves in Latin America, particularly in Colombia. In Venezuela on the other hand, the growth of petroleum production will be limited less by the possible increase in reserves than by the capacity of the world market to absorb such production.

TABLE I. LATIN AMERICA: RESERVES OF PETROLEUM AND NATURAL GAS

Country		*Petroleum (millions of m³)*	*Natural gas (thousands of millions)*
Argentina		582	224
Brazil		99	20
Chile		15	80
Colombia		223	
Mexico		818	a
Peru		53 b	28
Venezuela		2,705	859
	TOTAL	*4,495*	*1,211*
Other countries		23	
	GRAND TOTAL	*4,518*	*1,211*

SOURCE: Specialized publications, official and private publications and direct information.

a Gas reserves are included in petroleum reserves.

b 1963 figures.

The relatively high level of petroleum production and consumption of its derivatives in Latin America is accompanied by the existence and development of a large refining industry, a rich source of basic petrochemical raw materials.

In 1963, the capacity of the Latin American refineries topped 2.5 million barrels per day, 92.5 per cent of which constituted the existing capacity of seven countries. In Argentina, 83 per cent of the installed refining capacity was utilized, while in Brazil the refineries found themselves obliged to exceed the limits of their nominal capacity and to raise the figure to 114 per cent. In 1963, the refineries of the seven countries were on the average operating virtually at full capacity (97 per cent). In 1964, 42 per cent of this capacity was in Venezuela, but it is anticipated that this proportion will decline towards the end of the decade owing to the fact that, with the considerable increase in domestic consumption of refined products in the other countries, new refineries will be installed to ensure their self-sufficiency in refining capacity. By 1970, moreover, it is expected that each of the seven Latin American countries will have substantially expanded their average refining capacity, thanks to the construction of new, modern refineries and the closing down of obsolete plant.

A projection of the consumption of refined petroleum products for Latin America as a whole indicates that, by 1970, the figure will reach 2,200,000 barrels per day. In 1963, Venezuela accounted for approximately 6 per cent of Latin American consumption, Brazil for 21.6 per cent, Mexico for 21.4 per cent, and Argentina for 18.3 per cent; these countries are thus the major consumers of refined petroleum products in the region. If we take into account the general tendency of the world petroleum industry to situate refineries close to markets and to seek refining self-sufficiency, which all the Latin American countries are trying to attain or to maintain, a reduction

TABLE 2. LATIN AMERICA: PETROLEUM PRODUCTION, DOMESTIC CONSUMPTION OF DERIVATIVES, AND PETROLEUM REFINING IN SEVEN COUNTRIES, 1963

(Millions of barrels)

Country	*Production*	*Domestic consumption*	*Refining*	*Refining capacity*	
				Volume	*Percentage*
Venezuela	1,186	31	380 [a]	372	102
Mexico	116	113	120 [b]	138	87
Argentina	98	97	102 [c]	123	83
Colombia	60	24 [d]	28 [d]	30	93
Brazil	36	114	112 [e]	98	114
Peru	22 [f]	22 [f]	18 [f]	18 [f]	100
Chile	13 [g]	21	16 [g]	16 [g]	100

SOURCES: *Petroleum Press Service* and *Oil and Gas Journal*.

[a] Statistical appendix to the *Memoria del Ministerio de Minas e Hidrocarburos*, March 1964.

[b] Stock-market, 13 March 1964.

[c] Argentine Petroleum Institute, *Petrotécnica*, January 1964.

[d] *Boletín de Petróleos*, Colombia, 1963.

[e] PETROBRAS, *Boletim Econômico e Financeiro*, year VII, No 6.

[f] 1962 prices. *Estadística Petrolera del Perú*, July 1963.

[g] ENAP, *Boletín Estadístico*, annual abstract, 1963.

in Venezuela's share in Latin America's total refining capacity may reasonably be expected.

As regards the supply of petrochemical raw materials, it is very important to consider not only the over-all volume of refining in each country, but also the size of the refineries and the composition of their units. The fact that refining capacity is spread over a great many small-capacity establishments which is noticeable in a number of countries, for example in Argentina, Brazil and Colombia prevents residual gases from being supplied economically for the development of the petrochemical industry.

On the other hand, the capacity of the refineries does not in itself determine the quantity of gas available. The supply of gas, as well as depending on a great many factors such as the characteristics of the crude oils used and the quality and percentage distribution of the principal and other products, is determined primarily by the scale of molecular disintegration and rearrangement operations (thermal or catalytic cracking and reforming).

Table 3 shows the features of the present Latin American refineries and the distribution among the different countries. Only the catalytic processes are considered since they are more modern and of greater importance

TABLE 3. LATIN AMERICA: CATALYTIC CRACKING AND REFORMING UNITS IN RELATION TO TOTAL REFINING CAPACITY, 1964

Country	*Number of refineries*	*Total capacity (thousands of barrels/day)*	*Catalytic cracking*		*Catalytic reforming*	
			Thousands of barrels/day	*Percentage of total capacity*	*Thousands of barrels/day*	*Percentage of total capacity*
Argentina	13	378.7	59.5	15.7		0
Brazil	9	298.9	47.5	15.9	21.5 [a]	7.2
Chile	1	47.6	12.0	25.2	6.0	12.6
Colombia	5	84.3	41.0	48.4		0
Mexico	6	420.0	64.0	15.3	32.0 [a]	7.6
Peru	4	55.3	—	0		0
Venezuela	16	1,070.5	44.2	4.1	30.6	2.9
TOTAL	54	2,300.3	267.2	11.3	90.1	3.0
Other countries [b]	16	188.3	29.0	15.4	17.5	9.3
GRAND TOTAL	70	2,487.5	296.2	11.6	107.6	4.3
Total [illegible] Venezuela	*54*	*1,417.0*	*252.0*	*17.1*	*77.0*	*5.2*

SOURCE: *Oil and Gas Journal*.

[a] Including units whose construction is almost completed.

[b] Including Cuba.

as regards the supply of basic petrochemical raw materials.

Actually, 85 per cent of Latin America's refining capacity is now concentrated in the nineteen biggest refineries of the sixty-nine operating in the seven countries (see table 4). The average capacity of this group of refineries is 105,800 barrels per day, or 76,400 barrels per day if the Venezuelan refineries are excluded. Each of the nineteen major refineries represents an average capacity of over 40,000 barrels per day, or 2 million tons per year.

As regards this 85 per cent of refining capacity, it will be noted that the practice in Latin America in the matter of refining is to establish large distillation units, relatively modest catalytic cracking units and a limited catalytic reforming capacity in relation to the total capacity of the country concerned (see table 3). These features are particularly striking in the Venezuelan refineries, whose output is mainly geared to the demand of the export markets for derivatives and the ability of the international petroleum concerns to meet it.

The absence of large catalytic cracking and, to a lesser extent, reforming units limits, for the time being and in most of the countries, the possibilities of establishing petrochemical industries dependent on existing refineries. Nevertheless, the changes anticipated in the features and pattern of demand in the present decade enable us to foresee a certain improvement in this situation which will take the form of an increase in the average size of catalytic cracking and reforming units by 1970.

It is to be hoped that in several countries, including Argentina and Mexico, there will be some increase in the use of catalytic cracking processes in the refineries as a result of the steady improvement in the quality of gasolenes and the smaller relative growth of the market for fuel oil, which is being largely replaced by natural gas. Thus, in petroleum-importing countries, such as Brazil, the most likely trend, economically speaking, is towards the importation of larger quantities of fuel oil and local production of the more refined derivatives (light oils), which would also involve the corresponding installation of catalytic cracking units in the new Brazilian refineries. As a result of the structural change which the Latin American refineries will be compelled to introduce owing to the decrease in the percentage of fuel oil produced, they should by 1970 have larger quantities of the basic petrochemical materials in the residual gases and other liquid by-products, although the natural technical limitations which hamper the development of petrochemistry when it depends exclusively on petroleum refineries will still be present.

With respect to the importance of catalytic cracking and reforming units as a source of basic petrochemical raw materials, table 5 shows, by way of example, the percentage of products obtained in the atmospheric distillation of petroleum, from a catalytic cracking unit and from a catalytic reforming unit for a specimen crude petroleum of Venezuelan origin. If the quality and quantity of the end-products to be produced are known, it is possible to determine, by subtraction, the products which could be obtained for use as basic petrochemical raw materials. Obviously, these will always come from the surplus refinery production that remains after the market for fuels and lubricants has been supplied.

Meanwhile, despite the large quantity of natural gas available in a number of countries and given the situation of the petroleum refining industry in all of them, the establishment of petrochemical plants large enough to operate at internationally competitive production costs will also call for the installation in Latin America of special vacuum cracking (steam cracking) units capable of producing the required quantities of olefin and aromatic hydrocarbons, which constitute the basic petrochemical raw materials.

The purpose underlying the development of these special cracking processes has been to make possible the establishment of petrochemical industries in areas that have no natural gas or refineries; moreover, their development has to some extent detracted from the importance of the old idea that, where there are large supplies of these gases, there must necessarily be a wide range of petrochemical production. The technical process involved in developing the vacuum cracking processes on the basis of liquid petroleum fractions (propane, naphtha, or even petroleum) has, in the last few years, considerably changed the relative position of the various countries, and even of different areas of the same country, with respect to the prospects they offer for the establishment of petrochemical industries. It may be noted that, in Europe, Japan and in the United States, the petrochemical industry as it expanded, gradually acquired a certain independence of the petroleum industry and freed itself from the latter in the production of its raw materials through the process of steam cracking, so that such material ceased to be, as they had been initially, simple by-products of the petroleum refineries or of natural gas processing operations. This is due to the extraordinary expansion of the petrochemical industry which, in the more highly industrialized countries, already calls for increasingly greater quantities of raw materials to meet its needs.

The petroleum industry is unable to cover these requirements through its normal operations since it is

TABLE 4. LATIN AMERICA: SHARE OF REFINERIES WITH CAPACITIES EXCEEDING 40,000 BARRELS/DAY (TWO MILLION TONS/YEAR) IN THE TOTAL REFINING CAPACITY OF SEVEN LATIN AMERICAN COUNTRIES

1964

Country	*Number of refineries*	*Percentage of total capacity*	*Average capacity (Barrels/day)*
Argentina	4	70	73,000
Brazil	3	81	88,700
Chile	1	100	47,000
Colombia	1	40	46,000
Mexico	4	94	98,500
Peru	1	86	46,400
Venezuela	5	88	[illegible]
TOTAL	*19*	*85*	*105,800*

SOURCE: Secretariat of ECLA data.

TABLE 5. AVERAGE YIELDS OF A SPECIMEN VENEZUELAN PETROLEUM

	Atmospheric distillation	*Catalytic cracking*	*Catalytic reforming*
	Percentage volume	*Percentage weight*	
Hydrogen		2.5	1.4
Methane			3.0
Ethylene			
Ethane	0.1		4.2
Propylene		3.8	
Propane	1.0	1.6	7.9
Butylene		3.8	
Isobutane		4.7	
Butane	2.0	0.7	9.6
Gasolene	19.0	35.9	73.9
Kerosene	15.0		
Gas-oil	20.0	41.0	
Residue	42.9	5.1 (coke)	

SOURCE: W. L. Nelson, *Petroleum Refinery Engineering*, 1958.

mainly concerned with manufacturing liquid or gaseous fuels and lubricants and not essentially with supplying the chemical industry with basic raw materials.

The "steam cracking" process, in its various forms, is used both for producing ethylene from ethane, propane, naphthas and gas-oils and also for manufacturing aromatic hydrocarbons from liquid fractions. Distribution of the various hydrocarbons in quantities which may be suitably adjusted to the requirements of a petrochemical complex is another possibility opened up by the steam cracking process.

The steam cracking process is already being introduced in Mexico, in units for the production of ethylene from hydrocarbons recovered from natural gas (ethane); in Brazil, too, another installation is being constructed for the cracking of naphtha and ethane in conjunction with units which are being built as an integral part of a conventional fuels refinery.

By way of example, table 6 shows the average yields of olefin hydrocarbons which are obtained by the steam cracking process from different petroleum or natural gas fractions.

In conclusion, despite the substantial quantities of natural gas available in some countries of the area and despite the existence in the various countries of a petroleum refining industry which is tending to become sufficient to satisfy each country's domestic demand for refined derivatives, it is also true that the development of the petrochemical industry in Latin America cannot be based solely on the utilization of those raw materials which are available as direct by-products of these operations; it will also have to be pursued to some extent independently of the normal operations of the petroleum industry, receiving from the latter only the relevant quantities and qualities of the fractions and/or by-products it requires for the production of the basic petrochemical raw materials (naphtha-based ethylene, acetylene, propylene, etc.). These fractions and/or by-products must also enable the petrochemical industry in Latin America to develop in greater freedom without being exclusively dependent on the operations and prospects of the petroleum industry.

4. THE MARKET FOR PETROCHEMICAL PRODUCTS

The development prospects of the petrochemical industry in Latin America depend on the progress made by the various industries which use its products as raw materials. The potential demand of the chemical industry in each country for primary and intermediate products will progressively develop into effective and real demand as the industries manufacturing the required end-products are established and the countries concerned

TABLE 6. YIELDS OF BASIC PETROCHEMICAL RAW MATERIALS USING THE STEAM CRACKING PROCESS

(Percentages)

Product *Input*	*Ethane*	*Propane*	*Naphtha*		*Gas-oil*	
	Volume		*Weight*	*Volume*	*Weight*	*Volume*
Hydrogen	35.6	12.7		15.5		15.6
Methane	4.6	32.4		28.7		20.6
Acetylene	0.2	0.1		0.6		0.2
Ethylene	33.0	28.7		38.4		32.4
Ethane	28.5	7.9		3.4		2.9
Propylene	0.8	0.7		11.7		11.3
Propane		0.7		0.4		0.6
Butadiene	0.2	0.9		3.9		3.4
Butylenes				0.2		0.2
Butanes	0.1	1.9				
C_5	—	—	99	96.8	99.6	96.2
C_5 and lighter	—	—	30.5		20.0	
Gasoline	—	—	10.5		10.6	
Summary	100	100	100		100	

Source: Dr. Hermann C. Schutt and Dr. S. B. Zdonik, articles published in the *Oil and Gas Journal*.

make headway with the vertical integration of their chemical industries.

In contrast to the pattern found in most of the highly industrialized countries of the world, it has been found[1] that almost two-thirds of the production of the chemical industry in Latin America is in the light chemical industry, which manufactures consumer goods, preparations and mixtures, such as paints, cleaning and toilet products and synthetic detergents.

The growth of the Latin American chemical industry in the last decade has been largely due to accelerated import substitution in respect of consumer goods. Accordingly, since the growth of demand for consumer goods is relatively slow, this industry can maintain or raise its rate of growth in Latin America only in so far as it becomes an effective industrial sector concentrating on the manufacture of the primary and intermediate products it requires. If this is to be done, the manufacture of certain chemical products will have to expand much more rapidly than hitherto and the share of the industry's total output will have to increase.

In view of the fact that the use of basic petrochemical raw materials will enable a large part of the chemical industry as a whole to develop through the utilization of a very small proportion of the oil industry's by-products and in view of the natural expansion of the oil industry in the region, it is legitimate to assume that in the years to come the petrochemical industry will become the fastest developing sector of the entire Latin American chemical industry.

In the absence of recent information from several countries concerning the present domestic consumption of the chemical products which can be manufactured from basic petrochemical raw materials, an effort will be made to describe the situation of the Latin American market for some of these products by analysing the volumes imported by the larger countries of the region. Table 7 shows the imports for seven countries of fifteen chemical products representative of the petrochemical industry. The fact that no figure is given in the table for imports of a given product does not mean that the product is not imported by the country.

The absence of a standard industrial classification in the countries of the region and inadequate differentiation in the import statistics published in their foreign trade yearbooks make it very difficult to compile this type of information and impossible to give data on a larger number of products.

Moreover, in order to obtain a more accurate picture of the potential Latin American market for the main petrochemical items, imports of the end-products which could be manufactured in the country concerned provided that the basic petrochemical raw materials were available would have to be taken into account.

Furthermore, since there is no market for petrochemical products, as such, but rather a market for chemical products, some of which can, for economic reasons and because of the availability of raw materials, be made in petrochemical factories, any assessment of the Latin American market's demand for these products will have to take into consideration the possibility that substitutes may be found for certain raw materials in existing chemical industries now using derivatives of coal or of vegetable products (ethyl alcohol, glycerine, etc.).

It is not, however, the purpose of this report to analyse the Latin American market for petrochemical products in such great detail. In any case, the information which can be gleaned from various national sources concerning the present and future market for the main items is, generally speaking, incomplete and in some instances contradictory; moreover, it must be pointed out that when the ECLA 1960 survey of the region's chemical industry was being prepared, information was obtained directly from the various countries on growth trends in the demand for the different groups of chemical products, according to their uses, on the basis of which country estimates of the demand for the principal end-products in 1965 and 1970 were drawn up.

On the basis of the data provided in this survey on the possible expansion of demand in the Latin America countries for the principal end-products and of the information obtained in 1960 concerning the probable demand for certain primary and intermediate products, twenty-four chemical products of petrochemical origin were selected and projections were made of the demand for each of them in 1970 in the various countries of the region (see table 8).

This sample shows that the demand for these products in Argentina, Brazil, Mexico and Venezuela will represent three quarters of the total demand for them in Latin America, the percentage for Brazil being 32, for Argentina and Mexico approximately 19 each, and for Venezuela 6.

With regard to the plastics market, the rise in demand is due to a rapid substitution process in respect of traditional materials, such as paper, metals, wood and leather, in new branches producing consumer goods, in building and in industry. The consumption of plastic materials is continuing to expand in the various countries with the rise in the number of consumers and in income levels.

Using the criteria described in the survey, table 8 gives projections for 1970 of Latin American consumption of polystyrene, polyethylene, phthalic plasticizers and methanol, which are typical products of the plastics sector. There is a general tendency to manufacture these items from the basic petrochemical raw materials. Vinyl products were excluded as being more closely associated with the electrolyte industries, which use chlorine and acetylene produced from calcium carbide.

The textile industry is an important user of the products of the chemical industry in general, and of petrochemicals in particular, for the manufacture of synthetic fibres (polyamides, polyester, acrylics and vinylics). The range of synthetic fibres is very wide and, because of the intense competition between them and artificial fibres derived from cellulose and among the synthetic fibres themselves and because the market for most of these fibres is still in its infancy, the projections of demand for some products used in this branch of industry and shown in table 8

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[1] See ECLA, *La industria química en América Latina* (United Nations publication, Sales No.: 64.II.G.9).

TABLE 1. LATIN AMERICA: IMPORTS OF SELECTED CHEMICAL PRODUCTS REPRESENTATIVE OF THE PETROCHEMICAL INDUSTRY FOR SEVEN COUNTRIES, 1961 AND 1962

(Tons)

Product	Argentina		Brazil		Chile		Colombia		Mexico		Peru		Venezuela		Total	
	1961	1962	1961	1962	1961	1962	1961	1962	1961	1962	1961	1962	1961	1962	1961	1962
1. Methanol	2,486	9,265	1,825	6,727	284	370	980	2,120	4,423	4,897	58	32	209	364	10,400	23,775
2. Isopropyl alcohol	31 ᵃ	35 ᵃ	1,006	2,140					286	1,928			1,896	1,796	3,219	5,899
3. Acetone	30	4	2	1	82	64	782	937	3,158	2,754	341	467	677	650	4,957	4,854
4. Polyethylene	7,600 ᵃ	7,500 ᵃ	2,208	4,846		2,400 ᵃ	2,264	2,407							12,104	17,653
5. Styrene	7,400 ᵃ	5,200 ᵃ	2,017	1,906		326			5,089	4,914					14,526	12,515
6. Polypropylene	120 ᵃ	200 ᵃ	6			1,282 ᵃ	1,276	1,304							1,402	2,786
7. Phenol	40 ᵃ	201 ᵃ	301	334	15	20	158	319	1,262 ᵃ	1,525 ᵃ	6	1	329	57	2,171	2,457
8. Benzene	3,781	3,897	10,546	10,068			16	19	18,016	16,643	2	2	2,761	4,054	35,073	34,614
9. Toluene	…	…	4,355	5,129	152	190	20	128	19,809	14,364	201	251			24,537	20,062
10. Ammonia	7	21	12	13	114	55	386	254	63,994	35,343	70	46	823	771	65,324	36,504
11. Urea	4,300 ᵃ	5,600 ᵃ	14,579	13,975	332	908	315	414	26,725 ᵇ	31,016 ᵇ	316	156	831	1,814	47,428	53,893
12. Ammonium sulphate	12,782	4,394	126,408	117,752	300	173	9,804	4,884	1	3			19,197	19,453	168,662	146,659
13. Ammonium nitrate	2,307	725 ᵃ	1,322	1,426	7,407	7,992	1,016	833	11,595	840	11,514	5,109	2	7	35,303	26,930
14. Synthetic rubber	19,285	16,975	21,630	17,547	2,792	1,561	5,088	7,246	21,405	23,542	1,504	1,794	8,313	11,516	80,018	80,081
15. Carbon black	14,080	12,893 ᶜ	6,821	6,538	2,137	1,338	3,587	4,812	9,346	11,405	1,671	1,938	5,404	4,422	43,646	43,206

SOURCE: Foreign trade yearbooks of the countries concerned.

ᵃ Data based on information supplied directly by national institutions.

ᵇ Includes urea-based chemical fertilizers. Imports of technical-grade urea were 1961 — 2,801 tons, 1962 — 4,299 tons.

ᶜ According to direct information, imports for 1962 apparently amount to 17,370 tons.

TABLE 8. LATIN AMERICA: PROJECTION OF DEMAND FOR SOME PETROCHEMICAL FINISHED AND INTERMEDIATE PRODUCTS IN SEVEN COUNTRIES, 1970

Product	Argentina		Brazil		Chile		Colombia		Mexico		Peru		Venezuela		Sub-total		Other countries		Total	
	Thousand tons	Percentage	Thousand tons	Percentage	Thousand tons	Percentage	Thousand tons	Percentage	Thousand tons	Percentage	Thousand tons	Percentage	Thousand tons	Percentage	Thousand tons	Percentage	Thousand tons	Percentage	Thousand tons	Percentage
Finished products																				
Polystyrene	14.0	22.7	23.0	37.3	2.8	4.5	2.0	3.2	9.0	14.6	2.0	3.2	1.7	2.7	54.5	88.2	7.3	11.8	61.8	100
Polyethylene	25.6	18.1	44.8	31.8	2.7	1.9	8.1	5.7	26.4	18.7	4.1	2.9	8.1	5.7	119.8	84.8	21.5	15.2	141.3	100
DDT	0.8	7.8	1.5	14.6	—	—	0.1	0.9	6.9	67.0	0.2	1.9	0.8	7.8	10.3	100.0	—	—	10.3	100
BHC	2.6	19.9	4.0	30.9	0.5	3.8	0.8	6.2	3.0	23.0	0.8	6.2	0.5	3.8	12.2	93.8	0.8	6.2	13.0	100
Polyamide fibres	20.0	20.0	35.0	35.0	3.6	3.6	7.0	7.0	15.0	15.0	2.7	2.7	3.5	3.5	86.8	86.8	13.2	13.2	100.0	100
Synthetic rubber SBR	35.0	17.1	55.0	26.9	6.0	2.9	10.5	5.1	40.0	19.5	6.0	2.9	18.5	9.0	171.0	83.4	34.0	16.6	205.0	100
Rubber, cis-polybutadiene	15.0	22.2	27.0	40.0	1.0	1.5	2.5	3.7	10.0	14.8	1.0	1.5	4.0	5.9	60.5	89.6	7.0	10.4	67.5	100
Carbon black	21.0	15.0	40.0	28.6	4.5	3.2	7.0	5.0	29.0	20.7	4.5	3.2	11.0	7.9	117.0	83.6	23.0	16.4	140.0	100
Phthalic plasticizers	9.5	15.7	21.0	34.7	2.5	4.1	3.0	5.0	9.0	14.9	2.5	4.1	4.0	6.6	51.5	85.1	9.0	14.9	60.5	100
Urea	21.0	3.6	218.0	37.8	—	—	46.0	7.9	118.0	20.4	35.0	6.0	12.0	2.1	450.0	77.8	128.0	22.2	578.0	100
Primary and intermediate products																				
Methanol	15.0	18.5	28.0	34.7	3.5	4.3	6.0	7.4	15.0	18.5	1.0	1.2	3.5	4.3	72.0	88.9	9.0	11.1	81.0	100
Formol	17.0	16.7	35.0	34.3	5.5	5.4	8.5	8.3	20.0	19.6	2.0	2.0	3.0	2.9	91.0	89.2	11.0	10.8	102.0	100
Acetone	4.5	13.6	8.5	25.8	1.0	3.0	2.2	6.6	7.8	23.7	1.0	3.0	3.0	9.1	28.0	84.8	5.0	15.2	33.0	100
Iso-propyl alcohol	6.0	12.5	8.5	17.7	1.5	3.1	3.5	7.3	13.0	27.1	1.5	3.1	5.5	11.5	39.5	82.3	8.5	17.7	48.0	100
Styrene	25.5	20.1	41.5	32.8	5.0	3.9	5.0	3.9	21.5	16.9	4.0	3.1	7.0	5.5	109.5	86.2	17.5	13.8	127.0	100
Phthalic anhydride	5.3	14.3	12.2	33.1	1.7	4.6	2.2	5.9	6.7	18.1	1.5	4.0	2.4	6.5	32.0	86.5	5.0	13.5	37.0	100
Ethylene glycols	3.5	16.7	7.0	33.3	1.0	4.8	2.0	9.5	4.0	19.0	0.5	2.4	0.5	2.4	18.5	88.1	2.5	11.9	21.0	100
Iso-octyl alcohol	6.5	15.8	15.0	36.6	1.5	3.7	2.0	4.9	6.0	14.6	1.5	3.7	2.5	6	35.0	85.4	6.0	14.6	41.0	100
Adipic acid	17.1	22.5	35.0	46.1	3.0	3.9	5.0	6.6			2.1	2.8	3.0	3.9	65.2	85.8	10.8	14.2	76.0	100
Caprolactam	10.5	21.0	6.0	12.0	2.0	4.0	4.4	8.8	16.5	32.8	1.5	3.0	1.9	3.8	42.8	85.4	7.3	14.6	50.1	100
Cyclohexane	27.0	21.6	37.0	29.6	5.0	4.0	9.5	7.6	20.0	16.0	3.5	2.8	5.0	4.0	107.0	85.6	18.0	14.4	125.0	100
Phenol	18.0	39.0	13.0	28.3	1.5	3.3	1.5	3.3	7.0	15.2	0.4	0.9	1.5	3.3	42.9	93.3	3.1	6.7	46.0	100
Dimethyl terephtalate	8.5	21.2	1.60	40.0	1.2	3.0	3.6	9.0	4.0	10.0	0.8	2.0	1.2	3.0	35.3	88.2	4.7	11.8	40.0	100
Benzene	68.0	21.6	105.0	33.5	12.0	3.8	12.0	3.8	50.0	15.9	9.0	2.9	17.0	5.4	273.0	86.9	40.0	13.1	313.0	100
Dodecyl benzene	6.0	8.3	17.0	23.6	2.5	3.5	4.0	5.5	24.0	33.4	2.5	3.5	6.0	8.3	62.0	86.1	10.0	13.9	72.0	100
Ethylene	40.0	15.0	73.0	27.4	5.5	2.1	16.0	6.0	78.0	29.4	6.0	2.2	16.0	6.0	234.5	88.1	31.5	11.9	266.0	100
Ammonia	58.0	5.5	345.0	33.0	6.0	0.6	64.0	6.1	282.0	26.8	56.0	5.3	29.0	2.7	840.0	80.0	210.0	20.0	1,050.0	100

generally represent no more than potential demand as calculated in 1960, the year in which the survey was carried out. The projected distribution presupposes the development of a chemical or petrochemical industry capable of supplying at reasonable prices the raw materials required for at least the principal synthetic fibres.

With regard to future demand for the two main types of synthetic rubber, the figures shown in table 8 were obtained from projections made in anticipation of an increase in the motor vehicle parts. The distribution of consumption between the two types of synthetic rubber (styrene-butadiene rubber and the stereoisomeric types) will probably not conform to the proportions shown in table 8 for the different countries. Recent technological advances have improved the prospects for replacing natural rubber by synthetic types (the stereoisomers cis-polybutadiene and polyisoprene) and this could result in a greater demand for the latter products at the expense of the older copolymer styrene-butadiene (SBR).

Finally, some Latin American countries already produce synthetic detergents as a substitute for soap on a large scale. This happens in Mexico and Venezuela, where such substitution exceeded 30 per cent and 50 per cent respectively in 1959. The trend is in the opposite direction in countries which have ready access to supplies of oils and fats on good terms and also a well-established soap industry; where there has been an increase in demand in these countries, it has been due entirely to the introduction of foreign capital and technology designed to expand consumption. Thus, in Argentina and Brazil the use of detergents is still in its infancy, but it is assumed that although the process of replacing soap by synthetic detergents has been slow to start, particularly in Brazil, the demand for dodecyl benzene is bound to grow within a few years, at least until such time as the open-chain alkylates produced from normal paraffins or from the alpha-olefins are readily available on those markets.

Once the demand for certain chemical end-products shown in table 8 was known and account had been taken of the projects which were being considered in 1960 for the manufacture of those products in some countries it was possible to work out the demand for certain intermediate products for the chemical industry which could be manufactured from the basic petrochemical raw materials. Projections were therefore made of the demand for benzene, phenol, cyclohexane, caprolactam, iso-propyl alcohol and formol; these projections may be more accurately described as potential demand in the different countries if existing projects for the manufacture of the respective end-products are executed.

With regard to the demand for nitrogenous fertilizers, the above-mentioned survey included an estimate of the probable consumption of these fertilizers for the years 1965 and 1970. Table 9 gives a projection of the demand for nitrogenous fertilizers for 1970, expressed in tons of nitrogen. Of the total demand of the region for these products in 1970, Brazil's share will be 31.5 per cent, followed by Mexico with 24.5 per cent, Peru with 9.3 per cent, Colombia with 5.5 per cent, Argentina and Chile with 3.9 per cent each, and Venezuela with 2.4 per cent. As regards the low figure projected for Argentina, it should be pointed out that there the consumption of fertilizers is still in its infancy (0.9 kg per hectare), because extensive agriculture is practised and vast areas of farm land are available (there is over one hectare per head of population as compared with the average of 0.2 hectares for the seven countries).[4]

TABLE 9. LATIN AMERICA: PROJECTION OF DEMAND FOR NITROGENOUS FERTILIZERS IN 1965 AND 1970

(Tons of nitrogen)

Country	1970
Argentina	36 000
Brazil	286 000
Chile	35 000
Colombia	50 000
Mexico	223 000
Peru	85 000
Venezuela	22 000
TOTAL	737 000
Other countries	174 000
GRAND TOTAL	911 000

SOURCE: ECLA: *La industria química en América Latina*, United Nations publication, Sales No.: 64.II.G.6.

5. THE PETROCHEMICAL INDUSTRY TODAY

The pre-conditions for the establishment of petrochemical plants are determined by a multitude of closely interrelated factors, which vary widely not only from one country to another but often between different areas of the same country. The main factors influencing the siting of such plants include the supply and production cost of basic raw materials, the distances between the sources producing these materials, the location of the chief consumption areas, costs of transport for raw materials and products, national demand, export opportunities, competition of petrochemical products with products derived from other sources and, lastly, the existence of financial resources in the event that manufacture of the product is economically and technologically feasible.

Despite the availability of large amounts of natural gas and petroleum in a number of countries and despite the interest of governments and entrepreneurs, there are still relatively few plants in operation or under construction in Latin America. One reason for this is that the national markets for most of the products are even smaller than the minimum economic capacities of the plants; another reason is the large investments required for the establishment of these industries which in some cases exceed the financial capacity of national entrepreneurs. In addition, the technical skills needed for the industrial processes are in short supply and, as a general rule, the latter are controlled by the international enter-

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[4] ECLA: *La industria química en América Latina*, op. cit.

prises that have traditionally supplied the Latin American market.

These factors may be responsible for the fact that some petrochemical industries have not been found to be highly profitable investments in Latin America, as they usually are in countries with a higher level of industrial development. The production costs of some of those industries which satisfy national consumer markets are higher than the prices offered in the international market by the large exporting companies.

This happens, for example, in the case of a number of Latin American ammonia plants. Apart from administrative difficulties in plant operation deriving from the limited experience of the entrepreneurs in such industrial activities, these plants require considerably higher investments per unit of production than the large export enterprises situated outside Latin America and, in some cases, even in the region itself.

For ammonia, nitrogenous fertilizers and most petrochemical products, the scale of a plant's production is an extremely important element in its economy of production.[8]

Consequently, the economic viability of the smaller ammonia-producing plants now operating in some countries of the area and of future plants whose capacity is geared to national markets will be limited not only because of higher production costs but also because of the need to compete with the cheaper ammonia produced by large enterprises in countries close to the region. In order to offset this disadvantage, these plants should be granted special concessions by Governments in the form of exemptions or subsidies, or else they should belong to State enterprises.

In the Latin American petrochemical industry there is also a tendency to group a number of plants at a single site, either because raw materials or power is available under favourable conditions or because an important consumption centre is situated nearby. Both in petroleum refining and in the petrochemical industry, the desire to keep investment and production costs to a minimum has favoured the establishment of industrial complexes so integrated that the costs of the services and infrastructure needed for a developing region are distributed among the inputs of a large number of plants and the corresponding products. Similarly, the integration of the plants producing basic petrochemical raw materials with refining units or with units of plants that consume natural gas is designed to enable these raw materials to be manufactured at lower prices, thus contributing to the expansion of the petrochemical industry in Latin America.

Table 10 lists the petrochemical plants now in operation or under construction in Argentina, Brazil, Colombia, Mexico, Peru and Venezuela. A number of other petrochemical projects are under study or have been announced in various countries, but no recent information is available concerning the progress made.

The table also shows that many of the Latin American petrochemical plants are concentrated in certain areas in the form of industrial complexes. Thus, in Argentina there is such an industrial complex at San Lorenzo (Santa Fe); in Brazil a concentration of plants already exists at Cubatão (São Paulo) and another is being established at Caxias (Rio de Janeiro). In Venezuela there is the Morón complex. In Mexico, complexes based on natural gas are being built at Pajaritos and Reynosa and others, based on refinery by-products, at Minatitlan and Tampico.

Table 10 provides a picture of the situation of the petrochemical industry in Latin America, indicating the principal basic petrochemical raw materials which are already being used in the region, their origin and the other manufactures for which they are now used or will be used in the future.

6. SOME ASPECTS OF PRESENT INSTITUTIONAL CONDITIONS

Since natural gas and petroleum derivatives are the original raw materials of the entire petrochemical branch of industry, the character of this activity is different from that of the traditional chemical industry not only because of the nature of its products and the technologies used but also because of the geographical location of the plants and the economic and institutional conditions which influence its development.

The petrochemical industry based on natural gas uses a natural raw material whose composition varies with the geological features of each productive deposit; only on very rare occasions can the raw material be used for industrial purposes in the state in which it is obtained from the deposits. In most cases, special treatment is necessary, as a rule, this is economically justifiable when considerable amounts of gas are used by some large consumption centre as an industrial or household fuel. Since natural gas can be economically transported by pipeline over reasonable distances, the petrochemical industries using it should be situated near the deposits themselves or along the pipelines.

Because of these two circumstances which make the petrochemical industries based on natural gas dependent on the operations of the petroleum enterprises that work the gas deposits, it is extremely important to know the institutional system in force in the petroleum industry of each country and the facilities which this system can make available for the development of the petrochemical industry.

In those countries where petroleum activities are based on the system of long-term concessions granted to private enterprises (Peru, Venezuela and Colombia), the possibilities of using natural gas as a raw material for the petrochemical industry depend on the concessionaires' own policy as regards the expansion of their activities and the flow of new investment into the country. Since these concessionaires are usually enterprises whose operations are international in scope and which have at their disposal, in their countries of origin or at other

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[8] As regards economies of scale, see *La industria quimica en América Latina*, op. cit., chapter V and annex XVIII; *Studies in Economies of Industry: Cement/Nitrogenous Fertilizers based on Natural Gas*, United Nations publication, Sales No.: 63.II.B.3; and *Economias de escala en la industria quimica* (ST/ECLA/Conf. 11/L.17).

TABLE 10. LATIN AMERICA: PETROCHEMICAL PLANTS IN OPERATION OR UNDER CONSTRUCTION

Tons per year

Basic raw materials and primary or intermediate products	*Company and country*	*Present capacity*	*Future capacity*	*Probable start of operation*	*Production from*	*Used in the manufacture of*	*Present capacity*	*Future capacity*	*Probable start of operation*	*Remarks*
	IPAKO — Argentina (Ensenada, BA)	13,200	—	—	Residual gases	Polyethylene	10,000			
						Styrene		15,000	1965	
	PASA — Argentina (San Lorenzo, SF)	—		1965	Liquefied gas	Styrene		14,000		
	Duperial — Argentina (San Lorenzo, SF)	—	10,000		Naphtha	Polyethylene		10,000		
	PETROBRAS — Brazil (Cubatão, SP)	18,000	33,000	1965	Residual gases and naphtha	Polyethylene	11,000	20,000		For Union Carbide
Ethylene						Polyethylene	4,000	8,000	1966	For Eletroteno
						Styrene	10,000			For C. B. Estireno
	Ecopetrol — Colombia (...)	—	13,400							
	PEMEX — Mexico (Reynosa, Tams.)	—	36,000	1964	Ethane	Polyethylene		18,000	1966	
						Ethylene oxide		12,000	1966	
	PEMEX — Mexico (Pajaritos, Ver.)	—	36,000	1964	Ethane	Acetaldehyde		24,000	1966	
						Vinyl chloride		18,000	1965	
						Ethyl chloride		12,000	1965	
Propylene	YPF — Argentina (San Lorenzo, SF)				Residual gases	Isopropanol	1,200			
	PETROBRAS — Brazil (Cubatão, SP)	5,000	17,000	1965	Residual gases and naphtha	Isopropanol	4,200			For Rhodia
Butadiene	PASA — Argentina (San Lorenzo, SF)	—	32,000		Butane	SBR		35,000		
						Poly-cis-butadiene rubber		10,000		
	PETROBRAS — Brazil (Caxias, RJ)	—	30,000	1966	Butane	SBR	40,000			
Benzene	PASA — Argentina (San Lorenzo, SF)	—	26,000 *	1965	Naphtha	Styrene		14,000		
	PETROBRAS — Brazil (Cubatão, SP)	—	28,500	1965	Naphtha	—	—			Various customers
	PEMEX — Mexico (Minatitlán, Ver.)	—	105,000	1965	Naphtha	Dodecylbenzene	23,000			
						Dodecylbenzene		15,000		
						Cyclohexane		23,000		
Toluene	Fabricaciones Militares — Argentina (Campana, BA)	3,000	—	—	Naphtha	TNT			—	
	PASA — Argentina (San Lorenzo, SF)	—	26,000 *	1965	Naphtha	—	—			Various customers
	PEMEX — Mexico (Minatitlán, Ver.)	—	11,000	1965	Naphtha	—	—	—	—	Various customers
Xylenes	PEMEX — Mexico (Minatitlán, Ver.)	—	45,000	1966	Naphtha	—	—	—		Various customers

TABLE 10. LATIN AMERICA: PETROCHEMICAL PLANTS IN OPERATION OR UNDER CONSTRUCTION (continued)
(Tons per year)

Basic raw materials and primary or intermediate products	Company and country	Present capacity	Future capacity	Probable start of operation	Production from	Used in the manufacture of	Present capacity	Future capacity	Probable start of operation	Remarks
Ethylbenzene	PETROBRAS — Brazil (Caxias, RJ)	—	12,000		Naphtha	Styrene		12,000		
	PEMEX — Mexico (Minatitlán, Ver.)	—	18,000		Naphtha	Styrene		15,000		
Methanol	ATANOR — Argentina (Río Tercero, Córdoba)	—	10,000	1965	Natural gas	Formaldehyde	12,000		—	
	Casco — Argentina (Pilar, BA)	8,000	30,000	1967	Natural gas	Formaldehyde	6,500		—	
	ALBA — Brazil (Cubatão, SP)	10,000	18,000		Fuel oil	Formaldehyde	10,000		—	
	I.N.Q.F. — Mexico	—	15,000	1966	Natural gas	Formaldehyde				
Carbon black	Cabot — Argentina (Campana, BA)	13,000	—	—	Aromatic residues		—	—		
	PASA — Argentina (San Lorenzo, SF)	—	12,000		Aromatic residues	—	—	—		
	COPEBRAS — Brazil (Cubatão, SP)	18,200	—	—	Aromatic residues	—	—	—	—	
	C.C.C. — Brazil (Candeas, Ba.)	—	15,000		Aromatic residues	—	—	—		
	NEGROMEX — Mexico (Salamanca, Gto.)	15,000	—	—	Aromatic residues	—	—		—	
	United Carbon — Venezuela (Valencia)	6,350			Aromatic residues					
Carbon disulphide	DUPERIAC — Argentina (San Lorenzo, SF)	14,000	—	—	Natural gas	—	—	—	—	
Sulphur	PEMEX — Mexico (Poza Rica, Ver.)	40,000	—	—	Natural gas	—	—	—		At Poza Rica
	PEMEX — Mexico (Atzcapotzalco, DF)	11,000	—	—	Natural gas	—	—	—		At Atzcapotzalco
	PEMEX — Mexico (C. Madero, Tams.)	11,000	—	—	Natural gas	—	—	—		At Ciudad Madero
Ammonia	PETROBRAS — Brazil (Cubatão, SP)	33,000	—	—	Residual gases	Fertilizers *				At Cubatão
	PETROBRAS — Brazil (Camacarí, Ba.)		66,000		Natural gas	Urea	—	75,000		At Camacarí
	AMOCAR — Colombia (Cartagena)	90,000			Residual gases	Urea Fertilizers *	30,000			For ABOCOL
	Colombiana de Fertilizantes — Colombia (Barrancabermeja)	30,000	—	—	Natural gas	Fertilizers *				For ABOCOL
	PERTISA — Peru (Callao, Lima)	18,000	—	—	Fuel oil	Urea Fertilizers *	9,000	—		

Ammonia	I.V.P. — Venezuela (Morón)	33,000	—	—	Natural gas	Fertilizers [b]				
						Urea	16,500			
	GUANOMEX — Mexico (Cuantitlán), Ver.)	20,000	—	—	Natural gas	Ammonium sulphate	100,000			
	PEMEX — Mexico (Minatitlán, Ver.)	60,000	—	—	Natural gas	Fertilizers [b]				At Minatitlán
						Urea	46,000	—	—	At Minatitlán
	PEMEX — Mexico (Salamanca, Gto.)	60,000	—	—	Natural gas	Fertilizers [b]				At Salamanca
						Urea	97,000	—		At Salamanca

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[a] The figure of 26,000 tons per year represents the total capacity for benzene and toluene.

[b] "Fertilizers" covers the manufacture of both simple nitrogenous fertilizers in their various forms and also of complex fertilizers. For this reason, the table does not show the individual capacities of existing plants or the total of these capacities.

more convenient sites, a number of petrochemical plants established exclusively for export purposes, their interest in the development of the petrochemical industry in Latin America has not, up to the present, gone further than the exploratory stage, chiefly because national markets are small and there is little opportunity for intra-regional trade.

Petrochemical processes are the result of recent technological advances which, in most cases, require a high level of technical skill and reasonable financial resources. These two important requisites are readily available to the large enterprises which hold concessions to work the main petroleum deposits of the region, but not to those countries which do not use the concession system and whose petroleum industry is a State responsibility. In addition such countries require ample resources for developing their petroleum activities, and it should be pointed out that only a very small part of their resources is channelled into the petrochemical industry.

Furthermore, it is difficult to achieve satisfactory results in the foreign credit negotiations undertaken by national institutions to promote investment in the petrochemical industry unless these negotiations are supported by preliminary agreements on licensing, the use of patents, and the provision of the technical assistance required by these industries. Negotiation of such agreements with regard to the more modern processes that will lead to a possible cut in production costs is very often extremely difficult owing to the conflict of commercial interests between the grantor and the concessionnaire.

As regards the utilization of petroleum refineries as a source of basic raw materials, a further consideration is the fact that the situation in each country is probably closely related to the system of ownership of its refineries, i.e., whether their operation is in the hands of the State or of national private enterprises. In Mexico, Brazil, Cuba, Uruguay, Chile and Bolivia, all the refineries are owned by State enterprises or national private concerns. In Argentina, a little more than two thirds of installed capacity belongs to the State or national enterprises, and, in Colombia, about 50 per cent of oil refining is under State control (see table 11).

As has been said, a factor of great economic significance is the integration of petrochemical raw material production either with refinery units or with actual petrochemical plants. In the former case, the position of the refinery in supplying the fractions required is very important, and the control of intermediate operations lies to a large extent in the hands of the enterprises which operate the major refineries in each country. The nature and quantities of petroleum derivatives which a refinery is capable of supplying to the petrochemical industry depend principally on the operations carried out by this refinery and its processing capacity, i.e., they are dependent exclusively on technical and economic factors relating to the refining operation itself. Thus, the petrochemical plant may be compelled to determine the nature and volume of its products in the light not only of market possibilities but also of the capacity of its suppliers.

The Latin American refineries capable of supplying raw materials are generally widely scattered throughout each country. There are no concentrations of large-capacity refineries to lessen the dependence of the petrochemical plant on the operations of a single refinery. This operational dependence is even more marked in the case of the petrochemical and petroleum industries, owing to the long-term contract signed between the chemical and petroleum enterprises for the supply of the quantity and quality of raw materials required by the former for its operations. On the other hand, by reason of this

TABLE 11. LATIN AMERICA: OWNERSHIP OF OIL REFINERIES, 1963

Country	*National enterprise* [a]		*United States enterprise*		*European enterprise*		*Total*
	Thousands of barrels per day	*Percentage*	*Thousands of barrels per day*	*Percentage*	*Thousands of barrels per day*	*Percentage*	
Venezuela	2.3	0.2	748.6	70.0	319.6	29.8	1,070.5
Mexico	419.0	100	—	—	—	—	419.0
Argentina	233.7	62.7	75.0	20.1	64.0	17.2	372.7
Brazil	298.9	100	—	—	—	—	298.9
Colombia	46.0	48.8	48.3	51.2	—	—	94.3
Cuba	86.9	100	—	—	—	—	86.9
Peru	0.8	1.4	55.5	98.6	—	—	56.3
Uruguay	51.0	100	—	—	—	—	51.0
Chile	47.6	100	—	—	—	—	47.6
Ecuador	—	—	4.2	27.1	11.3	72.9	15.5
El Salvador	—	—	13.9	100	—	—	13.9
Bolivia	11.5	100	—	—	—	—	11.5
Nicaragua	—	—	5.6	100	—	—	5.6
Guatemala	—	—	3.8	100	—	—	3.8
TOTAL	*1,197.7*	*47.0*	*954.9*	*37.5*	*394.9*	*15.5*	*2,547.5*

SOURCE: *Oil and gas Journal.*

[a] Private and public enterprises.

agreement, the petroleum enterprise is often obliged to make additions or alterations in the plan of operations of the refinery for the sole purpose of supplying the raw material laid down in the contract.

This situation of the petrochemical industry with respect to refining has contributed towards the penetration of the petrochemical industry by the petroleum enterprises in the more industrially developed countries, and the same tendency has been noted in the Latin American countries. The price arrangement whereby the refinery undertakes to supply the petrochemical plant with a given fraction of the petroleum produced is nearly always a negotiation on which the interests of the two parties cannot be completely reconciled.

For this reason, in those Latin American countries where petroleum operations are mainly carried out by State enterprises, the government is extremely interested in making use of the possibilities of developing the petrochemical industry on the basis of the products of their refineries. This same concern naturally exists also in Venezuela and Colombia, whose State enterprises are now engaged in preparing plans for the expansion of their activities and for launching into new branches of the petrochemical industry.

At the present time, the Latin American market for petrochemical products is supplied to a great extent by the products of the large established concerns of the chemical industry. These products may come from various sources, namely, plants outside the region, plants set up in countries of the region by firms affiliated to or associated with these large concerns, with some financial participation; and even national enterprises licensed by the latter. This explains the permanent interest of international enterprises in the development of the petrochemical industries in the region, which would affect their exports to Latin America. In addition, the national enterprises, generally speaking, are at the stage of vertical integration of their production, and are trying to enter the petrochemical sector by replacing imports by products of local manufacture.

These two powerful and sometimes conflicting interests, together with the plans of State enterprises to participate in the stage subsequent to the simple production of basic petrochemical raw materials, have led the Latin American governments to take a very direct interest in promoting the development of the petrochemical industry in their countries. Thus, in Argentina and Mexico, the legislative bases have been laid for promoting the development of their petrochemical industries.

The need for governmental decisions and guidance in the development of the petrochemical industry in each country is justified by the fact that it is an activity which usually requires large investments beyond the financial means of the national enterprises and because, nearly always, plants are installed which have capacities that exceed national requirements and which therefore monopolize the markets which they supply.

In the case of Mexico, the existing legislation on this matter lays down that it is the prerogative of the nation, "through Petróleos Mexicanos or through organs or undertakings subsidiary to this institution or associated with it established by the State, in which private individuals may not participate financially in any form to manufacture those products which can serve as basic industrial raw materials, which result from the petrochemical processes based on the first important chemical transformation of refinery products or by-products or natural hydrocarbons of petroleum or are of fundamental economic and social interest to the State."

The processing of products derived from petrochemical processes subsequent to those mentioned above "constitutes the field in which operations may be carried out indifferently, without exclusivity, by the State or by private enterprise alone or in association with the State, through Petróleos Mexicanos or organs or enterprises subsidiary to that institution, associated with it established by the State."

Permits are granted to private investors for the processing of products of the petrochemical industry by express decision of the Federal Government and are subject to the legal provisions applying to foreign investments. The holders of permits are obliged to maintain permanently a minimum of 60 per cent of the capital in the possession of national investors, and, in addition, to sell their products wholesale at prices that do not exceed 15 per cent of current prices in the domestic United States market, provided and to the extent that the raw materials can be acquired in Mexico at prices similar to those mentioned. Apart from such permits, no exemption or fiscal incentive is granted to private investors wishing to establish petrochemical plants in Mexico.

In Argentina, a different principle is followed. Under a decree, basic petrochemical plants are defined as those which begin the productive cycle with petroleum or natural gas, their fractions or distillates, and produce mainly saturated olefin, diolefin, acetylenic, naphthenic or aromatic hydrocarbons and/or sulphur and/or hydrogen.

Petrochemical plants manufacturing one or more of the following products: synthetic rubbers, carbon black, fertilizers, pesticides, weed-killers, phenol resins and plastics, polyethylene, vinyl polychloride, polypropylene and polystyrene can also avail themselves of the benefits of this decree provided that they are combined in a single enterprise or economic complex with the basic plants.

The system in force in Argentina offers the following advantages among others: doubling of income tax and excess profits tax deductions and accelerated amortization of investments for tax purposes; exemption from stamp tax on contracts with State enterprises relating to raw materials; deferment of the tax levied in lieu of the assessment on the gratuitous transfer of property; exemption from customs duties and exchange charges on imports of machinery and equipment; and priority in the supply of raw materials by State organs.

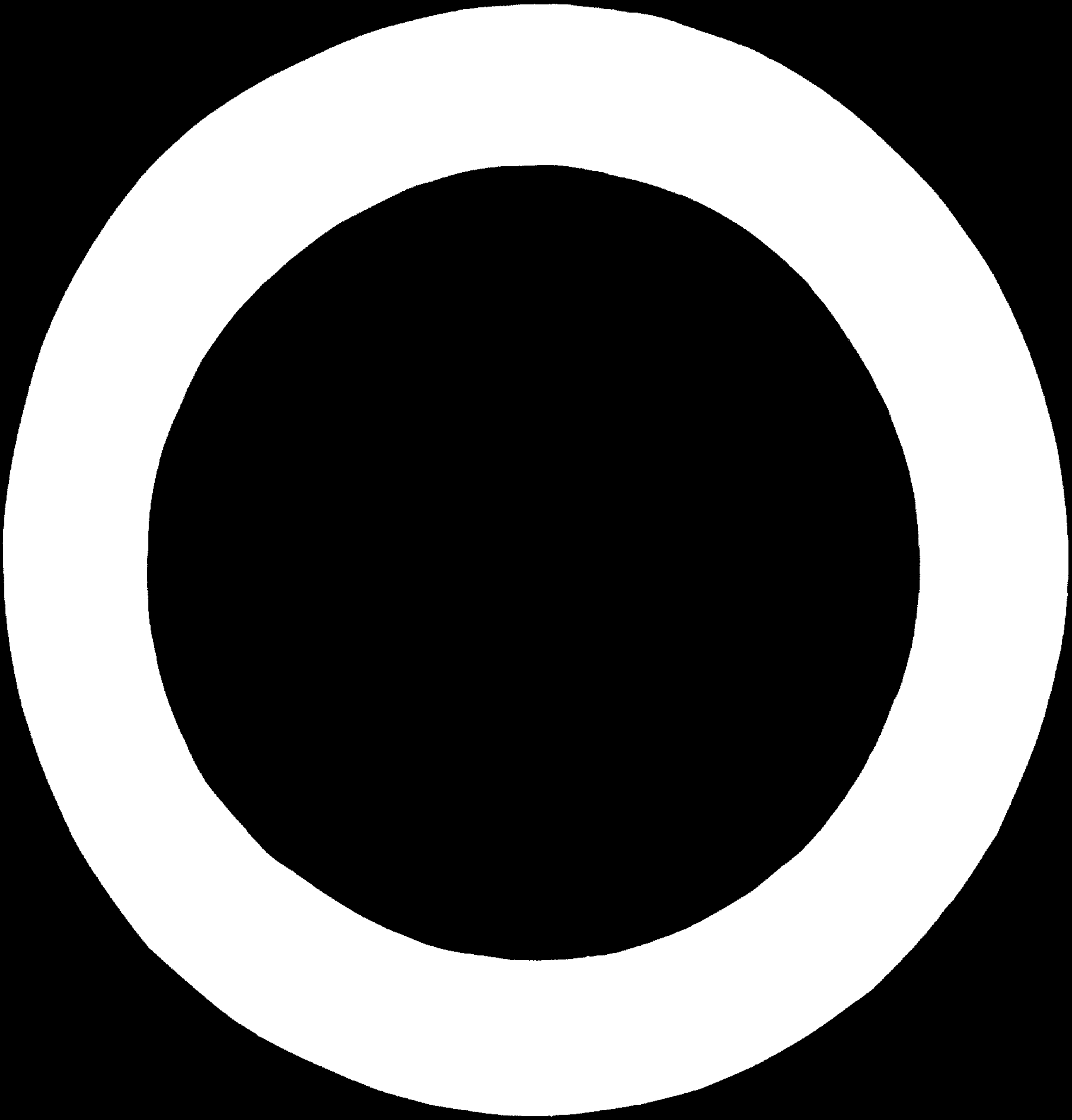
In Colombia, the legislation on industrial development includes the petrochemical industries among basic industrial activities which are exempt from the payment of income tax, but State participation in these activities has not been defined.

In Venezuela, 1956 saw the founding of the Venezuelan Petrochemical Institute, under the control of the Ministry of Mines and Hydrocarbons, the object of which is "the study, establishment, operation and development of industries processing minerals, hydrocarbons and other products related to the petrochemical industry". Information is lacking as to whether Venezuela's legislation on the promotion of industrial development includes any incentives specifically intended for the petrochemical industry or whether it defines the field reserved for private activity in this industrial sector.

In Brazil, whose petrochemical industry began to develop actively in 1954 following the establishment of the State petroleum enterprise, the Government has not yet determined the conditions for the development of this industry nor the scope of action of the State enterprise in industrial activities related to the production of basic raw materials. Under a resolution adopted by the National Petroleum Council in 1957, criteria were laid down to guide this body in approving private proposals for utilizing raw materials derived from petroleum. Such approval, however, does not oblige the State enterprise to supply basic raw materials to the private organization whose proposals have been approved by the Council.

Chapter VII

FINANCIAL AND LEGAL ASPECTS OF THE PETROCHEMICAL INDUSTRY



A. Financial aspects

INTRODUCTORY SUMMARY

In this chapter there is an investigation of the general financial milieu in which petrochemical establishments in different parts of the world operate. In particular, there is an examination of the capital structure and international investment policies of the world major petroleum and chemical concerns.

Capital requirements in the petrochemical industry are relatively high, the industry being amenable to the economies of large-scale operation. In fact, this industry is on the average more capital-intensive than most other capital-intensive industries. This phenomenon should unmistakably be borne in mind in the formulation of any petrochemical project. In general, capital funds are allocated to research and development, fixed capital (plant and equipment), and working capital. The industry has a considerable potential for internal-generation of working capital as the market for the final products is extended.

The major producers of petrochemical products are oil or chemical companies. The oil companies are considered more conservative in their investment policies than the chemical companies. The oil companies tend to rely more on internal sources of funds than the chemical companies.

In developing countries, part of the capital funds will necessarily have to come from the general public, government or institutions. In Japan, for example, the capital structure of the petrochemical industry is as follows:

Source	*Percentage of total capital in use*
Own capital	20
Japan Development Bank	6
Co-operative financing	65
Life insurance	3
Foreign investment	6

In ten years, the capital investment in Japan's petrochemical industry grew to ten times the initial outlay with vigorous government encouragement.

Various agencies — national or international — are interested in serving as sources of funds in the form of loans or outright grants for development projects, either on short- or long-term basis. Notable among these are the International Bank for Reconstruction and Development (IBRD), International Finance Corporation (IFC), Inter-American Development Bank (IDB), United Nations Special Fund, "Foreign Aid" and regional development banks. The IBRD provides loans of 10 to 25 year maturity in foreign exchange at rates ranging from 4 per cent to 6.25 per cent. It also helps with finding private investors to invest in development projects in developing countries. The IFC is interested in investment in specific projects and is permitted, unlike the IBRD, to invest in equity capital in association with private investors. The IDB tries to facilitate and supplement the flow of private capital into development projects in Latin America.

International and national financial institutions often complain against the shortage of credit worthy projects. But it is important to observe that a conservative credit policy is apt to create an illusion of such shortages. It is therefore necessary to ascertain whether the credit policy of the financial institutions is too conservative for industrial development in developing countries or whether there is, in fact, a genuine shortage of credit-worthy projects or may be some combination of the two shortcomings. At times, the low credit worthiness of projects is blamed on the inefficiency of project formulation.

The international agencies would rather encourage developing countries to appeal to the major international petrochemical companies to help them not only with transmission of know-how, but also with provision of funds. The credit-worthiness of these major companies happens to meet the requirements of the international financial institutions. Perhaps a new method of financing might be helpful in the development of the production of such petrochemical products as ammonia and fertilizers in countries where there are considerable petroleum resources.

The United Nations Special Fund, as a source of funds for technical aid to developing countries, provides financial aid for the preparation of pre-investment surveys, construction of training facilities and foundation of research institutes. Funds or real resources can also be transferred bilaterally, either as loans or grants or both, from one country to another as what is now commonly known as "foreign aid". The major givers of this type of aid include the United States (through the Agency for International Development and Export-Import Bank), the United Kingdom (through the Commonwealth Development and Finance Corporations), the USSR, France and Japan. The USSR gives aid to developing countries in the form of long-term credits or technical assistance. Japan aims her aid-giving at the promotion of her inter-

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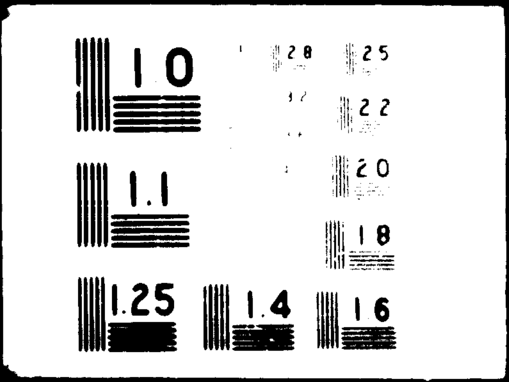

national trade. Although most of these agencies have not made any specific commitments to the promotion of petrochemical projects in developing countries, their financial commitments in other areas might turn out to be of help in the development of petrochemical industries in the countries which desire them. For example, the willingness both of the United States Agency for International Development and the United Nations Special Fund to help with meeting the cost of pre-investment surveys may be useful for petrochemical projects.

As a means of minimizing the problem of heavy capital requirements in the petrochemical industry, "joint-venturing" might be considered. Joint ventures are characterized by some form of international participation in the ownership of the capital of an enterprise. As of 1959, 31 per cent of all foreign investments in developed countries were joint ventures while in developing countries they comprised 17 per cent. There is an expectation that the rate of joint-venturing in developing countries will increase steadily. Developing countries are in general favourably disposed to joint-ventures for the purposes of facilitating a rapid transmission of technical and organizational know-how and forestalling foreign economic domination.

1. FINANCING OF PETROCHEMICAL VENTURES IN DEVELOPING COUNTRIES

Prepared by the United Nations Centre for Industrial Development

I. INTRODUCTION

Capital requirements

The petrochemical industry is typically subject to large economies of scale. The capital cost of a simple synthetic ammonia plant, for example, may be nearly $2.9 million for a unit with 10,000 tons/year of capacity and only $6.7 million for one five times that size.[1] Chiefly as a result of this, the production cost per ton will be about $67 for the larger plant, compared with $107 for the smaller one. In both the chemical and the oil industries, the main producers of petrochemicals, economies of large-scale production play an extremely important role in the ability of a firm to enter the market and to operate successfully. It is therefore clear that the financial requirements of most petrochemical activities, both in terms of the initial capital outlay and of the necessary amount of working capital are very high indeed.

Apart from the immediate implanting costs, petrochemical projects usually require long and costly research programmes for the development of products, processes and raw material sources. A high ratio of sales to investment is therefore necessary in order to recover promptly research and development outlays. The petrochemical industry is thus highly capital-intensive. Some data on petrochemical investment in the United States may illustrate this point: although the average investment went down somewhat from 1952 to 1957, it was still almost $12 million per plant in 1957.[2] It has also been estimated that while the capital cost per barrel per day was[3] about $12,500 in petrochemical plants, it was less than $4,300 in petroleum refineries. Further indication lies in the comparison of different industries as to a very significant financial ratio, the ratio between the value of net fixed assets and total tangible net worth. The median ratios for the period 1950-54 were: 53.9 in industrial chemicals, and 84.3 in petroleum and petroleum products, *versus* ratios of 33.9 for two other capital-intensive industries, industrial machinery and structural steel, and 6.1 for a relatively labour-intensive industry (coats and suits for women).[4] Moreover, there is no indication that the degree of capital intensity in the petrochemical industry is decreasing; instead, Law and Piemonte point out that petrochemical output per dollar invested has been decreasing steadily in recent times, indicating, of course, an increasing marginal capital-output ratio.[5]

We have thus seen that the financial requirements for construction of new petrochemical facilities are likely to be very high, both in an absolute sense and in comparison with other capital-intensive industries. As for the second half of our question, namely, the level of financial operating requirements, the answer is necessarily less definite, owing to the difficulty of obtaining separate financial data for petrochemical activities. The latter are carried out within petrochemical divisions of oil, chemical or other companies, and their results are seldom isolated from the consolidated report of the parent company. However, a good indirect indication may be obtained from the comparison between the chemical and oil industries and other industries, as to various relevant financial ratios. Table I shows the median ratios for the period 1950-54.

Both chemicals and petroleum have excellent indices of profitability compared with the other industries included. Relative total indebtness is higher in the labour-intensive industries; also, although the difference is not very large, it is higher in steel and machinery than in oil and chemicals. The difference in total indebtedness between the labour-intensive and the capital-intensive industries is mostly due to the different degrees of industrial concentration; the larger units that are typical of the capital-intensive industries considered have usually less need to seek outside sources of financing. Also, and more important, the relationship is reversed if only long-term debt is considered: the oil industry has the largest long-term debt/working capital ratio, and the construction industry the smallest. But the most interesting item is, for our purposes, the last one, i.e., the ratio between total net sales and net working capital.

If we discount the relatively low ratio for "coats and suits for women" as due mostly to a characteristic "inflating" of current assets deriving from the marketing necessity to keep large inventories at all times,[6] we can

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[1] P. Leprince, "The Petrochemical Industry", *Proceedings of the United Nations Interregional Seminar on Techniques of Petroleum Development*, New York, 1962.

[2] Bramston Cook, cited by: Robert L. Bateman and Alvan H. Tenney, "Economics of Petrochemicals" in: *Advances in Petroleum Chemistry and Refining*, John J. McKetta, ed.: Interscience Publishers Inc., New York, 1960.

[3] R. O. Law and M. Piemonte, "An Analysis of the Economics of the Petrochemical Industry" *Bureau of Business Research*, University of Oklahoma, 1954.

[4] Roy A. Foulke, *Diversification in Business Activity*, Dun and Bradstreet Inc., 1956.

[5] Op. cit.

[6] On the other hand, one should also take into account the fact that the Building and Construction industry has no inventories in the credal sense of the term, so that the sales working capital ratio is typically high.

TABLE 1. FIVE MEDIAN RATIOS 1950-54 FOR SIX LINES OF BUSINESS ACTIVITY IN[a] THE UNITED STATES
(Five-year average)

Ratios	*Industrial chemicals*	*Coats & suits for women*	*Bldg. & const.*	*Industrial machinery*	*Structural steel*[b]	*Petroleum products*
Current ratio	2.56	2.59	1.88	2.79	2.92	2.14
Net profits as percentage of net sales	6.11	1.22	1.79	4.54	4.05	8.13
Net profits as percentage of net worth	11.25	6.04	11.33	11.09	12.99	12.46
Total debt as percentage of net worth	59.70	104.10[c]	101.20	69.00	68.30	47.90
Long-term debt as percentage of working capital	44.90	45.40[c]	26.20	27.60	27.00	80.70
Net sales: working capital	4.24	5.67	9.98	3.67	4.43	5.72

[a] From the similar table in Foulke, op. cit. The ratios can be considered "normal", since they represent the average (five years) *median* ratio for a very large number of firms in each industry. It should also be pointed out that the fact that the figures are over ten years old presents no difficulty, since such ratios have a tandency to keep fairly constant through limited periods of time.

[b] Sell on short terms.

[c] 1954 only.

see that the capital-intensive industries have the largest working capital requirements relative to the volume of sales (and, of course, even larger requirements in the absolute, since the sales volume is greater in these industries), although no clear difference is noticeable between machinery and steel, on the one hand, and chemicals and oil, on the other. Inverting the ratio, the percentage of working capital on sales is 27.24 per cent for machinery, 23.58 for chemicals, 22.57 for steel, 17.47 for petroleum and 10.02 for building and construction.

Thus the conclusions to be drawn from the ratios shown are the following: the chemical and the oil industries in the United States are comparatively very profitable; they are financially very powerful and take only limited advantage of credit availability; long-term indebtedness makes up a predominant portion of total debt, indicating that outside financing is used only when necessary for long-term plans (typically, capital expenditures of a basic nature); and, finally, that working capital requirements, although not significantly greater than those for other capital-intensive industries, are at a high absolute level, and are higher than those for labour-intensive industries.

We have succinctly shown that petrochemical activities entail very high financial requirements, both in the construction of productive facilities and in their operation. This paper is intended to provide a summary view of the sources and accounts of funds generally available for petrochemical investment and to outline and discuss the main forms of ownership of petrochemical ventures in developing countries. Also, some cases that may illustrate the major financial and economic characteristics of investment in this field are presented.[7]

II. FINANCIAL STRUCTURE OF THE INTERNATIONAL OIL AND CHEMICAL INDUSTRIES

In this section, the operations of the international oil and chemical industries are analysed from a financial stand-point. Appendix II includes a study of prevailing methods of investment financing, and a comparison of selected financial items, especially with regard to the financial stability and practices of each firm examined and to the magnitude of the resources devoted to investment abroad and to petrochemicals.[8] Findings concerning the single items will be discussed later. Let us here comment briefly on recent investment patterns in the two industries.

The oil side of petrochemicals is, as a rule, more cautious in its spending plans than the chemical side. For example, petroleum companies in the United States have allotted 90 per cent of their 1963-66 plant and equipment spending plans to replacement and modernization, while chemical companies have earmarked more than 50 per cent of total capital spending for additional capacity.[9] The gross yearly capital expenditures of the world petroleum industry (excluding exploration expenses) have averaged $10,800 million annually between 1959 and 1962; $1,790 million of which (16.57 per cent) has been allotted to investment in refineries and chemical plants.[10] The following table, from several Chase Man-

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[7] Little information is available on the role of public institutions in petrochemical investment. The interested reader is, however, referred to appendix I for a brief review of the availability and direction of public funds in industrial investment in general and of the prevailing policies of international financial institutions.

[8] Those firms have been selected for study which have a major stake in petrochemicals. Although the list must be considered as purely indicative, it should be pointed out that the firms examined have produced in recent years well over 70 % of total world production of petrochemicals. Those financial items have been extracted from the company reports which bore the greatest relevance to the twofold purpose of the present section, namely, the financing methods of the firms and the resources destined to petrochemical investment.

[9] *Chemical Week*, April 27, 1963, p. 22.

[10] Chase Manhattan Bank, *Capital Investments by the World Petroleum Industry*, 1960; same, 1961, same, 1962.

hattan Bank studies, shows the geographic distribution of cumulative net investment in fixed assets as of December 1962.

Spending on refineries and chemical plants out of total spending has increased in recent years for the world oil industry. For the United States industry, earnings from foreign operations decreased from a peak of about 42 per cent of total earnings in 1958 to 37.2 per cent in 1962.[11] It should be mentioned, however, that the proportion was as low as 32 per cent in 1960; thus, a possible explanation of the 1958-62 decline could be the imperfect recovery from the 1959-60 recession in the United States. At any rate, the Chase Manhattan report attributes most of the 8 per cent increase in earnings from 1961 to 1962 to profitable petrochemical ventures abroad. A further stimulus for the United States oil industry to increase its petrochemical investments could be given by the slow but constant erosion of petroleum prices in recent years.

Although the United States petroleum industry has recently experienced a decline in its working capital, mainly due to a rise in dividend payments and in capital expenditures, so that the cash inflow in 1962 fell short of meeting cash requirements, the industry has typically had very little recourse to outside sources of financing. At the end of 1962 the ratio of debt to total capital employed for the 33 companies examined in the Chase Manhattan report was 13 per cent, the lowest since 1946.

Also noticeable is a trend towards replacing private debt with public debt; the latter constituted 35 per cent of total borrowed capital in 1953 and over 57 per cent in 1962. This financial "autarchy" is enjoyed also by oil companies other than the American ones, although, to be sure, outside sources of funds are used less sparingly by non-United States firms. Table 3 shows the distribution of borrowing by the United States oil industry by sources of funds.

From 1953 to 1962 the world oil industry experienced some decline of the rate of return on invested capital; the return on foreign investment also fell, but it still is significantly higher than the return on domestic investment.

TABLE 2. NET INVESTMENT IN FIXED ASSETS OF THE WORLD PETROLEUM INDUSTRY, DECEMBER 1962[a]

(Million dollars)

Area	*Total*	*Refineries and chemical plants*	*Refineries and chemical plants as per cent of total*
United States	32,150	5,175	16.1
Canada	4,025	440	10.9
Venezuela	2,825	305[b]	10.8[b]
Other Western Hemisphere	3,975	1,035	26.0
Europe	7,700	3,800	49.3
Africa	2,425	150	6.2
Far and Middle East	5,725	1,815	31.6
Unallocated	6,375		
TOTAL	65,200	12,920	19.8

[a] Chase Manhattan Bank, op. cit.

[b] Refineries only; no expenditure on chemical plants.

Overseas investment by the chemical industry has decreased in recent years, but the industry is still one of the leaders in launching foreign ventures. Also in the chemical industry, albeit to a lesser extent than in the oil industry, the emphasis of capital spending plans has recently shifted somewhat to modernization of plants and improvement of processes rather than new construction. As in the oil industry, United States firms have an incontestable supremacy as to financial resources and market penetration potential, while European chemical firms tend to participate in foreign ventures mainly on the commercial and technical level.

Another distinction to be made between chemical companies in the United States and in the rest of the world is that, as a rule, the American companies have a greater degree of financial self-sufficiency. "Cash flow, it seems, will continue to provide most of the capital funds needed by chemical companies".[14] Moreover, according to the financing plans of United States chemical firms, foreign investment will be financed less and less from external overseas sources, from 1963 to 1965,

TABLE 3. SOURCES OF OUTSIDE FUNDS FOR 33 UNITED STATES OIL COMPANIES, 1962[a]

Source	*Borrowing*	*Preferred stock*	*Common stock*	*Combined total*	*Percentage of total*
Public	232	70	103	405	59.8
Banks	175	0	175	175	25.9
Insurance Cos.	19	0	0	19	2.8
Others	78	0	0	78	11.5
TOTAL	504	70	103	677	100.0
Percentage	(74.4)	(10.3)	(15.2)	(100.0)	

SOURCE: Chase Manhattan, *Financial Analysis, etc.*, op. cit.

[a] Million dollars.

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[11] Chase Manhattan Bank, *Financial Analysis of 33 Petroleum Companies, 1962*, September 1963.

[14] *Chemical Week*, April 6, 1963, p. 25.

financing from the parent company is planned to increase slightly and self-financing from retained overseas earnings to increase constantly.[13] By the end of 1965 it is planned that 80 per cent of financing will be out of income with the rest equally divided between advances from the parent company and recourse to external overseas sources. Concerning the geographical distribution of United States chemical investment overseas, one notes a greater dispersion than exists in foreign investment of United States oil companies: 14 per cent of total foreign ventures in 1963 were in Britain, 10 per cent in Canada, 22 per cent in Western Europe and 54 per cent in the rest of the world.[14] Since the "rest of the world" comprises mainly developing countries, it can be said that United States chemical companies invest more in developing countries than their petroleum counterparts, at least in relative terms.

A common feature of both industries is the marked preference for complete ownership or at least majority control of foreign ventures and a trend towards direct participation in foreign markets, despite a slight rise in the number of licenses granted abroad. A distinction has to be made between the general policy of United States firms and that of European or Japanese firms; the latter seem, as a rule, to attach less weight to the requirement of majority control of the venture in which they participate, and a greater proportion of their operations abroad is given by licensing agreements, technical assistance and construction.

Although this latter subject is treated in detail elsewhere in the Conference material, it is worthwhile here to make a few comments.

The only safe generalization that can be made with regard to licensing practices is that they are typically "two-party" deals: the scheme of the agreement varies not only from industry to industry and from country to country, but also from individual case to individual case. Payment, modalities, limitations of licensing agreements depend on the importance of the patent in question, on the production and marketing programme, on the prevailing business and financial practices of the industry and/or of the country and, above all, on the general corporate policy and bargaining power of the companies concerned. Usually, licensing agreements are non-exclusive, i.e., similar contracts may be granted elsewhere by either party, but exceptions to this "rule" are frequent. It can also be said that some firms generally specialize in licensing and are more likely to grant further patent rights owing to the evolution of a standard form of agreement the firm can depend on.

Exempli gratia, we mention below a licensing agreement case, which although it does not reflect any typical pattern does show the complexity characteristic of such arrangements in the petrochemical industry.

At the end of 1963 National Distillers and Chemical licensed Toyo Soda Manufacturers Ltd. of Japan to use the former's high-pressure polyethylene process. The agreement, essentially technical, is exlusive in character and is scheduled to last for a period of ten years. The mode of payment is as follows: National Distillers receives a fixed licensing fee of $600,000 plus an engineering fee of $250,000; in addition, the company enjoys a continuing royalty of 2.25 per cent of sales on the first 15,000 tons sold, 2 per cent on the next 10,000, 1.75 per cent on the next 25,000 and 1.5 per cent on any amount sold over 50,000 tons. Finally, Toyo Soda contributes $250,000 annually, for the first five years, to National Distillers' research fund. Since the contract applies to a 40,000 tons/year plant, the three components of total payment, fixed fees (licensing plus engineering), percentage royalty on sales, and research fund contribution have, in this case, about the same financial weight in the compensation of the licensing company. It is clear at any rate that, due to the fundamental importance attached to the availability of a given technology, licensing agreements in the petrochemical industry entail a sizeable financial burden on the licensee.

The interested reader is referred to appendix II for a comparative summary of the position of the firms considered, according to various financial indicators. The appendix also contains a brief evaluation of the significance of such indicators and of the methodology followed.

Table 4 has been derived from the data in appendix II. It presents the *ranking* of the companies according to the items selected; the companies have been ranked in direct relation to all items except "long-term debt" and "long-term debt rate", under the assumption that a larger size, a higher profitability, a greater liquidity, a higher investment rate, depreciation rate and retained earnings rate, and a lower long-term indebtedness make for a stronger corporate structure, both from the financial and the economic stand-points. This assertion, of course, must be viewed in the context of the purpose of this study which is not to comment on the effectiveness of one or another type of corporate policies but simply to ascertain the financial position of each firm in view of its capability to participate in petrochemical operations abroad.

Some general findings of interest are:

(1) The oil companies are generally more liquid than the United States chemical companies; the difference, although significant, is not large. Both groups have a far greater liquidity than the European chemical companies considered;

(2) There seem to be little relation, if any, between size and profitability in either the United States chemical or oil companies; the explanation that comes most readily to mind is that the companies chosen are so large that all scale economies have been already exploited.

(3) Oil companies invest about the same percentage of their total revenue as do United States chemical companies and their rate of depreciation is also at a similar level. Both groups invest much less than does the European chemical group;

(4) Although the available data are scarce, there is enough evidence to state that the chemical companies' stake in petrochemicals, both from the sales and from

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[13] This trend has recently been reinforced by the voluntary restraints policy advocated by the United States Government to improve its Balance of Payments position.

[14] *Chemical Week*, December 28, 1963, p. 21.

TABLE 4. RANKING OF INTERNATIONAL OIL AND CHEMICAL COMPANIES ACCORDING TO SELECTED FINANCIAL ITEMS[a]

Companies	*Total revenue*	*Capital expend.*	*Working capital*	*Retained earnings*	*Long-term debt*	*Cash ratio*	*Current ratio*	*Profit rate*[b]	*Depr. rate*[c]	*Ret. earn. rate*[d]	*Work cap. rate*[e]	*L-T debt rate*[f]
Dupont	4	5	4	5	1	1	1	n.a.	17	12	1	1
U. Carbide	6	7	5	7	15	6	3	2	6	9	2	9
I.C.I.	7	8	7	9	9	17	8	8	16	5.5	7	7
Monsanto	9	10	8	8	13	7	6	7	8	5.5	4	12
Dow	10	15	11	10	4	15	12	6	5	7	11	8
Allied	11	16	13	11	6	5	4	9	13	11	9	10
Bayer	12	11	12	n.a.	7.5	13	14	n.a.	2	n.a.	14	15
Hoechst	13	13.5	10	n.a.	12	9	11	n.a.	4	n.a.	8	13
BASF	14	12	14	n.a.	5	11	15	n.a.	3	n.a.	16	14
Montecatini	15	6	15	n.a.	14	16	16	n.a.	9	n.a.	15	17
St. Gobain	16	13.5	17	n.a.	3	12	17	n.a.	1	n.a.	17	16
Koppers	17	17	16		2	14	2	11	7	10	6	4
Jersey Strd.	1	1	2	2	17	4	10	5	15	8	12	5
Gulf	3	3	3	3	11	2	5	1	14	4	5	3
Shell	2	2	1	1	16	3	7	10	12	3	3	2
B.P.	5	4	6	4	7.5	8	13	3	11	1	10	6
Phillips	8	9	9	6	10	10	9	4	10	2	13	11

[a] The companies have been ranked in direct relation to all items except "long-term debt" and "long-term debt rate"; the ranking is in inverse relation to the latter two items. For example, a company rated n. 2 on Total Revenue and n. 16 on Long-term debt has the second largest total revenue and the second largest long-term debt.

[b] Net Income Total Revenue 100

[c] Depreciation allowance Net fixed Assets 100

[d] Retained earnings Net Income 100

[e] Working capital Total Revenue 100

[f] Long-term debt Working capital

the investment points of view is much higher than the oil companies'; also, United States chemical companies are, as a rule, more interested in petrochemicals than European chemical companies, with the possible exception of Montecatini and BASF;

(5) Oil companies retain a higher proportion of their earnings than United States chemical companies. If one does not consider Jersey Standard, whose low retained earnings rate weighs heavily in the average, the percentage of retained earnings on net income in the oil group is almost double the corresponding percentage in United States chemical companies;

(6) The long-term indebtedness of oil companies, as expressed by the funded debt/working capital ratio, is significantly lower than that of the United States chemical group, in spite of the fact that Dupont has no long-term debt at all; the ratio for European chemical companies (2.32) is, however, almost four times that for United States chemical companies.

(7) Comparing the data presented in appendix II with the "normal" data presented in table 1, one notices that the average current ratios for the United States chemical and oil companies considered are in line with the median figures for the respective industries. The long-term debt ratio is significantly higher than the Dun & Bradstreet ratio for the chemical companies, and much lower for the oil companies. Finally, the median profitability in both industries is markedly lower than that of the firms analysed, a good indication of the existence of scale economies.[15]

III. MAIN TYPES OF PETROCHEMICAL VENTURES[16]

In this section, after a brief review of the notion of joint ventures in general, we shall summarize and classify all principal projects in developing countries related to the petrochemical industry.

The general definition of joint venture is the following: "any form of enterprise, however owned and controlled (which involves), some degree of international partnership".[17] For the purposes of this study, however, the emphasis must necessarily lie on a more limited notion, we shall therefore be concerned only with joint ventures "in the form of joint equity investments in petrochemical enterprises in the less developed countries by nationals or companies from the industrialized countries... together with nationals or companies from the capital-receiving countries themselves."[18]

Since 1955, the flow of private capital from the main advanced countries has been around $4 thousand million yearly and is by now approximately equal to the total volume of public aid. The direction of the two flows is, however, quite different. Latin America has been preferred

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[15] This indication is all the more valid in that the level of profits has generally tended to decline in both industries from 1954 to date.

[16] A large portion of the general information presented on joint ventures has been drawn from *Joint International Business Ventures*, ed. by Wolfgang G. Friedmann and George Kalmanoff, Columbia University Press, New York and London, 1961 to which we refer the reader interested in a thorough study of the subject. Detailed foot-notes have not been used (except for direct quotes) because various parts of the book have been consulted. The Friedmann and Kalmanoff study has been supplemented here by more specific information on petrochemical ventures from other publications and periodicals.

[17] Friedmann and Kalmanoff, op. cit., p. 5.

[18] *Ibid.*, p. 7.

by private investors to Africa and Asia: in 1957, Latin America's net-long-term foreign capital inflow was $1.5 thousand million *versus* a comparable amount of $100 million to ten low-income Asian countries (with a population three and a half times that of Latin America). The gap has been filled, to an extent, by public funds. As of 1957, total United States direct investment in ventures involving less than 95 per cent ownership was about $1.7 thousand million in developing countries, *versus* a comparable figure of about $4.7 thousand million in industrialized countries; these figures may be taken as representative of the extent to which United States business participated in joint ventures abroad. Although direct investment by United States companies is a greater proportion of total investment than portfolio investment in developing countries, United States investors engage in joint ventures to a greater extent in industrialized economies: joint ventures represented in 1957 31 per cent of foreign investment in developed countries and only 17 per cent in developing economies.

In the Federal Republic of Germany, direct investments are a relatively minor part of the capital outflow although their importance seems to have grown in recent years: in 1953-1958, the Federal Republic of Germany's direct foreign investments amounted to only about $520 million.

Japan's foreign investment structure is similar to that of the Federal Republic of Germany: direct investments are less important than other forms (e.g. commercial credits, medium-term loans, sales organizations abroad etc.) and the amount of such investment is small. However, direct foreign investment increased sharply since 1955. Also noticeable is a greater willingness of Japanese investors to engage in joint ventures with local capital in developing countries.

In this last respect, Italy is similar to Japan:[19] joint ventures are a very significant part of the capital in flow and outflow. Also very important are licensing and technical assistance agreements, even without requiring capital participation by the foreign firms. This last factor is partly caused by the scarcity of capital in Italy, scarcity which also makes for a favourable governmental attitude towards joint ventures abroad in which cash requirements are supplied by local partners.

It is possible to identify a recent trend towards an increasing importance of joint ventures in developing countries, coupled with a rising tendency to minority commitments on the part of the foreign investors. Among the developing countries, Latin America is the area where joint ventures constitute the largest proportion of foreign investments: as of 1958, joint ventures constituted in Brazil over 20 per cent of $3 thousand million worth of total direct foreign investment; in Mexico, 11 per cent of 5,555 million pesos of foreign investment in 1950-1957 was in joint ventures; important partnership arrangements also exist in Colombia. Thus, "as private direct investment in the less developed countries has increased, the use of the joint venture form of investment has also increased, although it still constitutes only a minor portion of the total of such investment".[20]

Oil companies generally have not engaged in joint ventures, although they have sometimes been compelled to do so by special circumstances. The attitudes of the chemical companies vary widely, from Dupont, which prefers to operate through fully-owned subsidiaries, to Union Carbide, which regards its foreign operations as independent units and allows participation of foreign partners after the new venture has become a going concern, to I.C.I., which is favourable to joint ventures but generally prefers partners from other industrialized countries. State concerns, like E.N.I. in Italy, are favourable to entering joint arrangements with other state enterprises abroad and seek participation of local governments.

As a rule, British and German companies are better disposed towards joint ventures than their American counterparts. However, it is the smaller capital-exporting countries, notably Japan and Italy, which have the strongest preference for this type of investment. This is probably, as already noted, a result of Japan's and Italy's limited financial resources; the explanation is even more valid in the context of petrochemical investment which, as we have seen, implies very heavy capital outlays.

Joint ventures are generally predominant in those fields of manufacturing, typically the newer activities, which require extensive funds and technical know-how; petrochemical activities, of course, stand first within this category. Participation by the local general public has so far been scanty, due to the characteristic thinness of the capital market in developing countries, but the situation has been improving with the development of financial institutions and mechanisms of exchange.

Joint ventures tend to be preferred by developing countries for the following major reasons: (1) they permit local capital participation in the benefits of economic development; (2) they generate a faster transmission of technical and organizational know-how; (3) they lessen the danger of foreign economic dominance. It is sometimes argued that these motives are, to an extent, in contrast with the goal of maximization of foreign capital inflow in those cases when local capital could have found alternative means of productive employment; thus it is said, measures of the type of the recent "Mexicanization" programme, have the effect of reducing the inflow of foreign capital without generating offsetting benefits for local capital. However, even admitting the correctness of the proposition, the argument underestimates the importance of a fast transmission of technical and managerial information.

Governmental minority participation has the advantage of insuring closer national scrutiny of foreign operations in the country, but may also entail an expensive use of scarce managerial resources. In general, governments of industrialized countries have set no definite policy with regard to joint ventures abroad of national companies. Private industry instead leans more and more

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[19] Italy, although a capital importer on a net basis, is a creditor country vis-à-vis the developing countries.

[20] Friedmann and Kalmanoff, op. cit., p. 37.

towards acceptance of joint arrangements in developing countries, usually for the following motives: (1) obtaining of management skills and maintenance of employee morale, (2) stronger marketing position, (3) improvement of relations with the Government and the public. The additional motive of saving capital and reducing business risks is normally valid only for joint ventures in other developed countries.

As for the already-mentioned trend toward a shift to minority foreign participation, companies of industrialized countries generally feel that minority holding of an enterprise abroad implies a gain of those fiscal and public relations advantages which are derived from a local identification of the venture.

Shifting now to a more specific discussion of those ventures related to petrochemicals, one notes first of all that the number of joint ventures is relatively higher than in other industries. Taking as example the list of refinery projects in the developing countries of Africa, Asia and Latin America, planned or under construction in 1962, one notes that 16 of the 51 projects were joint ventures of some kind; this proportion (over 30 per cent) is significantly higher than the average figures referred to before. Ten projects were wholly state owned, and four were joint ventures with governmental participation (all in Africa and all with E.N.I.). However, if one breaks down the figures between projects planned and projects already under construction, there is some evidence that the number of joint ventures increases as the time of actual construction approaches; while 9 out of 22 (40 per cent) projects under construction were joint ventures, only 3 out of 15 (20 per cent) were joint ventures among the projects pending.[21] An immediate explanation could be the underestimation of the cost of the venture at the planning stage, with the necessity at a later stage to seek partners to share the unexpectedly high financial burden of the project.

Let us now review the situation of the petrochemical industry in developing countries as of September 1963, and attempt to classify the projects.

Tables 5 and 6 have been derived in part from a survey on the world petrochemical industry by *The Oil and Gas Journal*;[22] the data relative to developing countries of Africa, Asia and Latin America have been utilized, and

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[21] List of projects from: *Petroleum Press Service*, February 1962.

[22] *Oil and Gas Journal*, special report, September 2, 1963.

TABLE 5. EXISTING AND PLANNED PETROCHEMICAL PROJECTS IN DEVELOPING COUNTRIES, 1963[a]

(Classified by area and by type of ownership)

Area	*No. of existing facilities*	*Per cent*	*No. of planned projects*	*Per cent*	*Total*	*Per cent*
Latin America	43	84.3	20	33.9	63	57.3
Africa	--		5	8.5	5	4.5
Asia	8	15.7	34	57.6	42	38.2
TOTAL	51	100.0	59	100.0	110	100.0
Ownership						
Private	33	70.2	30	58.8	63	64.2
Foreign	10	21.3	10	19.6	20	20.4
Local	11	23.4	10	19.6	21	21.4
Foreign-local	12	25.5	10	19.6	22	22.4
Public	14	29.8	21	41.2	35	35.8
TOTAL	47	100.0	51	100.0	98	100.0

Ownership

Area	*Private-foreign*		*Private-local*		*Local-foreign*		*Public*	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
Latin America	15	75.0	13	61.9	13	59.1	18	51.4
Africa	--	—	—				1	2.8
Asia	5	25.0	8	38.1	9	40.9	16	45.8
TOTAL	20	100.0	21	100.0	22	100.0	35	100.0

SOURCES: *Oil and Gas Journal, September 2, 1963*, for the list of projects; various periodicals for classification and further information.

[a] Developing countries of Europe excluded. Projects have been classified according to the predominance of one form of ownership, not according to the exclusion of all others. Thus, the inclusion of a project in the category, for instance of "private foreign" capital does not imply a total absence of participation of local or public capital.

TABLE 6. PARTICIPATION OF OIL AND CHEMICAL COMPANIES IN PETROCHEMICAL PROJECTS, 1963 [a]

Area	*Oil companies*		*Chemical companies*		*Joint oil-chemical*		*Total*
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	
Latin America	5 (12 %)	42.0	37 (88 %)	75.5	—	—	42 (100 %)
Africa	—	58.0	1 (100 %)	2.0	—	—	1 (100 %)
Asia	7 (32 %)	—	11 (58 %)	22.5	2 (10 %)	100	19 (100 %)
TOTAL	12 (19 %)	100.0	49 (78 %)	100.0	2 (3 %)	100	62 (100 %)

SOURCES: *Oil and Gas Journal, September 2, 1963*, for the list of projects, various periodicals for classification and further information.

[a] Public ownership projects not included; only those projects which could be definitely classified into one or another category have been included.

completed with information from several issues of various specialized periodicals. The survey was updated somewhat, but it still provides an incomplete picture of the industry in late 1963. Tables 5 and 6 contain a statistical summary of the list of projects, and show the percentage breakdown of the projects by geographic area, by type of ownership, by stage of the project (existing or planned). Only those projects which could definitely be said to belong in one or the other category have been so classified.

While no detailed comment on the single items contained in the tables is believed necessary, the principal findings are the following:

(*a*) The largest number of planned and existing projects were in Latin America; the difference with Asia and Africa becomes greater if one considers only the number of existing facilities, of which Latin America had 84 per cent;

(*b*) Thirty-five per cent of foreign investment in all areas was under the form of joint local-foreign ventures (22 projects out of 63 classified private ones); the percentage was relatively higher in Asia (41 per cent) than in Latin America (32 per cent) and no participation of local capital to foreign enterprises existed in Africa at that time;

(*c*) Wholly foreign ventures were 32 per cent of all classified private ventures: they were relatively less important in Asia (23 per cent) than in Latin America (36 per cent). The proportion of wholly local ventures was, instead, similar in both regions: 36 per cent in Asia, 32 per cent in Latin America;

(*d*) State owned and/or controlled projects constituted 36 per cent of all classified projects; the proportion was relatively much higher in Asia (42 per cent) than in Latin America (30 per cent) despite the extensive activities of State oil enterprises in the latter area (notably PEMEX, PETROBRAS and YPF);

(*e*) Oil companies sponsored 12 out of the 62 projects classified (19 per cent) and chemical companies 49 projects (78 per cent); oil companies were relatively more active in Asia than in Latin America.

On the basis of the above, one has enough evidence to state that:

(*a*) Joint ventures were in all regions more important relative to total foreign direct investment than suggested by the Friedmann and Kalmanoff study. Although part of the discrepancy is to be attributed to a recent general shift towards this form of investment, there is little doubt that the explanation also lies in the high degree of suitability of joint arrangement schemes to the characteristics of petrochemical projects;

(*b*) The greater frequency of joint ventures in Asia is not to be attributed to a higher preference of foreign investors for this form of venture in the area; on the contrary, oil companies, generally less favourably disposed towards joint ventures, sponsor a relatively greater number of projects in Asia. One must then explain the finding as a result of institutional factors and national Governments' regulations. The same factor must be taken as responsible for the lower number of wholly foreign-owned projects in Asia than in Latin America;

(*c*) The role of State enterprises and national public intervention in the petrochemical field is very significant and there seems to exist a tendency for it to increase in importance;

(*d*) Chemical companies were involved to a much greater extent in petrochemical projects than oil companies, approximately reflecting the relative importance of petrochemicals in the two industries' production programmes.

Throughout all of the above discussion, it must be kept in mind that only the distribution of *projects* has been analysed, not the distribution of the amount of capital invested; although the former can be taken, statistically speaking, as a good indication of the latter, this remark must qualify all of our findings. The only result which is reinforced, rather than weakened, by this consideration is the comment on the increasing importance of joint ventures and on their relatively greater role in the petrochemical field: since joint arrangements prevail, as a rule, in those projects which require greater capital outlays, the number of such arrangements is, if anything, an underestimation of the real importance, and growth of the joint venture form in the petrochemical industry.

IV. SELECTED CASE-STUDIES

In what follows, data on a few selected petrochemical projects in developing countries are presented in order to show some of the features characterizing recent investment in this field. These projects are located in Argentina, Brazil, Mexico, Kuwait, India and Yugoslavia. Various forms of ownership are represented, as well as different schemes, for capitalization. The product lines also vary from ammonia and nitrogenous fertilizers to plastics and synthetic rubber. Probably the most relevant aspects to be pointed out are the complexity of some of these arrangements, the dominant role played by the companies owning the technology and the process — "know-how", and the fact that participation of local capital and international financing organizations is present in one form or another in some of these cases.

Petroquimica Argentina S.A. (PASA).[23] This is a joint project of five American firms, Continental Oil Co., Cities Service Co., U.S. Rubber Co., Fish International Corp. and Witco Chemical Co., Inc. PASA is undertaking construction of a $72 million petrochemical project at San Lorenzo, a smalll town about 230 miles from Buenos Aires; $63 million are destined to plant and equipment expenses and the rest is slated for working capital and preliminary expenses. The PASA plant, located near a YPF refinery, is programmed for production of styrene, butadiene, SBR rubber, and benzene. About $15 million of the total construction cost are to be spent in Argentinian labour and materials, while a large part of the rest of the equipment was contracted with John Thompson Ltd. of the United Kingdom.

The project should give employment to about 700 nationals and be effective in transmitting to the country technical knowledge and managerial skills. The proposed capitalization of the project is as follows.

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6 % to 8 % five-to-seven-year class A debentures (supplier's credits)	30,000,000
Working capital loans	5,000,000
7.5 % five-to-ten-year class B debentures	18,500,000
Total debt	53,500,000
7.5 preferred stock to be purchased by spons. group/	13,500,000
Common stock to be purchased by sponsoring group	5,000,000 (85 %)
Additional common stock to be subject to warrants accompanying class B debentures	882,000
Total initially authorized common stock	5,882,000
TOTAL	72,882,000

It presents many interesting financial characteristics, the main one being the co-operation between private and public capital: the five sponsor companies contributed $18.5 million in common and preferred stock, in addition to supplying the necessary technical know-how and managerial skills, the suppliers of equipment agreed to accept class A debentures (five-to-seven-year maturity) as partial payment ($30 million) for their goods; the Chase International Investment Corp. (Chase Manhattan Bank subsidiary) and Lazard Frères & Co. agreed to supply and find purchasers for $18.5 million of class B debentures (ten-year maturity) partially on a "commitment" and partially on a "best effort" basis ($15.5 million of these debentures were bought partly by Chase and Lazard themselves and partly by 17 other North American and European investors); the I.F.C. purchased the remaining $3 million of class B debentures when it became clear that the entire issue could not be placed with private investors; a group of commercial banks will provide $5 million in short-term credits to partly fill working capital requirements; finally, and most important, A.I.D. agreed to guarantee convertibility to United States holders of all types of securities and to provide, when possible, insurance against expropriation and war risks.

The last element had a predominant role in the success of the venture, in view of the critical political and business conditions prevailing in Argentina in recent years. The June 1964 United States-Argentinian investment guarantee agreement had a relevant influence on the willingness of the five sponsors to launch the project and on the availability of suppliers' credit for equipment.

It has been estimated that the cumulative balance sheet of foreign exchange for the first 15 years since the beginning of construction would imply a gross gain of foreign exchange by Argentina of $482.5 million, deducing a total of $106.7 million in foreign exchange outflow (35.6 per cent for dividends and redemption of preferred stock, 30.2 per cent for debt retirement, 10.1 per cent for interest payments and 24.1 per cent for royalties and imported raw materials) the project would save the country a net amount of $321.8 million in foreign exchange during the first 15 years.

Also, by drawing funds mostly from private sources, drains on Argentina's lines of credit with international lending agencies were avoided.

Companhia Pernambucana de Borracha Sintetica.[24] Coperbo is building a synthetic rubber factory at Cabo (Recife), the first heavy industry facility located in the north-east of Brazil, as part of the Superintendency of Development for the North-east (SUDENE) five-year plan for the industrialization of the region, and Latin America's first polybutadiene rubber plant.

The plant, which will produce 25,000 metric tons year of polybutadiene for a total construction cost of $33 million, will be built over a three-year period and is expected to be on stream by the end of 1965. Construction has been contracted jointly to the Lummus Co. and to Firestone Tire and Rubber. A butadiene plant at Louisville, formerly owned by the United States Government

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[23] SOURCES: John G. McLean, "Financing Overseas Expansion", *Harvard Business Review*, Cambridge, March-April 1963, and various issues of specialized periodicals.

[24] SOURCES: Inter-American Development Bank, *Press Release* 14 July 1962, *Chemical Week*, 10 November 1962, p. 57, *ibid.* 6 June 1963, p. 21, *ibid.*, 20 July 1963, p. 29, *Oil, Paint and Drug Reporter*, 17 June 1963, p. 4

This case is included because of its interesting financial and licensing characteristics although, strictly speaking, it is not petrochemical production since the raw material is molasses alcohol, a by-product of the local sugar industry for production of synthetic rubber during the Second World War, was bought in November 1962 by Rohm & Haas Co. of Philadelphia and later sold to Coperbo. Lummus dismantled the plant and shipped it down the Mississippi and through the Gulf of Mexico to Recife. Lummus is responsible for the basic engineering, procurements of materials and supervision of construction, while Firestone will train local personnel to operate the factory (together with Lummus) and has been retained by Coperbo to manage the plant during the first 18 months of operation. In addition, Firestone is licensing its polybutadiene process, while know-how on the butadiene process will be furnished by Union Carbide.

Coperbo is being capitalized through a sales tax within the State of Pernambuco; eventually 74 per cent of its stock will be transferred to small private shareholders through the redemption of tax coupons, with the remainder held by the State.

The Brazilian corporation's capital investment will amount to about $8.6 million; the Federal Government of Brazil is contributing about $6.5 million to the project's financing through the Banco Nacional de Desenvolvimento Economico (BNDE); the Inter-American Development Bank (IDB) has granted a $3,615,000 loan from its ordinary resources, and the balance will be financed through various sources, including the Rohm & Haas Co. and a syndicate of French banks headed by Credit Lyonnais. The IDB loan will have a length of ten years and will bear interest of 5.75 per cent annually (including the 1 per cent commission allocated to the Bank's special reserve); it will be granted in dollars and other currencies, will be repayable in the currencies lent, in 14 equal semestral instalments, after a three-and-a-half years grace period, and it will be guaranteed by the Banco Nacional de Desenvolvimento Economico.[35]

The Cabo plant will employ 500 Brazilian workers, and it has been estimated that operations of Coperbo will result in annual net savings of foreign exchange amounting to $6.5 million. It is also expected that the rubber plant will generate important forward linkages and lead to the establishment in the region of a rubber-products industry.

Negromex S.A.[36] Negromex is a private Mexican enterprise founded in 1961 for the construction and operation of Mexico's first carbon black plant, at Salamanca. It will operate on liquid hydrocarbon feed from the nearby PEMEX refinery and will have an annual capacity of 15,000 metric tons; all production will be absorbed by the Mexican tire industry.

The project will have a total cost of about $3.2 million; Negromex financing accounts for 65 per cent of the cost; $413,000 will be provided by Mexican banks, and the remainder, $700,000 (22 per cent), will come from a long-term loan from the IDB ordinary resources. The IDB loan will be given partly in United States dollars ($132,000) and partly in Mexican currency; the loan has a length of six years and it carries a 5.7 per cent interest rate (including the 1 per cent commission to the Bank); it will be repaid in ten equal semestral instalments, after an eighteen-month period of grace.

Negromex has obtained licensing and technical assistance from Phillips Petroleum. In exchange for 10 per cent of the stock Phillips will provide detailed process information and two engineers to assist the enterprise during the construction period and during the first years of operation.

According to studies and projections on consumption of carbon black in Mexico, the import-substituting activities of Negromex will result in net savings to the country amounting to $2 million yearly starting in 1965 and to at least $3.5 million a year from 1970 on.

Shuaiba.[37] Kuwait has long been interested in setting up industries to use effectively some of the revenue from oil sales. In mid-1961 plans were for the first time drawn for a petrochemical complex at Shuaiba, as part of a long-term development plan for an industrial park in the area. Such a complex would produce ammonia, urea, ammonium sulphate and other ammonia derivatives and would use as feed natural gas from the Burgan oil fields.

The facilities will be mainly owned and operated by a new company, formed especially for this purpose, the Kuwait Petrochemical Company. The company, a holding firm organized on 23 July 1963, is owned 80 per cent by the Kuwait Government, 5 per cent by the Kuwait National Oil Co. (KNOC) and 3 per cent by Kuwait National Industries Co.; at a later stage, the remaining 12 per cent of the shares will be offered in public subscription to Kuwait nationals. A probable development of the venture is the breaking up of the parent company into various subsidiaries with offer of part of the stock to foreign interests; in fact, British Petroleum and Gulf Oil have already been invited to participate in the development of a petrochemical industry in the country.

The first plant of the complex will probably be a 400 tons/day ammonia unit, in which British Petroleum and Gulf will each have a 20 per cent interest. The contract for construction of the unit was let in early 1963 to Foster Wheeler Ltd. of England.

Coromandel Fertilizers Ltd.[38] The company will build and operate a $72 million fertilizer project in India, one of the major projects of the Third Five Year Plan, and the only privately owned fertilizer plant in the country. Construction, started in mid-1964, is expected to be completed in about thirty months; the plant will have a capacity of 365,000 metric tons/year of ammonium phosphate (valued at over $35.8 million) and of 16,500 tons/year of urea. It will be built at Vishakapatnam in Andhram, a region well provided with transporta-

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[35] It also brings IDB involvement in the north-east of Brazil to a total of $30 million.

[36] Inter-American Development Bank, *Press Release*, 15 March 1963, and information from various issues of specialized periodicals.

[37] Sources: *Chemical Age*, 22 Feb. 1963, p. 293; *Chemical Week*, 17 August 1963.

[38] Sources: *Chemical Trade Journal*, 6 March 1964, p. 312; *Fertilizer Development Council Newsletter* (Israel), Jan., 1964, p. 10; *International Financial News Survey*, 1 May 1964, pp. 146-47; *Oil, Paint and Drug Reporter*, 47, Apr. 1964, p. 5; *Chemical Week*, 2 November 1963, p. 67.

tion facilities, and will use as feed naphtha and refinery gases from the nearby Caltex refinery at Madras.

Coromandel Fertilisers has been formed as a joint foreign venture: East India Distilleries Ltd., a British-owned Madras firm, is to own 53 per cent of the issued capital, with the remainder jointly held by two American participants, the California Chemical Company (a wholly owned subsidiary of Standard Oil of California) and the International Minerals and Chemicals Corporation of Skokie, Ill.

The company will shortly come into the market attempting to raise $8.4 million in equity shares as part of the necessary funds. The two American companies will contribute about $5.5 million to the venture and the Agency for International Development and the Export-Import Bank of Washington has agreed to lend a total of $44.6 million to the venture.

It has been estimated that, by the time the plant goes on stream, it will save India about $21 million a year in foreign exchange.

National Organic Chemical Industries Ltd. (NOCIL).[illegible] This company announced in June 1964 the establishment of a large petrochemical complex in the Bombay area, the first of its kind in India. The project is estimated to cost £22.5 million ($US 63 million). NOCIL's initial capital will amount to £7.5 million ($21 million) to be subscribed one-third each by the Mafatlal Group, Shell International Chemical Company and the public.

For import of equipment £11 million ($30.8 million) will be required; all this foreign exchange will be covered by Shell's initial subscription and the balance as a long-term loan by Shell Petroleum Co. from sources outside the Aid India Club. The project will be capable of processing 225,000 tons of naphtha per annum from the Burmah-Shell Refinery in Bombay yielding ethylene, propylene, benzene, butadiene, etc. for the manufacture of chemicals and plastics. The engineering and construction of the NOCIL project will be carried out by Stone and Webster Eng. Corp., United States and Bataafse Internationale Chemie Maatschappij (B.I.C.M.) Holland, an associate of Shell Int. Chemical Company.

A wide range of chemicals and PVC will be manufactured by NOCIL itself. Hoechst Dyes and Chemicals Ltd. (HDC), Indian Dyestuff Industries Ltd. (IDI) and Polyolefins Industries Ltd. (PIL) will also be operating on the same site. HDC will use ethylene to make vinyl acetate and expand its present polyvinyl acetate production. PIL will make Ziegler high density polyethylene and catalysts. The latter is a new company with paid up capital of £2.6 million ($7.3 million), which will be equally subscribed by NOCIL, Farbwerke Hoechst and the Indian public. IDI's electrolysis plant is to be located in the same area to produce chlorine which will be used by NOCIL for PVC manufacture.

Organsko Kemijska Industrija (O.K.I.), Zagreb.[illegible] The O.K. Petrochemical complex at Zagreb will have a productive capacity when completed of about 20,000 tons polyethylene (I.C.I. process), 6,000 tons polystyrene, 8,000 tons styrene and 14,000 tons benzene. The process design of the ethylene plant and mechanical design of the ethylene, styrene, polystyrene, phenol acetone, benzene desulphurization, cumene and ethylbenzene plants, as well as the offsite facilities, were supplied by Foster Wheeler, United States.

Feedstocks are ethane, propane and butane gases and low octane gasolene obtained from a nearby dearomatization plant.

The total capital investment amounts to 47,000 million dinars ($62 million at the exchange rate of 750 dinars to the dollar, of which about 90 per cent consists of fixed assets, the rest being working capital). The following breakdown of the investment in fixed assets illustrates the relative shares of imported and domestic equipment.

Fixed assets	*In [illegible] dinars*	*Percentage*
Imported equipment plus erection	[illegible]	[illegible]
Others, payable in foreign currency	[illegible]	[illegible]
Construction work	6,628,494	[illegible]
Domestic equipment plus erection	6,305,764	[illegible]
Others, payable in domestic currency	1,964,000	[illegible]
Total	42,[illegible]	100

The imported equipment was financed out of a Development Loan Fund Loan in the amount of $23 million payable in 14 1/2 years and carrying 5 3/4 per cent interest. Domestic financing was secured through a loan out of the General Investment Fund and Republic Investment Fund with a repayment of 20 years and 6 per cent interest rate.

It was estimated that the plant would result in foreign exchange savings of about $6.6 million per year when in full operation.

[illegible] *Neue Zürcher Zeitung*, 9 July 1964.

[illegible] *Construction of the Plastics and Chemicals Factory, Zagreb*, Jugoslovenska Investiciona Banka (J.I.B.), Beograd, July 1959 plus information obtained directly from the J.I.B. and specialized periodicals.

APPENDIX I

The role of public institutions in industrial investment

This appendix contains a short review of the availability and direction of international financial resources. Since it is not possible to derive from the reports of the major international financial institutions and of the various governmental foreign aid agencies precise information on the extent to which these sources of capital have been active in financing petrochemical investment in particular, the aim of this appendix will necessarily be the more general one of furnishing an over-all view of the use of the international financial resources available for industrial investment in general and of the terms and conditions for obtaining such resources

Although this information is available elsewhere in greater detail, an over-all summary is included for the sake of completeness.

(a) MAJOR INTERNATIONAL AGENCIES [a]

International Bank for Reconstruction and Development. Aggregate loanable funds as of 30 June 1963 amounted to $7,033 million: bond issues and loans sold accounted for about 80 per cent of the Bank's loan disbursement of $5,425 million (as of June 30, 1963). The articles of agreement of the Bank state that total financial commitments shall not exceed total subscribed capital, plus reserves and surplus, the resources as of 30 June 1963 amounted to over $24 thousand million. At the same date, the Bank's long-term debt was $2,525 million ($620 million of which are in foreign currencies).

As of 30 June 1963, total development loans of the Bank in Asia, Middle East, Latin America and Africa amounted to $5,011 million ($1,739 in Latin America, $2,355 in Asia and Middle East, $917 in Africa), 25 per cent of which (about $1,000 million) were loans to private borrowers with government guarantees; also 4.5 per cent of total loans went directly to private industrial projects.

The Bank usually provides the borrower with the foreign exchange needed and grants him a period of grace before starting repayment; loans are normally between 10 to 25 years, but a trend exists towards lengthening the period of maturity and lowering interest rates, mainly in order to make more effective use of the large surpluses and reserves of the IBRD. The rates of interest charged have ranged between 4 per cent and 6.25 per cent, and are based on the rate at which IBRD borrows from the capital market to which 1 per cent is added as annual commission and .25 per cent for administrative expenses. IBRD intends to devote more of its resources in the future to the financing of industrial projects and help develop new industries in developing countries through technical assistance.

In addition to issuing bonds and notes, the IBRD also sells in capital markets loans made to its borrowers, thus reducing, to some extent, its functions to those of a fiscal agent who will ensure the servicing of the obligations subject to the agreed transactions; sales from such sources accounted in 1963 for 61 per cent of total annual IBRD loans.

The IBRD has also endeavoured to seek private investors willing to finance development projects. As of 30 June 1963 the Bank had entered 15 such joint financing arrangements, two of which were for projects in developing countries.

International Finance Corporation. The IFC was established in 1956 as an independent affiliate of IBRD, and has an authorized capital of $100 million. It is designed to finance single industrial projects mainly in the developing countries, in association with private investors and *without* guarantee of repayment by the member Government concerned, in those cases where "sufficient private capital is not available on reasonable terms". Unlike the IBRD, the IFC is permitted to invest in the equity capital of the enterprises to be financed. Government participation in an enterprise does not preclude IFC from participating also, as long as the project retains its private nature. The average size of IFC participations has been $1.25 million, the agency, until recently mostly concerned with the financing of manufacturing projects, is shifting to the consideration also of those agricultural or services projects that may contribute to the growth of manufacturing.

To 30 June 1963, IFC has been able to increase its available resources by additional funds, and bring them to a total of $155.8 million (including subscribed capital). The bulk of IFC's investment has so far been directed to Latin America (65 per cent), while Asia and the Middle East received 16 per cent and Africa 9 per cent. The products towards which the agency's investment has been directed have been steel, cement, pulp and paper, electric power and fertilizers.

IFC has since 1962 also become increasingly active in facilitating the formation of private development banks and finance corporations in developing countries where capital markets are thin; its equity investments in such institutions amounted to $14.1 million, *versus* a comparable figure of $203.8 million for the IBRD and of $10 million for the International Development Association, the second IBRD affiliate.

Inter-American Development Bank. The IDB has the function, among others, "to supplement private investments when private capital is not available on reasonable terms and conditions". The Bank grants technical and financial assistance (usually not over 50 per cent of the project cost and not in the form of equity investments) and guarantees loans by private lenders. Like the IFC, the Bank does not require governmental guarantee of its loans, but may not act over objections by the Government.

The IDB's authorized capital stock was increased in the beginning of 1964 to $2,150 million, $1,675 million of which is the callable portion of the capital, serving as a guarantee for the Bank's obligations. IDB loans are usually of a length variable between 6 and 20 years, are repayable in the currency loaned and carried in 1963 a 5.75 per cent interest rate (plus a .75 per cent commitment fee on undisbursed balances).

In addition to ordinary capital, members also subscribed to a Fund for Special Operations, whose resources serve "for the making of loans on terms and conditions appropriate for dealing with special circumstances arising in specific countries or with respect to specific projects" (article IV); these loans can be made under lower interest rates and longer maturities than ordinary loans, and may be repaid in local currency. In 1963, this type of IDB loan had a length up to 25 years and carried an average interest rate of 4 per cent. In January 1964 members' quotas were increased by 50 per cent, bringing the total resources of the Fund to $220 million, as against total loan commitments up to December 31, 1963 of $120 million.

The Bank's financing is directed to large industrial projects, and to medium-sized firms; assistance to the latter is channelled indirectly through intermediary institutions in the country concerned. As of 31 August 1963 the aggregate lending of IDB was $203.4 million, $61.4 million of which had gone directly to private enterprises for, presumably, large-scale projects; one-third of the remainder (presumably for small and medium-size enterprises) was provided for by the Fund for Special Operations.

The size of industrial loans that the IDB has made varies from $125,000 to $16 million; in all countries, IDB prefers to establish lines of credit for the smaller loans and has so far loaned about twice as much for relending as for direct industrial lending. Of the 22 direct industrial loans granted as of November 1962 two were in petrochemicals and one went for an oil refinery project, while agricultural processing, cement and pulp and paper accounted for 13 loans.[b]

Finally, the IDB has acted in many countries as agent for implementing the financial provisions of the Alliance for Progress, has often acted in an advisory capacity to Governments and private enterprises, has elaborated and launched an export credit scheme for the financing of Latin American exports of capital goods, and is actively promoting the Latin American Free Trade Area (LAFTA).

Other regional agencies for the financing of industrial development are the Central American Economic Integration Bank, the African Development Bank and the proposed Asian Development Bank. Although these institutions may in the future assume a

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[a] This section is mostly based on a summary of chapter II of the United Nations Secretariat paper E/3905 (*The Promotion of the International Flow of Private Capital*, 26 May 1964). Although E/3905 is mainly concerned with the flow of *private* capital, chapter II contains an over-all review of the activities of the public international financing agencies. The paper has also been extensively used in section (b), where information thereof is specifically footnoted.

[b] John W. [illegible], "The Inter-American Development Bank and Industrial Development in Latin America", *Industrialization and Productivity*, Bulletin 7, United Nations, New York, 1964, p. 53.

relevant role in their respective regions, they are not here discussed owing to the present scarcity of their financial resources.

United Nations Special Fund.[c] The Special Fund has been active in providing financial help for the preparation of pre-investment surveys, for construction of training facilities and for the foundation of research institutes.

Governments of 112 countries are contributing to the Fund. The major contributors (Canada, Federal Republic of Germany, France, India, Italy, Japan, Netherlands, USSR, United Kingdom and United States) account for about 85 per cent of the 1959-64 total contributions of $326 million.

The total cost of the approved programme has reached $837 million, $335 million of which are contributed by the Special Fund. The Fund's activity is distributed as follows: $171 million (51 per cent) for international experts, $63 million (19 per cent) for contractual services, $84 million (25 per cent) for imported equipment and $17 million (5 per cent) for fellowships. Sixty per cent of the total programme cost is provided by the recipient countries, and is distributed as follows: $105 million for national personnel (21 per cent), $226 million (53 per cent) for building and other facilities and $131 million for local equipment, supplies and services (26 per cent).

Approved projects are distributed among 82 countries, representing all areas of the developing world. The cost of the projects ranges from $250,000 to $6.5 million with an over-all average cost of $2.238 million per project. One hundred and fifty-two projects were in the primary sector (40.6 per cent), 35 in mining, 122 (32.6 per cent) in infrastructures and 65 (17.4 per cent) in manufacturing. Thus, although the Fund is mostly oriented towards projects in the agricultural and social overhead fields, its contribution to manufacturing activities is significant. Especially noteworthy are the financing of pre-investment surveys on petrochemicals, and the establishing of petroleum and petrochemical research institutes in several developing countries.

(*b*) FOREIGN AID

The agencies here discussed are very different in nature from each other, as also are the dominant forms of aid granted by them.

(1) *United States*

The public institutions principally involved in financing development projects abroad are the Agency for International Development (AID) and the Export-Import Bank of Washington (Eximbank).

AID's functions are varied: loans, grants (also in local currency), technical assistance and aid in development research; the Agency also administers the United States investment guarantee programme. Development loans are granted if private sources of financing are not available on reasonable terms and if the loan furthers long-range development programmes, and under the specific condition that approval of the Government of the country concerned be obtained. Other specific conditions, to which exceptions are allowed, are that both principal and interest be repaid in United States dollars and that the planned project should not be competitive with United States business. The importance of development loans in AID's total programme has been increasing in recent years; such form of assistance constituted 35 per cent of total assistance in 1961, 50 per cent in 1962 and 64 per cent in 1964.[d]

In 1963, the development *loan* commitments of the Agency amounted to a total of $1,288 million, approximately 50 per cent of which were in industry and mining (estimated).

Development *grants* tend mainly to promote the development of human resources, although they may also be granted to finance infrastructure projects or economic experts' assistance in developing countries. This type of aid amounted in fiscal 1963 to $331 million, a 45 per cent increase over the previous year.[e]

Potentially very important for petrochemical projects is the assistance given by the Agency in meeting the cost of surveys to determine the investment potential of a project. AID is authorized by the Foreign Assistance Act to advance to private investors up to 50 per cent of the survey cost; repayment takes place after the business has been set up; although only United States nationals and corporations are eligible, the condition for receiving assistance is that the project be consistent with the country's development schemes.

The total AID commitments in the fiscal year 1963 amounted to $2,432 million, a 4.2 per cent decrease from 1962; development loans amounted to $1,288 million (53 per cent), supporting assistance to $431 million (18 per cent), grants to $357 million (14 per cent) and contributions to international organizations to $149 million (6 per cent).[f]

The geographical direction of AID assistance is exemplified by the distribution of development loans in 1963. Latin America received $343 million (including Alliance for Progress loans), or approximately 27 per cent, Africa $98 million (7.6 per cent), the Far East $67 million (5.2 per cent), with the Near East and Asia receiving the rest (60.2 per cent); the distribution of loans is thus roughly in line with the population of the beneficiary areas. The same is true, generally, of other AID assistance.

The *Export-Import Bank* of Washington was created to facilitate trade by Executive Order in 1934 under the NRA programme. Eximbank is mainly active in providing export credit guarantees in insurance and in granting long-term loans to public and private foreign purchasers of United States goods and services for projects in developing countries. Total authorizations of the Bank averaged $1,171.6 million yearly in 1957-63, with a 1962 peak of $1,861.2 million; appropriations for development project credits averaged in the same period $491.7 million yearly, about 42 per cent of the total. Development loans are subject to the condition that they be not competitive with private capital. Also, the amount of the loan cannot exceed the financing required by the dollar import requirements of the projects. Government guarantees are not necessary but the borrower is required to defray part of the cost, half of the cost if he is a private borrower. The length of the loans ranges up to 25 years, and interest rates are determined according to the cost of funds in the capital market.[g] The export financing activity of the Bank has declined in recent years, while its role as a guarantor and insurance agent has become more relevant.

The Bank's involvement in petrochemical projects has so far been rather limited. One example of its contribution in this field is the participation in a polyethylene project in Japan, in January 1964 the Bank gave Ube Industries Ltd. a $3.1 million loan covering part of the implanting cost, loan to be repaid in 8 years starting after a one-year period of grace.[h]

(2) *United Kingdom*[i]

No single agency exists in the country for the co-ordination of foreign aid efforts, but rather a number of governmental agencies with separate fields of activity. The most important of these are the Commonwealth Development Corporation and the Commonwealth

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[c] SOURCE: *Impact*, a United Nations Special Fund Report, 1964. *The Implementation of the Programmes Approved by the Governing Council at its Second Through Eleventh Sessions*, United Nations Special Fund, 7 May 1964.

[d] *The Promotion of the International Flow of Private Capital*, op. cit., p. 45.

[e] *Ibid.*, p. 46.

[f] A.I.D. *Operations Report*, data as of December 31, 1963; note that the total includes loans and grants under the Alliance for Progress programme, that supporting assistance and grants include previous years' commitments and that grants include those under the Social Progress Trust Fund of the IDB.

[g] *The Promotion* etc., op. cit., p. 52.

[h] *International Financial News Survey*, 3 April 1964, p. 67.

[i] *The Promotion*, etc., op. cit., pp. 59-65.

Development Finance Company, that supplement the private financing system. In 1958 the *Commonwealth Assistance Loans* were introduced for the purpose of aiding recently independent countries; the loans usually run for thirty years, and carry a rate of interest equal to the one at which the Government borrowed the funds plus a 0.25 per cent; the grace period may be as long as ten years and in some cases interest and service charges may be waived.

The *Commonwealth Development Corporation* finances public and private industrial ventures in developing countries of the Commonwealth which have achieved independence since 1948, under both the form of loan and of equity investment; however, the Corporation usually sells its interest in a joint venture after the latter has become a going concern. The role of the CDC in industrial investment is very limited indeed, since most of the Corporation's activities are in the primary sector and in public utilities and other overhead projects.

The *Commonwealth Development Finance Company*, established in 1963, has a total authorized capital of $85 million of which $21 million is paid up. While its resources are thus scanty, the Company performs a needed function as promoter of private financing of industrial projects in the developing countries of the Commonwealth. The CDFC has no direct projects of its own, but its finances are available for private projects that are commercially viable and contribute to the development of the country concerned; conditions for obtaining CDFC funds are that expert management be available to run the project, that the investors raise a portion of the funds themselves and that as much financing as possible be obtained through private channels. As is usual practice for British public financing agencies, activities are run under commercial terms and the interest rates charged are linked to the rates paid by the CDFC itself, plus a margin for tax liability. CDFC has co-operated closely with other governmental agencies, both British and foreign: its activities are very diversified industry-wise. It has joined in particular in assisting in the formation of national development finance corporations in India, Pakistan and Ceylon.

In the financial year ending 31 March 1961 new commitments by the CDFC totalled about $10.5 million (nine projects); in the year ending 31 March 1962 new commitments were $5.7 million (eight projects); seventeen projects ($10 million) in 1963 and thirteen new projects in the year ended 31 March 1964 ($10.5 million). Outstanding CDFC commitments are now about $79.8 million.

(3) *USSR*

The Soviet Union's contribution to economic development abroad is chiefly oriented in two directions: long-term credits and technical assistance.

The long-term financing programme of the USSR vis-à-vis the developing countries is relatively recent, having begun to a significant extent only after 1955. Total funds made available to developing countries in the form of long-term loans in the period 1955-60 amounted to the equivalent of about $2,500 million (at the pre-1961 rate of exchange and expressed in constant 1960 prices), $2,375 million of which were distributed among eleven countries: India received the largest amount ($800 million), and, together with the United Arab Republic and Indonesia, it was granted about two-thirds of all credits in the period considered.[j] The distribution of such financing by type of economic activity has been fairly widespread ranging from credits for personnel training programmes to specific financing of industrial projects; although the main emphasis has been on machinery, iron and steel, assistance for refinery and petrochemical projects has also taken place.

The loans have had an average period of maturity of 12 years and carry an average rate of interest of 2.5 per cent. A frequent practice consists of allowing the debtor to repay the principal through delivery of commodities. No specific conditions are usually attached to the loans aside from the approval of the credit receiving Government.[k]

The Soviet Union also undertakes the formation of specialized training institutes and research laboratories in the developing countries; one relevant example in petrochemicals is the organization and construction of a petroloum and gas institute in Algeria and a technical college attached to it. Both are to be turned over, without compensation, to the Algerian Government.[l] The technical assistance programmes are administered by the State Committee on Economic Relations, which operates through four commercial organizations. These are: (1) V/O "Technoexport", which renders technical assistance in building and reconstruction of ports, airports and other public transportation facilities, of textile, pharmaceutical and dyestuff plants, of building materials and manufacturing facilities and of education facilities, and assists in prospecting for oil, gas and minerals;[m] (2) V/O "Prommashexport", which exports complete equipment necessary for the building of heavy engineering, machine tool, agricultural machinery plants and others and gives technical assistance at all stages of construction through the furnishing of know-how and of skilled specialists;[n] (3) V/O "Technopromexport", which is mostly concerned with energy-plants irrigation and hydraulic projects;[o] and (4) V/O "Tjazhpromexport", which supplies equipment and materials for various types of industrial plants. The agency is highly specialized in assistance for iron and steel works and oil refineries and renders assistance on various production and operation problems.[p]

There is some evidence that both long-term lending and technical assistance programmes have been somewhat stepped up since 1960; the major characteristic of Soviet foreign aid programmes, i.e., the allocation of aid to specific projects, seems to be unchanged.

(4) *Federal Republic of Germany*

In the period 1950-63 Germany granted nearly $6,000 million in development aid, of which $3,333 million originated from public sources (55.6 per cent). Germany also has a substantial interest in the IBRD, having subscribed $1,050 million to the capital stock of the latter, participates in the Development Fund of the European Economic Community for about one-third ($200 million), shares in the European Investment Bank of the EEC, also for about one-third ($300 million), and has agreed to subscribe $52.9 million of the capital stock of the International Development Association.[q] The Federal Republic also has a broad range of technical assistance and training programmes. The main institutions in the Federal Republic of Germany which are involved in granting development assistance are the public Kreditanstalt für Wiederaufbau (Reconstruction Loan Corporation) and the semi-public Ausführkredit AG (for export credits). The former is more important in terms of its contribution to the financing of industrial ventures in developing countries, and its structure is similar to that of Eximbank.

The assistance is either given for a specific project or for general development programmes. In recent years, the share of investment abroad out of total credits has risen from 24 per cent in 1959 to 64 per cent in 1961.[r]

(5) *France*

Total aid expenditures increased by 26 per cent between 1956 and 1962. In 1962 total aid was $1,400 million, of which $980 million

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[j] V. Rimalov, *Economic Co-operation Between the USSR and Underdeveloped Countries*, Foreign Languages Publishing House, Moscow, 1961 (?) pp. 43-45.

[k] *Ibid.*, p. 48.

[l] Pravda, 7 May 1964, cited in: *International Financial News Survey*, 29 May 1964, p. 175.

[m] "Technoexport" publication.

[n] "Prommashexport" publication.

[o] "Technopromexport" publication.

[p] "Tjazhpromexport" publication.

[q] *Ministry for Economic Co-operation*, Federal Republic of Germany, 2 August 1964.

[r] *The Promotion*, etc., op. cit., p. 79.

was Government-to-Government aid; the ratio of total foreign aid to Gross National Product was almost 2 per cent in 1962. It is felt by the French authorities that such ratio is adequate and should be maintained in the future, if other industrial nations make a similar effort.[s]

So far, strong preference has been given to North Africa: in 1962 aid to the region constituted over 85 per cent of total aid and over 95 per cent of Government-to-Government aid; also, 95 per cent of the 46,000 French technical advisers abroad were in North Africa. However, it is currently felt that a greater dispersion of international aid is advisable, although preferential treatment for Africa should continue. The French authorities also feel that the primary objective of their foreign aid programmes should be assistance in the improvement of agriculture productivity and in the development of light industry, while the development of heavy, capital-intensive industry should be financed jointly by several countries or by international financial institutions.[t]

Despite this attitude, French aid has played a relevant role in the development of petrochemical industries in developing countries and will presumably further increase it in the future. One element of French aid policy which could be conducive to such development is the large proportion of general Government-to-Government loans, usually granted without specification of the use of the funds. An excellent illustration of this tendency is the $150 million credit granted to Mexico in late 1962: the funds, repayable in ten years at 6-6.5 per cent interest, were turned over to Nacional Financera to be used at its discretion; in fact, such financing will be mostly used for further development of the Mexican petrochemical industry.[u]

France is also participating directly, through various public and semi-public agencies, in petrochemical projects in developing countries. The most important single project is the 1964 agreement between the Iranian Government and the Institut français du pétrole (IFP) for participation of the latter in a planned $116 million petrochemical complex: the French Government will provide $60 million in credits, while the IFP will provide technical studies, personnel to help create a permanent Iranian staff and will aid in setting up laboratories.[v]

Government financial assistance to developing countries is provided by the *Caisse centrale de coopération économique* (CCCE). Almost all autonomous resources of the Caisse are distributed as loans (70 per cent as long-term loans, 25 per cent as medium-term loans, 5 per cent as equity financing), carrying an average interest rate of 5.5 per cent. As a general rule, the CCCE provides up to 50 per cent of the cost of the project but, depending on the capital structure of the recipient enterprise and on its earning and loan repayment capacity, the quota may be exceeded.[w]

(6) *Italy* [x]

Development loans are administered by public institutions specialized in medium-term financing, of which the *Istituto Mobiliare Italiano* (IMI) and the *Banca di Credito Finanziario* (Mediobanca) are the most important, and by government financial holdings, especially the Istituto Ricostruzioni Industriali (IRI) and the Ente Nazionale Idrocarburi (ENI).

IMI, created in 1931, has currently a capital of $32 million and derives other resources from foreign loans markets; it has provided the bulk of medium-and long-term financing, with a total amount of loans outstanding of $1,800 million as of December 1962. Length of loans is usually ten years, with a 7-7.5 per cent interest rate; the institution normally supplies one-third of the total investment cost and requires governmental guarantee for loans to developing countries.

Mediobanca, established in 1946, has at present a capital of $9.6 million and derives other resources from medium-term saving accounts, bond issues and rediscounting; it has the main function of providing medium-term credits through the discounting of bills in Italy or foreign countries and also participates in the equity financing of industrial, financial and commercial firms in developing countries.

IRI undertakes direct participation in developing countries, either through local firms or by providing the entire capital for the undertaking. Although two-thirds of IRI's investments are earmarked by Law for the South of Italy, the institution is becoming increasingly active in investment activities in developing countries, and its financial resources are fairly large.

ENI is, for the purposes of this paper, by far the most important Italian institution concerned with the financing of development projects abroad. ENI is active in petrochemicals through two subsidiaries: *Agenzia Nazionale Idrogenazione Combustibili* (ANIC), owned by 51 per cent, which operates the productive facilities, both in Italy and abroad, and *Snam Progetti* (fully owned) which is active in the technical assistance and construction fields. In 1961 the social capital was doubled to $115.4 million, for a total of 72 million shares.[y] ENI's petrochemical participations abroad are mostly concentrated in North Africa and the Middle East and the enterprise prefers to secure participation by local governments. Most of ENI's financial assistance abroad is in the form of equity financing and of technical assistance. In the period 1960-63, ENI has undertaken development projects, mainly under the form of joint-ventures with local governments totalling $513 million, in Greece, India, Iraq, Poland, Spain and Yugoslavia and in 15 African countries.[z]

(7) *Japan*

Japan's total foreign aid in 1963 totalled $265 million, including payments for war reparations; the ratio of aid to GNP fell from .97 per cent in 1961 to .66 per cent in 1962 and to .53 per cent in 1963. However, this trend is expected to be reversed following planned government steps to relax terms and conditions of export credits and to promote direct loans through inter-governmental agreements.[aa]

So far, Japan's foreign aid has been largely under the form of credits to Governments of developing countries for the purchase of Japanese capital equipment.[bb]

In Japan two institutions, the Export Import Bank of Japan and the Overseas Economic Co-operation Fund, grant credit and investment funds to developing countries.

The *Export-Import Bank of Japan*, formed in 1950 and reorganized in 1952, gives financial assistance to Japanese firms involved in ventures abroad and may also guarantee their liabilities, extend loans to foreign Governments and enterprises for the import of capital goods and technical services from Japan. India and Pakistan have been the beneficiaries of the largest portion of the loans. As of 31 March 1963, export credits constituted almost 85 per cent of the Bank's financial operations (Yen 267,000 million) while import credits amounted to 1.5 per cent and development loans to 13.5 per cent.[cc]

The Overseas Economic Co-operation Fund (OECF), which began operations in March 1961, complements the Export-Import Bank in development financing activities abroad. The agency, besides granting loans for specific projects, finances feasibility studies and

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[s] *Le Monde*, various issues, Paris, December 1963.

[t] *Le Monde*, various issues, Paris, January 1964.

[u] *Chemical Week*, 6 October 1962, p. 41.

[v] *Chemical Week*, March 7, 1964, p. 40.

[w] *The Promotion*, etc., op. cit., pp. 71-73.

[x] *The Promotion*, etc., op. cit., pp. 85-89.

[y] Ente Nazionale Idrocarburi, *Annual Report*, 1962.

[z] *The Economist*, 28 March 1964, cited in *The Promotion*, etc., op. cit., p. 89.

[aa] *International Financial News Survey*, 5 June 1964, p. 186.

[bb] *Chemical Week*, 12 January 1963, p. 57.

[cc] *The Promotion*, etc., op. cit., p. 91.

pilot projects. Its loans have a length of up to twenty years, including a five-year grace period and carry an interest rate not below 3.5 per cent.[dd] In those cases where the project is considered basic and efforts to obtain equity financing from other institutions have been unsuccessful, the OECF may acquire equity investments, under the condition that the shares be sold as soon as practicable, in order to release the agency's funds.

Japan's aid has been concentrated mostly in South-East Asia, India and Pakistan; and trends towards a greater geographical dispersion are not noticeable, but it is likely that Japan's role in assisting in petrochemical projects in the area will become more significant in the near future.

[dd] *Ibid.*, pp. 91-92

APPENDIX II

The following table contains a summary picture of the companies examined in relation to the financial items selected, together with aggregate totals and averages for the chemical and oil groups respectively.[a] Naturally, the aggregate figures have limited relevance. Where possible, the data represent four-year averages[a] (1960-1963) for each company, in order to avoid the distortions of once-and-for-all variations. The items presented attempt to describe the companies relative to profitability, liquidity, long-term indebtedness investment policy, extent of operations abroad and in petrochemicals.

Size is best measured by the value of net total sales, however, for purposes of comparability, total revenue, which is usually little different has been used.

The index of profitability used is net income as percentage of total revenue; although the shortcomings of such index, when comparing firms belonging to different industries or with widely different output-mixes, are well-known, it is in this case a fairly good measure of comparative profitability, since all companies chosen manufacture most of the products in the petrochemical field. It would not do, however, to compare oil and chemical companies on this basis; rather, the comparison should be made between the figures presented here and the "normal" ratios presented in the introduction. Another index has been added — the ratio of net income to working capital — which is useful in measuring profitability of concerns whose operating funds are provided in large part by long-term borrowing; in this case, the index has been computed when the long-term debt/working capital ratio was greater than 1.

It is commonly agreed that the cash ratio provides a better test of liquidity than the current ratio; however, both are here shown, in order that the comparison between United States and non-United States companies on this account may be more meaningful.

Long-term indebtedness has been indicated through the long-term debt/working capital ratio; also, where possible, the average rate of interest on long-term debt paid by each company has been computed.

Investment policy is depicted by the percentage of capital expenditure on total revenue, by the annual depreciation allowance as percentage of net fixed assets, and more generally, by the percentage of retained earnings on net income; also, the total revenue/capital expenditure ratio has been presented, as a proxy for the sales/investment ratio.

Finally, the extent of operations abroad and in petrochemicals is expressed through the percentage of sales abroad and in petrochemicals on total revenue and the percentage of expenditures abroad and in petrochemicals on total capital expenditures; unfortunately, this information is rarely available.

Let us now give a brief look at the general activities of the chemical and oil companies selected for study.

Dupont. Dupont de Nemours is the largest chemical enterprise in the world. Born out of a financial group, it still retains to a high degree the financial solidity and self-sufficiency typical of such concerns. Net sales have topped in 1963 the $2.5 thousand million mark and the firm presents an over-all picture of extreme financial stability.

Dupont has been in the front ranks of technological innovation for a long time and has gained considerable advantages from its pioneering in synthetic fibres (mainly polyesters and polyamids). In recent years the firm has consistently paid the highest dividends of the group of firms considered here, but more than enough has been accumulated in capital and revenue reserves to allow internal financing of research or construction projects of practically any size.

Although sales abroad constituted in 1960-63 about 17 per cent of total sales, Dupont is still basically a domestic-oriented concern; thus, it has the potential to become a major factor in petrochemical developments abroad if profitability of domestic operations should decline. Financing of investment and of operations has in recent times come entirely out of internal resources; the company does not report any long-term indebtedness for the last years.

Union Carbide. Union Carbide, the second largest chemical firm in the world in 1963, with a total revenue of $1,694 million, has a high stake in petrochemicals: over 63 per cent of its average annual capital expenditures in 1960-63 were in chemicals and plastics. However, the company's petrochemical interests in developing countries are relatively minor: as of September 1963, the only major venture in which it participated was the Cubatao polyethylene plant of Union Carbide to Brazil.

The company enjoys the second highest rate of profit of the United States chemical firms examined and its financial position is very favourable. Its reliance on long-term debt as a source of funds is about average for United States chemical standards and the over-all position of the firm would make it possible, if necessary, to call on an untapped reserve of credit good will. Union Carbide's annual investment rate is rather low, but its depreciation rate is among the highest, indicating a trend towards modernization of plant and equipment and the adoption of new processes.

As with Dupont, Union Carbide's present limited involvement in petrochemical ventures abroad, combined with its abundant financial resources makes the company a potential major participant in future petrochemical ventures in developing countries.

Imperial Chemical Industries. I.C.I. is the largest European chemical group and the third largest in the world. It has very diversified products and markets: almost all major petrochemicals are represented in the company's range of products, and all areas of the world in its export markets. Sales abroad account for about 47 per cent of all sales and are in large part directed to developing countries; however, owing to a trend towards newer and more sophisticated products during the past fifteen years, the geographical pattern of I.C.I.'s exports is shifting away from developing economies.[b]

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[a] Medians have not been used because of the smallness of the sample. Bayer, Hoechst, BASF, Montecatini and St. Gobain do not publish wholly consolidated statements; the estimates given in *Eight West European Chemical Shares*, Investment Research Group of the Amsterdamsche Bank N.V., Banque de la Société Générale de Belgique, S.A., Deutsche Bank A.G., 1964, of consolidated figures for the above companies in 1962 have here been used.

[b] *Eight West European Chemical Shares*, Investment Research Group of the Amsterdamsche Bank N.V., Banque de la Société Générale de Belgique, S.A., Deutsche Bank A.G., 1964.

I.C.I.'s objective of building an integrated synthetic fibres industry in the United Kingdom capable of competing on an equal footing with American producers led to the unsuccessful attempt in 1961 to incorporate Courtaulds.[c] The company has recently launched an intensive drive to obtain new export markets, mainly directed toward the USSR and other centrally planned economies; late in 1963 the company expressed its willingness to act as a contractor in supplying complete plants to the USSR, a partial reversal of the previous policy of limiting licensing and provision of know-how.[d] I.C.I.'s participation in petrochemical ventures in developing countries is, however, limited: as of September 1963 the only important ventures were the San Lorenzo (Argentina) plant (phthalic anhydride and other products) and a planned polyethylene plant, also in Argentina, both operated by I.C.I.'s subsidiary, Duperial S.A.I.C.

The company has adequate working capital and its dependence on long-term indebtedness is limited, partly as a result of a relatively high proportion of retained earnings (over 38 per cent of income in 1960-62). However, it has one of the lowest annual investment rates in Europe (10.16 per cent of total revenue in 1960-62) and its depreciation allowance is significantly below the average.

Monsanto. Sales of petrochemicals accounted in the last four years for at least 60 per cent of the company's total revenue. Monsanto's international sales outlets are very diversified and no area of specific interest is identifiable; instead, the company's direct investments abroad are concentrated in Latin America (Monsanto Mexicana and Monsanto Argentina).

The company's activities abroad are mostly concentrated in the production of PVC and polystyrene, although its over-all range of petrochemical products is much wider. The company has manifested in recent years a declining interest in minority ownership and has concentrated most of its efforts on the fully owned subsidiaries.[e]

Its profitability is about average among the United States chemical group and, although its working capital is adequate by any standard, the long-term debt/working capital ratio is over 1.25, the highest among the United States chemical firms examined, a clear indication of a relatively unusual willingness to rely on outside financing. On the other hand, the company's rate of investment is the highest of the United States chemical group (13.5 per cent) and its depreciation allowance adequate.

Dow. The Dow Chemical Co. is, together with Allied, one of the least internationally oriented of the group. International operations have accounted in the last few years for little more than 10 per cent of the company's total revenue. As of September 1963 the company had only one petrochemical project in a developing country, the Dow Hellenic Chemical Industries Ltd. plant at Lavrion, Greece.

Dow's profitability is about average, but its financial position is among the least solid by United States standards, although still fairly satisfactory: an acceptable funded debt/working capital ratio (.88) is achieved only through a relatively small working capital. In October 1963 the company conducted a successful refinancing operation, selling $100 million in debentures to the public and using the proceeds to repay an approximately equal amount of short- and long-term debts.

Dow is highly research-oriented, both towards the discovery of new processes and towards the development of new products. Its investment rate is adequate by United States standards, while set-asides for depreciation and obsolescence are the highest in the United States group.

Allied Chemical. Allied, until recently considered by chemical men as "an investment group with a branch in chemicals", has become an important factor in the petrochemical industry through the acquisition, on February 20, 1962, of Union Texas Natural Gas Corp. According to the company report of 1963 "this acquisition will provide the company with a basic position in hydrocarbon raw materials, a growing business in those areas of the natural gas and oil business where conditions and opportunities appear favourable.... The first major step toward developing the benefits which will flow from this merger is the planned building by 1964 of a large petrochemical complex in Louisiana, previously announced." The company is still mostly domestic-oriented: all principal projects in recent years, with one notable exception, are in the United States or Canada. The exception is the large commitment assumed by Allied through its 35 per cent participation in the only major oil-chemical joint venture in the petrochemical field, the $22.5 million ammonia and fertilizers complex at Miaoli, in China (Taiwan) together with Mobil (35 per cent) and Chinese Petroleum (30 per cent).[f] Allied's [illegible] in 1960, were over 45.7 per cent of total revenue in 1963. The company's profitability is the lowest of the United States group except Koppers'; its financial position is slightly below United States standards, with a relatively low working capital/total revenue ratio (.21) and a relatively high funded debt/working capital ratio (1.08). Its depreciation allowances are also low, but the rate of investment is in line with the rest of the United States group.

Bayer.[g] Following the decartelization of IG Farben Industrie, the group was divided into several companies, of which Bayer is the largest. With a total revenue of $818 million in 1962, Bayer is also the second largest chemical company in Europe. Petroleum derivatives account for over 50 per cent of the company's well-balanced production, and foreign sales are about 46 per cent of total sales. Until recently the company exported mainly specialized products, but a trend has set in towards the growth of subsidiaries abroad, so that it may be expected in the future that Bayer will increase its exports of intermediates. Probably due in part to the type of petrochemicals so far manufactured and exported, Bayer's petrochemical investment activity in developing countries has been very limited: at the end of 1963 the only existing facilities were in El Salvador (insecticides plant). The company was to participate in a large ($25 million) intermediates project in India, together with Hoechst, BASF and the Indian Government but, owing to a series of adverse circumstances, the German firms withdrew.

No data on net income are available, and any statement as to the profitability of the company (and of the other European companies) cannot be substantiated with any confidence. Bayer's financial situation must be viewed in the context of European practices. Operating capital is adequate by European standards and dependence on outside financing is relatively slight. By the same token, the company's rate of investment (14 per cent of total revenue) which would be very high in the United States, is below the average of the European group; its "rate of innovation", as expressed by the percentage of depreciation set-asides over net fixed assets is, on the contrary, the highest in Europe after Saint Gobain.[h] Expenditures on research are equivalent to 4.4 per cent of total sales.

Hoechst. The production programme is diversified and well balanced among raw materials, synthetic fibres, dyestuff and

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[c] The attempt ended definitely in May 1964, when I.C.I. exchanged its 37.5% interest in Courtaulds (plus $28 million) for British Nylon Spinners Ltd., which it owned jointly with Courtaulds (*Chemical Week*, May 9, 1964). The unsuccessful bid was a major factor in leading the Labour Party to the now-famous vow to nationalize I.C.I. if it ever would have the chance.

[d] *Chemical Week*, December 28, 1963, p. 24.

[e] *Chemical Week*, March 9, 1963, p. 37.

[f] Another important project has recently entered the planning stage. Allied will have 4[illegible]% interest in a joint venture with the [illegible] Andhra Sugars Ltd. for construction at Kothagudem of a $[illegible] million ammonia and urea plant (*Chemical Week*, January 4, 1964).

[g] Information on Bayer, Hoechst, BASF, Montecatini and Saint Gobain is derived in part from Eight West European Chemical Producers, op. cit., and not directly from company reports.

[h] A word of caution is here in order: while in the United States accounting practices are fairly uniform and the method of depreciation usually similar for all companies of a given industry (namely the one that, given the characteristics of the industry, allows minimization of fiscal burden), in Europe, owing to different tax codes and fiscal policies, accounting methods vary from country to country, even in the same industry. Thus, any comparison between rates of depreciation, whether among European companies or between United States and European companies should not be given too much weight.

TABLE A. COMPARISON OF SELECTED FINANCIAL ITEMS FROM INCOME

Items	*Du Pont*	*Union Carbide*	*I.C.I.* (*)	*Monsanto*	*Dow*	*Allied* (*)	*Bayer* (*)	*Hoechst* (*)
Current assets	922	732	776	426	364	280	314	362
Cash and marketable securities	325	142	21	96	49	61	70	91
Current liabilities	156	247	382	173	196	99	196	191
Working capital [a]	766	485	394	253	168	179	118	171
Long-term debt	—	464	246	318	148	195	221	262
Interest payments	—	17 [2]	15 [5]	14	8	8	8 [2]	11 [2]
Net fixed assets, at cost	2,440	969	1,536	712	585	597	381	371
Annual depreciation allowance [b]	176	145	116	95	95	64	69	62
Capital expenditures [c]	258	175 [3]	160	140	99	94	116	108
Exp.s abroad	n.a.	n.a.	43 [5]	n.a.	n.a.	n.a.	n.a.	n.a.
Exp.s in petrochemicals	n.a.	111 [4]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Total revenue	2,353 [1]	1,629	1,575	1,032	908	841	818	770
Sales abroad	391	n.a.	771	n.a.	n.a.	n.a.	376	293
Sales of petrochemicals	n.a.	n.a.	n.a.	n.a.	n.a.	360	n.a.	n.a.
Net income	431 [1]	155	114	74	71	57	n.a.	n.a.
Dividend payments	349	108	70	29	44	41	n.a.	n.a.
Retained earnings	81	47	44	45	27	16	n.a.	n.a.
Cash ratio [d]	2.08	.57	.05	.55	.25	.62	.36	.48
Current ratio [e]	5.91	2.96	2.03	2.46	1.86	2.83	1.60	1.89
Net income/working capital ratio [f]	not appl.	not appl.	not appl.	.29	not appl.	.32	n.a.	n.a.
Total rev. capital exp. ratio	9.12	9.31	9.84	7.37	9.17	8.95	7.05	7.13
Net income as per cent of tot. rev.	n.a.	9.51	7.24	7.17	7.82	6.78	n.a.	n.a.
Capital exp. as per cent of tot rev.	10.96	10.74	10.16	13.56	10.90	11.18	14.18	14.02
Working capital as per cent of tot. rev.	32.55	29.77	25.01	24.51	18.50	21.28	14.42	22.20
Sales abroad as per cent of tot. rev.	16.62	n.a.	48.95	n.a.	At least 10 per cent	n.a.	45.96	38.05
Petrochem. sales as per cent of tot. rev.	n.a.	n.a.	n.a.	At least 60 per cent	n.a.	42.80	n.a.	n.a.
Dividends as per cent of net inc.	80.97	69.67	61.40	61.40	61.97	71.92	n.a.	n.a.
Ret. earnings as per cent of net inc.	19.03	30.33	38.60	38.60	38.03	28.08	n.a.	n.a.
Expend. abroad as per cent of cap. exp.	n.a.	n.a.	21.61 [5]	n.a.	n.a.	n.a.	n.a.	n.a.
Petrochem. exp. as per cent of cap. exp.	n.a.	64.00 [3]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Depr. allowance as per cent of net F.A.	7.21	14.96	7.55	13.34	16.24	10.72	18.11	16.71
Long-term debt as per cent of work. cap.	—	95.67	62.43	125.69	88.09	108.93	187.28	153.21
Inter. payments as per cent of curr. liab.	—	6.88	3.93	8.09	4.08	8.08	4.08	5.76
Inter. rate on long-term debt (ave.) per cent	n.a.	3.66	6.10	n.a.	n.a.	n.a.	3.62	4.20

SOURCES: Annual Reports, 1960-1963 and: *Eight West European Chemical Shares*, Amsterdamsche Bank *et alii*, 1964.

Note: All figures, except ratios and percentages, are in million U.S. dollars. Items and percentages may not add up to correct total because of rounding to nearest million $.

LEGEND: —: nil or negligible, n.a.: not available; not appl.: not applicable. All data refer to calendar years.

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[a] Current assets less current liabilities.

[b] Includes depreciation, amortization, obsolescence and depletion.

[c] On construction of new plant and equipment or expansion and improvement of existing ones.

[d] Cash and marketable securities, current liabilities.

[e] Current assets, current liabilities.

[f] Applicable only when the $\frac{\text{long-term debt}}{\text{working capital}}$ is greater than one.

[1] Does not include revenues from General Motors holdings, of which Du Pont is divesting itself in accordance with the final judgement (May 1, 1962) in the Du Pont-GM antitrust case; the net income from such holdings is, however, included in Du Pont's net income. Thus, in this case, it is not possible to determine the rate of profit by comparing net income to total revenue.

[2] On long-term debt only.

[3] "Construction expenditures".

[4] "Chemicals and plastics": probably an overestimation.

[5] 1962 only.

[6] Relates only to: Union Carbide, Monsanto, Dow, Allied, I.C.I. and Koppers.

[7] Relates only to: Du Pont, I.C.I., Bayer, Hoechst, and BASF.

STATEMENTS AND BALANCE SHEETS OF 17 COMPANIES, AVERAGE 1960-63

BASF (8)	*Monte-catini* (6)	*Saint-Gobain* (6)	*Koppers*	*Total and average chemical*	*Jersey Std.*	*Royal Dutch-Shell*	*Gulf*	*B.P.* (5)	*Phillips*	*Total and average petroleum*
257	353	103	110	4,999	3,674	4,074	1,396	1,095	414	7,266
66	30	30	10	991	1,422	4,394	530	235	96	2,453
171	271	80	36	2,198	1,879	1,666	533	660	207	3,593
86	82	23	74	2,801	1,795	2,408	861	435	207	3,673
150	415	65	27	2,511	817	984	256	221	231 [11]	1,808
6 [8]	19 [8]	6 [8]	1 [8]	113	99	25 [8]	9	11	11	100
380	512	129	88	8,700	6,578	4,875	2,409	1,159	1,079	12,457
68	61	49	12	1,012	564	996	243	130	132	1,274
110	218	100	18	1,604	966 [13]	787 [13]	357	354	155	n.a. [13]
n.a.	n.a.	n.a.	6	n.a.	478	n.a.	n.a.	n.a.	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	n.a.	216 [14]	64 [15]	43	23	n.a.	n.a.
714	666	650	295	12,251	10,099	8,339	3,398	2,063	1,254	19,114
264	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
n.a.	n.a.	n.a.	70 [10]	n.a.	339	650 [16]	n.a.	n.a.	n.a.	n.a.
n.a.	n.a.	n.a.	7	n.a.	827	549	345	186	112	1,626
n.a.	n.a.	n.a.	5	n.a.	541	221	133	75	62	881
n.a.	n.a.	n.a.	2	n.a.	286	328	212	111	50	715
.39	.11	.37	.28	.45	.76	.84	1.01	.54	.46	.67
1.50	1.30	1.29	3.06	2.27	1.95	2.45	2.61	1.66	2.00	2.02
n.a.	n.a.	n.a.	not appl.	n.a.	not appl.	not appl.	not appl.	not appl.	.54	not appl.
6.49	3.06	6.02	16.39	7.64	11.61	10.5	n.a. [17]	n.a. [17]	n.a. [17]	n.a. [17]
n.a.	n.a.	n.a.	2.37	7.61 [8]	8.22	6.6	10.15	9.01	8.93	8.51
15.40	32.73	16.61	6.10	13.09	8.61	9.4	n.a. [17]	n.a. [17]	n.a. [17]	n.a. [17]
12.04	12.31	3.54	25.08	22.86	17.84	28.8	25.34	21.08	16.51	19.22
36.97	n.a.	n.a.	n.a.	33.62 [7]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
n.a.	n.a.	n.a.	23.73	n.a.	3.37	10.77	n.a.	n.a.	n.a.	n.a.
n.a.	n.a.	n.a.	71.42	71.06 [9]	65.41	40.30	38.55	40.32	55.36	54.18
n.a.	n.a.	n.a.	28.58	28.94 [9]	34.59	59.70	61.45	59.68	44.64	45.82
n.a.	n.a.	n.a.	33.33	n.a.	55.19	n.a.	n.a.	n.a.	n.a.	n.a.
n.a.	n.a.	n.a.	n.a.	n.a.	24.94	8.1	n.a.	n.a.	n.a.	n.a.
17.89	11.91	37.98	13.63	11.63	8.57	11.0	10.09	11.22	12.23	10.23
174.40	906.00	282.60	36.48	89.64	45.51	24.3	27.73	50.80	121.25	49.22
3.51	7.01	7.90	2.78	5.14	3.14	1.90	1.74	1.73	5.07	2.78
4.00	4.98	9.23	4.30	4.49 [9]	n.a.	4.28	n.a.	n.a.	n.a.	n.a.

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[8] Relates only to: Du Pont, I.C.I., Union Carbide, Monsanto, Dow, Allied and Koppers.

[9] Relates only to: Union Carbide, I.C.I. Bayer, Hoechst, BASF, Montecatini, Saint-Gobain and Koppers.

[10] Probably overestimated, since the corresponding category in the company report comprises "Chemicals dyestuffs, and plastics".

[11] Includes the amount due within one year.

[12] Exclusive of exploration expenses.

[13] Since exploration expenses in oil companies are very large, and since many companies do not provide information on net capital expenditure, all aggregate magnitudes and ratios related to the latter have not been here presented.

[14] Includes refineries.

[15] "Chemical Plants", probably overestimates expenditures on petrochemicals, since Shell Chemical produces also most basic chemicals.

[16] "Chemical sales" see note 15.

[17] See note 13.

(5) 1960-62 average.

(6) All data are for 1962 *only*, also, since these companies do not publish consolidated statements, most figures are estimated.

(7) Data for 1960 and 1961 do not include the operations of Union Texas Natural Gas Corp., absorbed by Allied in Feb. 1962, the four year "average" must thus be considered as simply indicative.

(8) Data for 1960 are not included, since the company did not publish its first consolidated report until 1961. Figures are therefore averages for 1961-62.

intermediate organics, pharmaceuticals, agricultural chemicals and inorganic chemicals. Sales abroad constituted about 38 per cent of total sales. As in the case of Bayer, expansion of foreign subsidiaries is causing a shift in Hoechst's exports from highly specialized products to supporting raw materials and thus towards developing countries. The company planned, as of September 1963, together with the Indian firm Mafatlal Industries Ltd., a petrochemical plant and naphtha cracker at Bombay.[i] A significant proportion of the firm's foreign earnings derives from consulting engineering work: the company provides know-how, technical assistance and often complete plans of plants and equipment; it usually prefers, however, to leave construction entirely to the client.

Hoechst has the least favourable equity ratios in the German group; on the other hand, the Amsterdamsche Bank report suggests, that Hoechst perhaps has large hidden reserves.[j] Its liquid position, instead, is the strongest of all European firms. Hoechst invests annually the lowest proportion of its revenue among the European chemical companies considered; its depreciation rate is the smallest after Montecatini and it spends about 4.1 per cent of sales on research.

Badische Anilin and Soda Fabriken. BASF is the largest plastics producer in Europe after I.C.I. and the largest supplier of supporting raw materials for fully synthetic fibres. Other products are nitrogenous fertilizers, paints and dyes, and solvents. Forty-seve[illegible] cent of BASF sales go outside Germany, and the company is shifting to the production of sophisticated products; it has a high degree of vertical integration and a leading position in the petrochemical field. The firm planned, as of September 1963, jointly with Cole & Co., a polystyrene plant at Thana, India; it also was one of the parties, together with Bayer and Hoechst, to the abortive plans for the Indian intermediates plant.

The corporate financial structure of BASF is definitely not strong; although long-term indebtedness is contained within tolerable limits, a low cash ratio and current ratio and an inadequately small proportion of working capital on total revenue are clear indications of a general lack of liquidity and thus of lack of short-term flexibility. On the other hand, although they are not quite satisfactory, BASF shows the most favourable equity ratios of the European group. The company spends on research about 4.1 per cent of sales, keeps annual capital spending at a fairly high level, and has a fairly high rate of depreciation.

Montecatini. This is the largest Italian chemical company and accounts for more than 50 per cent of Italian plastics production. The structure of the group is mostly vertical, with the company producing over 80 per cent of its own electric energy requirements. Montecatini has in the last four years been undoubtedly the most dynamic chemical concern in Europe, mostly due to the stimulus of development programmes for Southern Italy. The firm has many foreign interests in developing countries; however, the only major participation in the petrochemical field is in the planned Trombay, India, polypropylene complex, a joint venture with the Tata group.

Montecatini's financial position is definitely the weakest in the whole group of companies considered: its capital outlays in recent years have been huge, while sales have lagged behind; the financial ratios reflect clearly forced expansion without sufficient equity, a marked lack of liquidity and excessive reliance on long-term indebtedness. The concern's financial difficulties have been very serious, aggravated by large expenditures on single giant projects. The biggest one, the Brindisi petrochemical complex, was the major factor that caused the company to reshuffle its top management and to take major steps to remedy the situation: it signed in June 1963 a cross-licensing, non-exclusive agreement with Dupont for all their present and prospective United States polypropylene patents[k] and in January 1964 sold to Royal Dutch-Shell a 50 per cent interest in the Brindisi complex, forming a new subsidiary, Monteshell Petrochemical.[l]

It is to be expected that, after an improvement of the financial situation of the firm, which is already taking place to some extent, Montecatini will adopt more cautious capital spending policies and try to reduce its oversized debt. The company's depreciation rate is the lowest in the European group, while its investment rate and research expenditures (5 per cent of annual sales) are the highest.

St. Gobain. Chemicals and petrochemicals constitute about 50 per cent of the company's sales, while glass alone accounts for 42 per cent and paper for 6 per cent. St. Gobain could thus be classified as a glass company (it ranks third in the world on a sales basis) rather than as a chemical company. The concern's chemical interests are mainly vested in Péchiney-St. Gobain, a 50-50 participation with Péchiney, which is mostly domestic-oriented. The company was reorganized in 1962, and share issues were emitted in 1961 and 1962. As a consequence, St. Gobain's equity ratios are adequate, whilei ts liquid position is almost as inadequate as Montecatini's, with a slightly higher cash ratio and the same current ratio, the lowest of the whole group. Its rate of investment is the second highest in the European group, and research expenditures in the chemical sector amount to about 4 per cent of chemical sales.

Koppers. This is the smallest of the companies here examined and relatively the most active in petrochemical investment abroad. Petrochemicals account for only about 20 per cent of total sales, but Koppers' investment abroad is mostly in this field. The company is interested primarily in Latin America (Argentina, Brazil, Chile) and owns three petrochemical complexes there through foreign subsidiaries. Although profitability of the concern is the lowest of the whole group, its management is modern and progressive and the company presents a very dynamic picture.

Unfortunately, however, Koppers' financial resources do not match its interest in the petrochemical industry in developing countries: the financial structure of the firm is well balanced both in terms of liquidity and of long-term indebtedness, but its resources do not allow for the financing of major projects. However in 1963, the company concluded an agreement with a group of 10 banks which makes available to the company a $30 million line of credit over an eight-year period.[m] Koppers' depreciation rate is rather high for the United States group, but the company has invested on the average a very low 6.1 per cent of total revenue annually between 1960 and 1963.

Standard Oil of New Jersey. Jersey Standard is one of the ten largest industrial corporations in the world. With a total 1963 revenue of well over $11 thousand million, it is the largest oil company in the world. Standard Oil's chemical interests are headed in two directions, an increased emphasis on manufacture of finished products and a world-wide expansion of ammonia and fertilizer production. In 1962 Standard Oil formed a Chemical Co-ordination Group to intensify total chemical effort; the management unit is set up within the parent company, but is totally separated from the traditional oil business. Standard Oil has a favourable attitude towards investment abroad: "Standard Oil and its affiliates continued to identify themselves with the development needs of countries where they operate...."[n], and the company is apparently satisfied with its financial performance abroad: "We believe we have been successful in our policy of overseas investment over the years, despite the problems, and we anticipate further sound business opportunities...".[o] Standard Oil's capital expenditures abroad increased from 53 per cent of total capital expenditures (excluding exploration expenses) in 1960 to over 62 per cent in 1963, with a slight setback in 1962; capital expenditures in petrochemicals and

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[i] For further information, see the NOCIL project, in chapter IV, of this paper.

[j] Eight West Eur. Chem. Shares, op. cit., p. 11.

[k] *Chemical Week*, June 15, 1964, p. 21.

[l] *Chemical Week*, January 4, 1964, p. 26.

[m] *Company Report for 1963*.

[n] *Company Report*, 1961.

[o] *Company Report*, 1963.

refineries decreased slightly from 24 per cent of total expenditure in 1960 to less than 22 per cent. However, the magnitude of such investment is still remarkable, with $553 million spent abroad in 1963 of which $192 million was spent on petrochemical facilities. Jersey Standard operates two ammonia projects, one in Colombia, and one in Costa Rica; it also planned in 1963 two joint projects in Greece, one in the Philippines (through its subsidiary, Esso Standard Fertilizers and Chemicals) one in Argentina (through Esso Petrolera Argentina) and one in El Salvador, all for the production of ammonia and fertilizers, except for the Argentinian project, which is to produce aromatics.

The percentage of net income over total revenue was almost 9 per cent, a satisfactory figure even considering Standard Oil's size. As could be expected, the long-term debt/working capital ratio is very small, since it is natural to assume that a large, successful company will have no need to recur to outside financing to any significant extent. It is more interesting, instead, to note the level of the current ratio, that does not reach 2.00; the company thus seems to enjoy a high degree of short-term flexibility without keeping the level of its current assets unduly high.

Royal Dutch-Shell.[p] The Royal Dutch-Shell group is the second largest oil concern in the world, with 1963 sales amounting to about $6,500 million. Of this, about 11 per cent came from sales of chemicals (mostly petrochemicals).

The importance of the group for petrochemical financing is enhanced by the fact that most of its petrochemical investment goes abroad. Shell companies have a solid footing in Europe, recently widened by the acquisition of a 50 per cent interest in the Montecatini complex at Brindisi. Their present involvement in developing countries is relatively limited, but there is evidence of an increasing interest in these areas. Thus, the group holds minority interests in several petrochemical ventures in developing countries: in addition to the 33 per cent participation in the NOCIL project in India (see under case-studies in chapter IV of this study), the group has holdings in Spain and Argentina. Participation in these ventures includes provision of know-how and technical assistance.

Royal Dutch-Shell has both the lowest profit rate and the smallest relative long-term debt among the companies considered. Depreciation as percentage of net fixed assets is about average among the companies considered. Its liquidity position is satisfactory and the level of retained earnings adequate for most types of expansion or construction projects. Investment in petrochemicals constitutes a smaller proportion of total capital expenditure than the proportion of petrochemical sales on total sales; the explanation may lie in a lower incremental capital-output ratio for petrochemicals. It is, however, unlikely that, if the present rate of petrochemical investment is kept constant in the future, the group's stake in the field will significantly increase. Thus, for the purpose of financing petrochemical investment in developing areas, the potential importance of the Shell group may depend more on a geographic shift of interest rather than on an increased involvement in petrochemicals generally.

Gulf. In the decade 1954-63 Gulf invested over $90 million in petrochemical facilities, in addition to its investment through British-American and through Goodrich-Gulf, in which it has a 50 per cent interest; except for the activities of the latter company, Gulf's operations in the petrochemical field remained those of a basic supplier to other manufacturers. On September 14, 1963, Gulf announced an offer of $41 a share for all the 3 million-odd shares of the Spencer Chemical Co. common stock, and has since fully acquired the company. With the absorption of Spencer, Gulf has become a major manufacturer of a variety of finished products. Thus, in a sense, the company is a newcomer to the important sectors of petrochemical investment abroad; as the Report for 1962 states, it was only in that year that the company's operations were carried overseas, after 10 years of petrochemical growth in the United States. In the decade 1951-61 Gulf's rate of growth from its over-all United States operations has been approximately 10.6 per cent yearly, while the growth from world-wide operations has been 11.5 per cent. However, after 1959, the share of foreign operations in the firm's income has remained approximately constant around 40 per cent.

The profit rate is the highest of the oil group, averaging over 10 per cent in 1960-63; the company does not rely much on long term debt (rather, its funded debt working capital ratio is the lowest of the oil group), and obtains most of its financial requirements out of its very high retained earnings rate. Gulf's investment rate is slightly higher than Jersey's, and its depreciation rate the second lowest of the oil group, after Jersey's.

British Petroleum. The B.P. group had, as of December 1963, 138 subsidiary and associated companies: 64 of these fully owned, 11 owned by more than 50 per cent but less than 100 per cent, 25 owned by 50 per cent and in the remaining 34 companies the group has a minority interest. No clear pattern of corporate policy emerges, if one discounts the natural preference for full ownership. As is to be expected, 12 joint ventures are with Shell, 7 of these are 50-50 and the remaining 5 are Shell-controlled. Fifty-eight companies are in developing countries, and 7 of these in Africa. Only 7 ventures are clearly petrochemical in nature. B.P. is a very complex structure, and the second largest oil company in Europe, with $2,063 million of average total annual revenue in 1961-62. Its operations are truly international in nature, with a high degree of geographical dispersion.

The financial structure is in line with the oil group average, for what concerns long-term indebtedness, while the liquidity position of the company is the least solid in the group, although still satisfactory by any standard. B.P. retained in 1961-62 about 60 per cent of earnings and enjoyed the second highest profit rate in the oil group.

Phillips Petroleum Co. Phillips is the smallest of the oil companies here examined, with $1,296 million of total revenue in 1963 and $114 million of net income. Although separate figures are not available, the company is known for its involvement in foreign ventures and for its interest in petrochemicals (especially carbon black). It has half-interest in companies that have built new carbon black plants using Phillips process in France, Italy and South Africa, a 30 per cent interest in another such project started in December 1962 at Durgapur, India and a 10 per cent interest in Negromex, a company building a similar plant in Mexico. The same Indian joint company, Phillips Carbon Black Ltd., is planning an expansion of its Durgapur plant and a new plant at Cochin for various products.

The company has a very favourable attitude towards licensing and providing technical assistance, usually under the condition that it be allowed to participate in the venture; it ranks second among United States oil companies in the number of patents owned. Its liquid position in the least strong after B.P. in the oil group and it tends to finance a large proportion of its long term expenditures from outside sources.

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[p] The authors gratefully acknowledged the information directly supplied by the company.

2. FINANCIAL AND OTHER PROBLEMS FOR JAPAN'S PETROCHEMICAL INDUSTRY

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CHAPTER I. GENERAL REVIEW

When the plans to foster, facilitate and encourage growth of Japan's petrochemical industry were announced by the Ministry of International Trade and Industry in July 1955, the news was received by the related chemical industry circles with many doubts because they were skeptical whether the petrochemical industry, requiring as it does the colossal investment sums for facilities as well as the highly advanced technology and high-pitched operation, could really be developed in Japan where both the scale of economic activities and the available market were limited.

The gross chemical industry output in those days, excepting chemical fibres, amounted to $1 500 million and the annual investment in the facilities amounted only to $90 MM. However, in less than a decade, the chemical industry has attained such remarkable and rapid growth that the output doubled, reaching $3,600 MM of which the petrochemical industry, in particular, shared 15 per cent or $500 MM. On the other hand, during the same period, there was a 15 per cent price drop for general chemical industry products and 46 per cent price drop for petrochemical products. Accordingly, in terms of these price drop percentages, the petrochemical industry's substantial share works out as much as 20 per cent. All of these facts not only show that the petrochemical industry took the initiative in bringing about the chemical industry's amazingly rapid growth and development, both quantitatively and qualitatively, in less than ten years, but prove that the growth of the petrochemical industry did play a key role in raising the chemical industry's position in Japan's industrial structure up to the international level.

The total investment for the petrochemical industry during those years amounted to $900 MM, and an additional $320 MM investment is expected to be made during 1964. This latter investment represents 7 per cent of the $4,600 MM to be invested this year in Japan's entire mining and manufacturing industry facilities and the petrochemical industry, with its output estimated to reach $700 MM annually, is believed to lead all the other chemical industries of Japan.

The ammonia industry, which had depended for raw material source on coal or water electrolysis, has recently switched to natural gas, crude oil, naphtha, petrochemical plant's surplus gas, etc. If such materials are taken into the broader-sense petrochemical industry, it is not an exaggeration to say that at least 30 per cent of Japan's chemical industry is being replaced by the petrochemical industry.

CHAPTER II. MAKE-UP AND FINANCING OF CAPITAL

The total investment in petrochemical production facilities during the past nine years amounted to $900 MM, of which 20 per cent or $180 MM was financed with the capital and capital surplus and the balance of 80 per cent with borrowed capital, mostly loans.

The capital make-up of all the industrial enterprises of Japan is 30 per cent owned capital plus 70 per cent borrowed capital, from which it can be said that the petrochemical industry depends more on borrowed capital.

The high dependency of Japan's industrial enterprises on borrowed capital has resulted from expenditures during World War II as well as from spending of accumulated capital for the post-war reconstruction. In undertaking new enterprises, therefore, it is natural to depend on the loan and, because the interest rate on the loan is as high as 9 per cent, the minimum 10 per cent dividend is required and to enable this dividend rate, 20 per cent before-tax profit must be realized by securing a minimum 10 per cent margin on the sales. With these factors as premises, the enterprise must be capable of furnishing such investment opportunities as to acquire the maximum loan with the minimum capital. Such are the circumstances peculiar to Japan's industrial economics.

While the petrochemical industry can furnish such investment opportunities, it is also true that the petrochemical industry has at the same time a number of risks, such as whether it is sufficiently capable of digesting the inducted foreign technology to undertake commercial production; whether the products are sufficiently marketable ones; even if the products have marketability, whether there is enough demand to guarantee the plant to operate at such rates as to ensure necessary profits, and so forth.

The financial institutions of Japan, despite many vicissitudes, have continued to render financing services to many enterprises up to the present. However, it should not be the policy of a bank to assume by itself such risk as to undertake priority financing to a specific industrial company, since "credit and reliability first" is the motto of all banks. Herein lies the opportunity for the co-operative financing system to display its *raison d'être*.

On the other hand, the Japanese Government, which approved the petrochemical projects under the Foreign Investment Law, has taken the proper steps, first for the ethylene centres and later for commercialization of specific new technologies, by letting the Japan Development Bank (governmental financing institution) finance the state funds. Although the amount of such financing was no more than 6 per cent of the amount invested in the entire facilities, and only 10 to 15 per cent in the case of individual enterprise, with such financing as a priming, the co-operative financing jointly with the private financial institutions has been stimulated and materialized: namely, of late, such co-operative financing is usually provided by the Industrial Bank of Japan, the Long-Term Credit Bank, etc. in combination with several city banks and trust banks, the former's long-term loans playing the key role.

As a rule, the conditions of the loan are: interest rate is 9 per cent and, after a two-year deferment, is repayable in five years. Thanks to the favourable growth of the petrochemical industry, on an average 25 per cent of the total amount invested in facilities has been fully repaid with the depreciation funds and other operating surplus. Generally speaking, if 50 per cent of the amount invested in the entire facilities is depreciated within five years of investment and at the same time the collateral loan should be repaid, the financial position would be remarkably improved since the owned capital 20 *vs* borrowed capital 30 ratio can be maintained. However, the fact is that because the demands for petrochemical products increase at too rapid a speed, there is no time to improve the financial position, being always pressed with ever increasing expansion fund requirements.

As for the financiers for the petrochemical industry, there are in addition to those mentioned above, the Life Insurance Syndicate and foreign investments (as to the latter, detailed explanations are given under chapter III) and following is a breakdown of the capital and funds invested in the entire petrochemical production facilities of Japan.

	Million dollars	*Per cent*
Owned capital	180	20
Financed by the Japan Development Bank	50	6
Non-governmental co-operative financing	590	65
Financed by the Life Insurance Syndicate	30	3
Foreign investments	50	6
TOTAL	900	100

CHAPTER III. FOREIGN INVESTMENT

The foreign capital invested for commercialization in Japan of the petrochemical industry totalled $132 MM ($72 MM for induction of foreign technology plus $60 MM for special imported machinery equipment and catalysts), of which $100 MM was for funds for facilities and the balance for manufacturing costs. Of the $100 MM facilities funds, $20 MM was capitalized as know-how subscription in kind and $10 MM as cash subscription.

Accordingly, of the $900 MM invested in the entire facilities, the $50 MM foreign investment consists of $20 MM know-how subscribed in kind, $10 MM cash subscription, and $20 MM ordinary loan; so that the capitalized foreign investment, that is, subscription in kind plus cash subscription, amounts to $30 MM which represents only one-sixth of $180 MM owned capital. In the case of joint venture companies, since the funds required for facilities are capitalized in almost all cases, this "one-sixth ratio" appears at a glance to have a considerable weight; however, if the above $30 MM capitalized foreign investment plus the equal $30 MM subscription from the Japanese side is compared with the $900 MM invested in the entire facilities, the ratio is no more than 7 per cent.

In establishing a joint venture company with a foreign company pursuant to the provisions of the Foreign Investment Law, approval is given only when the technology is so highly advanced that without such a company there is no chance in Japan of commercialization and on condition that the Japanese side shall have the substantial management rights, the foreign company shall have as shareholders less than 50 per cent voting rights. As for the technical information to be subscribed in kind it needs separate appraisal and authorization by the court and, as in the case of the induction fee for ordinary technology, tax is imposed on the royalty. After applying all of such fundamental rules, 10 joint venture companies have been established in Japan. These joint venture companies, with their respective special technologies and products, are making contributions to Japanese industry.

Of Japan's entire crude oil processing capacity 60 per cent is owned by those companies jointly established with foreign companies on a 50-50 subscription basis, and 70 per cent of the naphtha that Japan's petrochemical industry requires as raw material is being supplied by these joint venture companies without any interference from the foreign oil companies for that matter.

CHAPTER IV. DEGREE OF CONVERGENCY

"The moderate-capacity chemical industry companies holding respectively to their own grounds" is the exact expression to illustrate the current situation of Japan's chemical industry. Even the top class's sales represent no more than 5 per cent of all-Japan chemical industry's sales volume. Since it was less than a decade ago that Japan's petrochemical industry was developed and because no company can easily undertake commercial production, the number of petrochemical companies is relatively limited and yet their convergency is not so conspicuous.

The annual output of petrochemical products for the year 1963 recorded the $500 MM mark. This is the value of the combined outputs of those 31 companies belonging to the Petrochemical Industrial Association, and the per company output averages no more than $16 MM.

Of these 31 companies, 12 are those combining petrochemical and other chemical industries, and the other 19 companies are those exclusively engaged in petrochemical industry. The former 12 companies may be classified by main business as follows: petroleum refining three companies, integrated organic chemical industry three companies, fertilizer five companies, and fibre one company.

Irrespective of whether undertaking exclusive business or combined business, these companies can be classified into those engaged in integrated petrochemical industry with ethylene centres and those handling certain derivatives. From this it follows that there are five preceding ethylene centres of 100,000-ton scale each, four succeeding ethylene centres of around 50,000-ton scale each, and 22 other companies to be combined with these two groups.

While each of the two top class petrochemical companies had ethylene capacity representing 20 per cent of all Japan's 450,000-ton ethylene capacity for the year 1963, in respect of the ethylene sales, these two companies each shared $70 MM or 14 per cent of the $500 MM petrochemical output recorded for the same year. This is because both companies, instead of undertaking the manufacture up to all the finished products, leave some derivatives to be produced by other companies belonging to their respective complexes.

Such being the *status quo*, it is perhaps reasonable to say that Japan's petrochemical production capacity is converged to a degree met halfway between the decentralized United States chemical production capacity as represented by Du Pont's share of only 7 per cent and the "oligarchy" prevailing in the European countries.

Presently, the capacity of each of these ethylene centres is being expanded and by the end of 1964, the combined capacity of the nine ethylene centres will total 900,000 tons, the top 160,000-ton centre and 4 centres of over 100,000-ton each holding the lion's share, and thus Japan's ethylene capacity ought to be ranked second in the world. At a glance such production scale may invite some doubts as being excessive for Japan. However, this is quite understandable from the fact that each of Japan's synthetic resin, synthetic fibre, and rubber manufacturing industries for which the petrochemical industry is supplying the necessary raw materials, has already established production records in their respective fields to be ranked second in the world. Furthermore, after the year 1965 it is reasonable to foresee that, in order to regulate and ease the differentiation between the preceding companies and succeeding ones, the capacity of the latter four companies will preferentially be raised to the 100,000-ton level and, at the same time, the preceding companies' centres and other new centres to have more than 100,000-ton capacity will be invited to move to the new seacoast industrial zone where plants of more than 100,000-ton capacity can be installed.

If all of the forgoing is taken into consideration, Japan's ethylene capacity is estimated to attain the 1,500,000-ton mark before the end of 1970. In that event, however, the production share of each company will voluntarily be coordinated out of the free will of the industry itself as well as by the pertinent guidance of the Government based on the Foreign Investment Law and, therefore, convergency of the capacity is not considered to move too much towards "oligarchy" even though the production scale will be considerably increased.

CHAPTER V INVESTMENT OPPORTUNITIES

For the customary organic chemical industry, the amazing development and growth that the petrochemical industry has attained since the year 1955 proved a real stimulus since the industry was at the outset skeptical about such development. At the same time it made a considerable impression on the ammonia industry, the carbide industry, the fermentation industry, etc., and it was felt that there was an urgent need for constitutional improvements. As a result, various companies started in earnest investing in petrochemical production facilities irrespective of whether they specialize in petrochemical production or otherwise. In spite of such an investment boom, no adverse effects are so far evident thanks to brisk demands. On the other hand, they are worried about expensive depreciation and interest costs resulting from over-investment in facilities as well as from big drops in the product prices.

When the petrochemical project was started in 1955, there was the probability of managing a once-a-year turnover of the amount invested in the facilities. After the operation wtas actually started, however, due to narrowing of the product price margin to the international level as well as to intensified sales competition in Japan, the price index fell in 1963 to 54 per cent, representing as much as 46 per cent drop in the product price. Therefore, the turnover of the investment for the facilities is due to decrease by the corresponding percentage. However, the turnover is barely maintained at 70 per cent a year, due partly to curtailed installation cost itself rendered possible by the enriched experience.

As to the depreciation, most of the companies specialized in petrochemical production had adopted from the beginning the fixed instalment method. On the other hand, those companies undertaking petrochemical production as a side-line, were obliged to follow the conventional proportional instalment method pursuant to the tax law and, because they advanced into the petrochemical industry, the more they endeavoured at constitutional improvement the more they suffered from excessive depreciation burdens and they had to take great pains in realizing a profit and maintaining the dividend. The Government, in order to cope with such a situation, revised its policy and allowed the companies to adopt freely for respective plants either a fixed instalment or proportional instalment method.

In the case of the company undertaking the petrochemical production as a side-line, if its petrochemical production has sufficient weight of considerable merits, it goes without saying that the company's business will improve, which reflects favourably in its stock price and the capital can be increased readily and profitably. In the case of those companies specializing in the petrochemical industry, there are many that achieved success due to the advantages of starting production earlier and the profits from integrated operations. However, of all these companies, there is only one company that offered its stock for public subscription and had its stock listed on the stock market.

In the United States, the petrochemical industry is said to be an unprosperous industry. In that country, the av-called "petrochemical industry companies" are mostly joint ventures of which shareholders are petroleum refining companies and organic chemical industry companies. For the sake of these two parent companies' prosperity, the joint venture company is made to render services at negligible profits.

In Europe or Japan where no oil field is available, petrochemical industry uses naphtha as starting material. There are various forms of this enterprise: one of them is where the operations up to the naphtha cracking are carried out by a petroleum refining company; another is where a petroleum refining company lets its fully owned subsidiary company undertake the cracking of naphtha; still another is where, as in the case of the United States, a petrochemical company, organized jointly by a petroleum refining company and an organic chemical industry company, attends to the cracking of naphtha. Whichever of these three cases is followed, it is essential to bear in mind that even if highly advanced foreign technology was inducted, it will be worthless to merely imitate and reproduce the technology because, unless the inducted technology is further improved and advanced by combining it with the technical skill that the enterprise itself had developed and amassed, it is neither possible to realize profits nor to stand the severe international competition. It [illegible] bringing [illegible]

CHAPTER VI CONCLUSIONS

During the past nine years the petrochemical industry of Japan has made amazingly rapid progress and development, and shouldering the efforts to improve the basic industrial structure, has made a remarkable contribution toward modernizing Japan's industry [illegible]. Whole performance of these [illegible] is dependent to a large extent upon the pertinent leadership of the Government as well as upon the endeavors in the part of the respective enterprises. Special thanks and appreciation should be extended to the advanced chemical industries and engineering companies of Europe and the United States of America for furnishing the highly advanced technologies, services and generous co-operation.

Now that the basic essentials on which to organize and operate Japan's petrochemical industry [illegible] been established, we are determined to make further efforts toward accomplishing technical improvement and new inventions, and we look forward to the day when we shall have put Japan's petrochemical industry on an unshakable international foundation.

3. THE PATTERN OF RAISING FUNDS IN THE PETROCHEMICAL INDUSTRY IN JAPAN

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The Japanese petrochemical industry is young — only ten years have passed since the start of normal production of petrochemicals. Nevertheless, this industry has recently made impressive strides, and now the nation is one of the world's major petrochemical producers on a standing with other advanced producing nations.

The industry's rapid growth is attributed partly to the upsurge in domestic demand, which stemmed from the expansion of industrial activities that accompanied the rapid economic growth following war rehabilitation. But the developments — in terms of quality and quantity — in the oil refining industry which is the major supplier of raw materials, have constituted the important factor in this growth, because the petrochemical industry depends entirely on naphtha cracking for its raw material olefin, and it has formed the petrochemical complexes as productive setups, embracing the oil refineries.

In undertaking the production of petrochemicals in an earlier period the petrochemical industry had to depend on overseas producers for major technology. This is possibly because during the Second World War the means for technological exchange with other nations was closed, and the industry lagged far behind in technological development, especially the engineering development which took place in the organic synthetic chemical field. In one sense, however, it cannot be overlooked that the industry was already in a position to assimilate the advanced technology of the organic synthetic chemicals and high polymer chemistry, which were introduced from abroad. The potential seems to have been fostered in synthesizing ammonia, producing polyvinylchloride (PVC), developing polyamide fibres from before the war, and after the war in the development of technologies for vinylon (polyvinylalcohol fibre), urea, phthalic anhydride, ethylene oxide, etc.

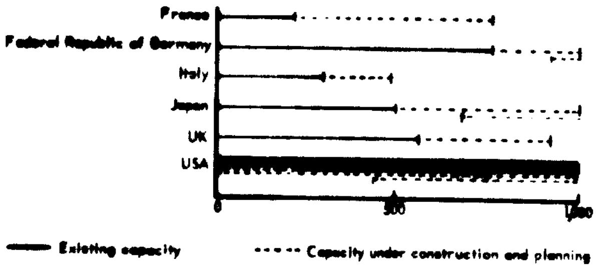
The same can be said to be true of the market picture. What made the rapid expansion of man-made non-cellulosic fibres possible was the high-level of our traditional cotton spinning industry, and the access to market outlets for petrochemicals, i.e. polyethylene and polystyrene, which was provided by the processors of plastics who had long experience in phenolics and PVC resins. Considering that the petrochemical industry itself is not a leading industry but can be viable in mutual association with a number of industries, i.e., oil refining, textile and machinery, the high level of our industrial activities as a whole has constituted a major factor in promoting the production of petrochemicals.

While our chemical industry assumed a pattern of development in which the inorganic chemical field, i.e., chemical fertilizers, was the nucleus before the war and even during the period of rehabilitation after the war, it now has to seek its prime mover in the expansion of the organic chemical field, especially petrochemicals, which have excellent growth prospects; this is because the growth in demand for inorganic chemicals has moderated and the developments overseas in the organic branch of the chemical industry are striking.

As can be seen from the above analysis, commercial production in the petrochemical industry has been undertaken with two aspects in view, i.e., the establishment of the petrochemical industry within the frame of an entirely new industry, and the structural transformation of the conventional chemical industry.

However there is a great risk in the undertakings owing to the fact that, in addition to requiring enormous expenditures to set up production of petrochemicals, the industry itself is one of the newest fields and technological innovation is going on at a greater rate than in other fields. Therefore, even though the industry has made rapid growth since the war, it has not yet accumulated sufficient internal reserves. Thus it is too heavy a burden for each company to undertake production by itself, so there are many instances where companies have combined to undertake a project in the form of a complex. Also setups have become more or less complicated; in most cases, they establish subsidiaries or joint investment companies responsible for the project. Especially, competition has intensified recently at home and abroad, and investment expenditures have been increasing, while the market has been declining. As a result, it will be quite a long while before the expenditures invested can be recovered. In view of this, in order to shield the direct effects of their adventures in petrochemicals on the performance of the existing branches, producers in many cases have established wholly owned subsidiaries. Moreover, many cases indicate that overseas producers attracted by the growth potential of our petrochemical industry have offered technological assistance for their participation in investment; this is one of the major reasons for the increase in the number of new companies.

Fourteen companies were included in the First Term Programme for the Development of Petrochemicals, which was started in 1955; seven of these companies were new in undertaking production of petrochemicals. Also, only fifteen of the forty-seven companies engaged in



Source: *European Chemical News*, June 19, 1964.

Chart I. International comparison of capacities for ethylene
In thousands of tons yearly

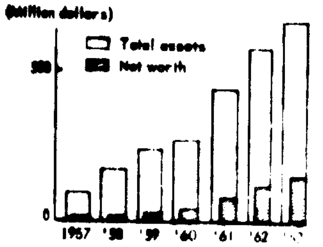


Chart III. Trends in total assets and net worth of four major petrochemical companies

production by 1954 had moved into petrochemicals with existing setups; the remaining thirty-two were new companies established in the form of subsidiaries and joint companies.

The tendency has been especially conspicuous recently. As illustrated in chart II, the number of companies established during the past five years reached twenty-four – of which, six companies were in the form of joint ventures with overseas producers in entering into technological contracts, six wholly owned subsidiaries, and six similar subsidiary companies.

Along with the rapid development of the petrochemical industry, the enterprisal scale of the related industries has been steadily increasing from year to year. As there are many cases in which undertakings for producing petrochemicals are planned as an integral part of the operation diversification by existing enterprises, we can observe that in general the assets of major specialized petrochemical producers have been increasing steadily, as shown in chart III. However, because the existing as well as the newly established companies have depended heavily on external sources in raising funds for setting up production, as will be stated later, in not just a few cases their net worth ratios have been below the levels of the average for manufacturing industries and the average for the chemical industry, although the absolute net worth has been increasing steadily; this contrasts appreciably with the composition of assets of great overseas chemical producers, who hold abundant reserves.

I. THE PATTERN OF SUPPLYING INDUSTRIAL FUNDS IN JAPAN

It may be said that following the rehabilitation after the last war the Japanese economy entered its growth phase and has since progressed steadily. During 1947-1961 the real gross national product grew at an average annual rate of some ten per cent; this is much greater than that of other advanced industrial nations, and even that of the pre-war period. It is believed that the growth has been accelerated by the high-level of investment in plants and equipment. The relative weight of private equipment investment in the gross national product stood at around 7-12 per cent until 1956; since then it has ranged from 15-23 per cent.

Japanese private enterprises were dealt a heavy blow by the last war. Also, because they were pressed by the need of expanding productive facilities in order to adapt themselves to the growing economy, they have not been in a position to accumulate reserves.

As a result the high level of equipment investment has been met primarily by external funds, almost all of which were financed by loans.

II. CHARACTERISTICS OF FUND RAISING IN THE PETROCHEMICAL INDUSTRY

The level of equipment investment in the petrochemical industry was kept within $50-100 million during 1955-1960, the First Term Programme for the Development of the Petrochemical Industry. However, once the construction phase was started under the Second Term Programme for 1960 on, investment increased markedly.

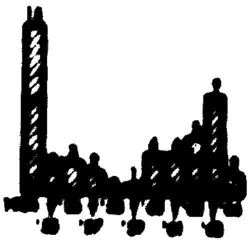


Chart II. Number of newly established companies for the commercial production of petrochemicals

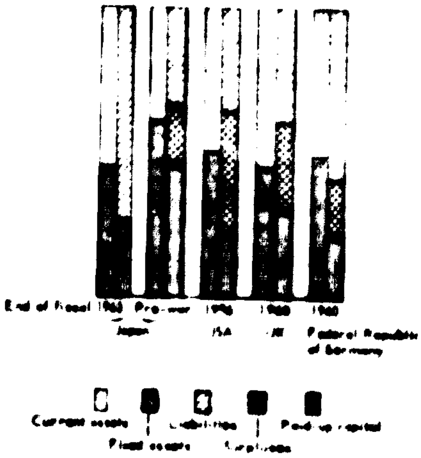


Chart IV. Comparative chart of the composition of assets liabilities, and net worth an estimate, in actual figures, is $300 million a year. Along with this the relative weight of the petrochemical industry's equipment investment in the total chemical industry's equipment investment has been increasing. Also this trend has encouraged investment by every branch of the organic chemical industry, which is closely related to the petrochemical industry, thus pushing up the chemical industry's level of equipment investment.

It is believed that the high level of equipment investment by the petrochemical industry has been backed by the striking increase in domestic demand. Yet because of this rapid rate of growth, the industry had to depend on external sources for funds required. Actually, of the total equipment funds of $806 million which were raised during 1957-1963 by the petrochemical producers, no more than 29.1 per cent was met with depreciations and reserves, and the net worth accounted for 40.6 per cent of the total funds procured, including additions to capital.

Yet we can observe a great change in the pattern of raising funds between the period 1957-60 when the First Term Programme was in force and the recent period. That is, in the First Term Programme, because the petrochemical industry was a new field, and the newly established companies were in many cases engaged in starting production, some 70 per cent of capital requirements were met with loans. However, in raising funds to finance the Second Term Programme 1961-63, financing with internal reserves increased along with the expansion of enterprisal bases, and the dependence on loans declined accordingly.

This can be attributed to the fact that, because the petrochemical industry carried out enormous equipment investment under the First and the Second Term Programmes, depreciations increased every year as much as the increase in fixed assets, besides it was possible to put increased facilities into operation on completion thanks to the steady increase in demand, which contributed to the increase in sales. Thus, although selling prices declined, the advantages of the expanded facilities have exceeded the disadvantages of the price declines; the earning position has strengthened by degrees.

If we study the difference in the components of loans between both periods, we can see that the Government source funds, which had a large relative weight during the First Term Programme, declined, and the reliance on foreign capital increased greatly.

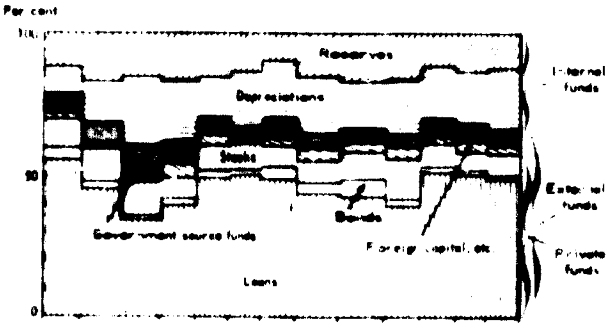


Chart V. Percentage composition of industrial funds supplied, by sources

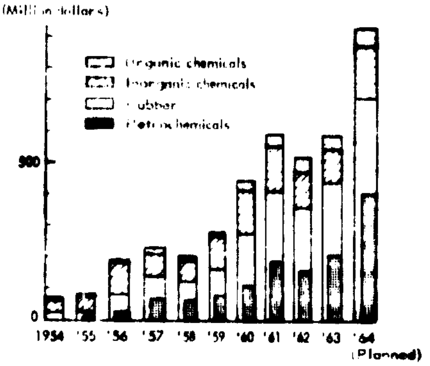


Chart VI. Trend in equipment investment by the chemical industry, its components

Primary reasons for the decrease in the weight of the Government source funds possibly are: while, during the First Term Programme, government funds were actively invested in this field for the purpose of encouraging the new petrochemical industry, it seems that in the Second Term Programme there was a rush of projects to produce petrochemicals because of the industry's growth potential. Thus the initial objective of fostering this new industry was more or less attained. As a result, the investment of government source funds has not been as active of late as it was in the First Term Programme. However, our petrochemical industry is still in its growth period, and if the industry is to survive the severe international competition, it should be strengthened more and more. In the light of this, we believe that the input of government source funds will be made selectively and emphatically.

Because the scale of the petrochemical industry has been expanding rapidly and the domestic money market has been very tight since 1961, making it difficult to raise funds needed for the commercial undertaking of petrochemicals, the dependence on foreign capital has risen greatly. Seeing that there is always an excess of demand in our money market, the raising of funds in the overseas market, depending on the terms, will help enterprises greatly by making capital available at relatively low interest. It seems that the major reasons for the relatively many cases in which petrochemical producers entered into financial contracts with foreign interests lie in the following facts: the growth potential of our petrochemical industry is attractive; and the industry has a worldwide spectrum in respect to marketing and technological development, making the industry closely associated with the foreign chemical industry.

Now we shall compare the pattern of raising funds in Japan's petrochemical industry with that of other industries. First, in relation to general industries, it is noted that the petrochemical industry depends less on the securities market, i.e., stocks and bonds, and relies on borrowings for this corresponding part. This contrasts particularly to the electric power industry, which depends on bond issues for a fairly large part of its funds and the steel industry, which depends on stocks. Of all, the oil refining industry depends mostly on foreign capital; this springs from the character of the industry. The petro-

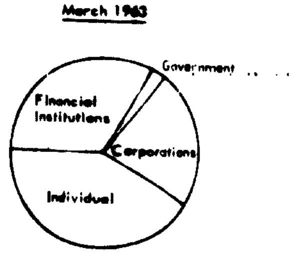


Chart VII. Distribution of stockholdings, by major investors

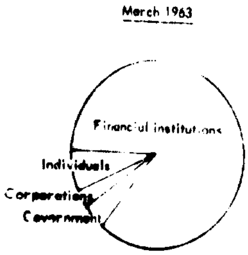


Chart VIII. Amount of corporate bonds purchased by major investors

chemical industry's dependence on foreign capital is much smaller than the oil industry's, yet it is appreciably higher than the average for all industries.

III. PROBLEMS IN RAISING FUNDS, BY SOURCES

1. *Internal funds*

The sources of internal funds available for investment are depreciations and reserves. In Japan it is common to all industries that the relative weight of depreciations in raising investment funds is the greatest, and this is especially true of the petrochemical industry.

Major reasons for this are: the industry is required to make early depreciations in order to adapt itself to the rapid pace of technological innovation; the Government within the frame of its policy to encourage the industry has set a liberal limit for depreciation allowances by applying the extraordinary depreciation system.

Also, the setup of the petrochemical industry has contributed to this tendency, that is: because, as already stated, the petrochemical companies are in most cases set up as subsidiaries or joint investment companies and only in a few cases offer stocks on the open market, so they are scarcely pressed to declare profits for dividends.

2. *Funds from the securities market*

In Japan the scale of stock issues has increased remarkably in recent years. However, it cannot be said that this is definitely related to the increase in the scale of our securities market. It is noted that major stockholders in Japan are corporations and financial institutions; moreover, it is characteristic that the holdings of stocks are not for employing current assets but are in the form of reciprocal holdings. This fact, together with the dependence of corporations on loans, suggests that the considerable funds raised in the stock market are in some way or other related to bank credits. Because only a few petrochemical companies offer stocks in the open market, this tendency is particularly conspicuous in the petrochemical industry, and capital increases for raising funds have been covered by their parent companies. Yet, because of institutional factors that even though the rate of dividend on stocks is generally high and the interest paid for loans is treated as necessary expenses by the tax law, dividends on stocks are subject to corporation tax, so the funds raised in the stock market are actually relatively high in cost, one of the problems in raising funds in the stock market.

The bond market has been expanding at almost as rapid a rate as the stock market. Broken down by investors, however, we see that nearly 90 per cent of total issues are held by financial institutions. This, together with the fact that the circulating market has not been sufficiently fostered, means long-term lending by financial institutions.

The scale of the bond issue market as shown by its character as stated above, is yet limited, even though it has expanded recently. Moreover, because of the issue priority placed on government-guaranteed bonds, local municipal bonds and electric power bonds, general corporate bond issues are restricted considerably. Especially, it is very difficult for the petrochemical companies to issue new bonds because they lack past showing in this field.

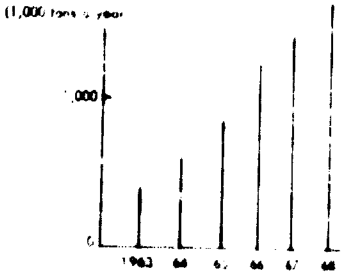
3. *Loans*

(i) *Government-affiliated financial institutions*

The supplies of industrial funds from government sources are granted within the frame of the Treasury Loan and Investment Programme of the national Budget. Of these, Treasury investment is granted in the form of the direct Government contribution to particular companies. However, the Japan Synthetic Rubber Co., Ltd. is the only petrochemical company qualified for this finance. A large weight in the supply of funds is accounted for by loans granted through government-affiliated financial institutions.

Government-affiliated financial institutions are the Japan Development Bank, Export-Import Bank of Japan, Hokkaido and Tohoku Development Finance Corporation, Small Business Finance Corporation, etc.; among these the role played by the Japan Development Bank in lending funds for equipment investment has been the greatest.

Treasury funds made available through the Reconversion Finance Bank, the predecessor of the Japan Development Bank, played a major role in supplying industrial funds until 1948. Since then with the great change in our financial policy, the role has been passed on to private funds and Treasury funds are now playing only a complementary role, in quantity and quality, to private funds. Treasury fund loans to the petrochemical industry have



Source: The Ministry of International Trade and Industry

Chart IX. Forecasts of demand for ethylene been granted largely through the Japan Development Bank.

(ii) *Private financial institutions*

The function of private financial institutions in the supply of industrial funds is represented by the large relative weight of loans and, in addition, these institutions have exerted great influence on the securities market by investing in bonds and holding stocks, as stated before. This was caused partly by institutional factors in which the money supply accompanying the increase in economic growth has been made through the Bank of Japan's loans. Still, it cannot be overlooked that for reasons of the tax system and low interest policy, capital cost is relatively low.

Private financial institutions are ordinary banks engaged in normal banking business, long-term credit institutions lending long-term capital with sources obtained through issues of bonds, and trust banks operating primarily trust business, etc. While there is some specialization by the institutions according to the type of the funds to be supplied, the fact is that, with the great dependence of our enterprises on loans, there is fairly close associations between financial institutions and business enterprises.

IV. CONCLUSION

It may be said that the rapid growth of our petrochemical industry has been supported financially primarily by external funds. Seeing that it is a new industrial field and growing at a remarkably rapid rate, it is natural that the industry takes on this character. The strong growth potential seems to have made the raising of an enormous amount of external funds possible.

Our petrochemical industry is still in its growing period, and will expand rapidly in the future. According to the demand forecasts prepared this spring by the Ministry of International Trade and Industry, demand for ethylene in 1968 will be more than three times that of 1963, reaching 1,690,000 tons.

PATTERN OF RAISING EQUIPMENT FUNDS IN THE PETROCHEMICAL INDUSTRY — NET INCREASE

(%) *percentage composition*

	1957-60	*1961-63*	*1957-63*
Total funds raised (million dollars)	288	518	806
Stocks	12.2	10.9	11.5
Bonds	1.5	1.0	1.2
Borrowings	70.0	51.9	58.3
(Japan Development Bank)	(11.1)	(2.9)	(5.9)
(The Industrial Bank of Japan) (Long Term Credit Bank of Japan)	(23.3)	(7.7)	(13.3)
(City banks)	(26.0)	(9.4)	(15.4)
(Trust, insurance)	(5.9)	(13.5)	(10.7)
(Foreign capital)	(2.9)	(12.6)	(9.1)
Internal funds	16.3	36.2	29.1

SOURCE: The Ministry of International Trade and Industry.

It is probable that the level of investment in plants and equipment will increase more and more in order for the industry to meet the increase in demand. It is expected that, while internal funds available for employment will increase by degrees along with the increase in depreciations, the trend in the dependence on external funds will show little decline, because equipment investment will be made at a high rate. However, as was stated before, the petrochemical industry is a prospective field with a worldwide spectrum in that it is definitely sensible to effects of the world supply and demand situation. Also since the industry is undergoing rapid technological innovation, we can by no means assert that the commercial undertakings are accompanied only by little risk. We believe that these are, so to speak, characteristics inherent to the petrochemical industry. In light of this it is highly desirable that the industry be sufficiently strengthened by preventing the rush of small and medium enterprises, and consolidating the managerial foundations, in order to absorb the risks involved in the commercial production of petrochemicals.

COMPARISON BETWEEN PATTERNS OF RAISING FUNDS IN MAJOR INDUSTRIES (1962-63)

		Percentage composition (per cent)					
	Amount (million dollars)	*Internal funds (of which depreciations)*		*Stocks*	*Bonds*	*Borrowings (of which, foreign capital)*	
All industries	8,176	45.0	(37.7)	15.0	7.0	33.0	(4.4)
Petrochemicals	394	39.6	(36.6)	5.9	1.4	53.1	(9.4)
Electric power	1,982	46.5	(34.0)	15.5	17.5	20.5	(—)
Iron and steel	1,213	28.7	(31.9)	26.9	6.1	38.3	(5.1)
Oil refining	481	41.2	(32.1)	6.1	0.5	52.2	(28.9)
Man-made non-cellulosic fibres	299	33.2	(—)	18.6	5.4	42.8	(6.9)

SOURCE: The Ministry of International Trade and Industry.

4. SOME ASPECTS OF FINDING AND FINANCING PETROCHEMICAL PROJECTS

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1. Project finding in general

After government policy-makers have completed their difficult task of formulating economic policy, after the planners have completed the challenging work of drafting a development plan, after the laws to encourage or even establish new industries have been enacted, after friendly development financing institutions have been created and have begun operating, there still remains to be done the work upon which the development effort depends. Someone must identify, define, and organize specific and sound projects or enterprises.

One of the frequent complaints of national and international financial institutions serving developing countries is directed at the "shortage" of well-worked-out projects ready for financing. There even appears to be a certain amount of competition among such institutions in seeking to finance promising projects. The project shortage, together with the availability of substantial funds for lending, has helped contribute to the significant increase in the number of development banks in recent years. International financing agencies sought to make loans to something useful in as many countries as possible, and development banks qualified admirably, especially since it was possible to shift to them part of the burden of project finding. The availability of loan funds through these local institutions has tended to stimulate local entrepreneurs and thereby the development of new projects seeking such financing.

Governments and public and private development financing organizations are acutely aware of the real and substantial costs associated with the investigation required to determine "bankability" or "investability." This high "cost-of-looking" faced by entrepreneurs and by development bodies is an important problem for developing countries and has shaped very significantly the number and nature of projects which ever reach financing agencies, not to mention those which actually are approved. For example, large organizations, whether governments or private companies, can more readily afford to meet the loan application information required by these agencies in this regard than can local entrepreneurs or small companies. Feasibility studies themselves offer economies of scale in that the same investigative effort is usually required for large projects as for small ones.

The search for suitable projects has led to a number of techniques seeking to multiply the number of project possibilities. For many years the United Nations and Member Governments have provided experts and other forms of technical assistance to help governments in project formulation. In a number of countries such assistance is being funneled through local institutions, such as development banks or other development institutions. More recently, the United Nations Special Fund has financed a series of pre-investment surveys. Some international lending institutions have embarked on a programme of loans and grants to developing countries to finance for them the technical and professional services required for finding and preparing projects suitable for government or private investment. The United States Agency for International Development currently provides an investment survey cost-sharing programme for interested potential investors and recently established an information system designed to make readily available hundreds of recent studies of industrial investment opportunities in developing countries. While such studies are hardly the primary determinant of private investment decisions, they are part of the information services which are helpful to and engage the attention of potential investors.

2. Finding petrochemical project possibilities

It has been reported that more than fifty new petrochemical plants went into operation in 1963 in the developing countries of South and South-East Asia, Africa, and Latin America. There appears to be little need for special devices or incentives to encourage the search for petrochemical projects in countries whose investment climate is favourable, whose markets are reasonably large, and whose resources include natural gas or petroleum refineries.

The major integrated petroleum companies are interested and well-equipped to find and develop new petrochemical projects. Just as petrochemicals are a by-product of refinery operations, so are petrochemical project opportunities sometimes a by-product of refinery concession negotiations with governments interested in acquiring a petrochemical industry. The economies of integration and of large-scale units, the continuing need for research and development, and the technical complexities in the production of petrochemicals lead international financing agencies to encourage developing countries to turn to major international petrochemical companies which are prepared to provide financing as well as know-how.

Countries can turn to a number of foreign industries, in addition to petroleum, which have gained petrochemical experience rubber, textile, chemical, photographic, and gas transmission companies. A number of countries have created government-owned corporations responsible for developing petrochemical facilities. These organizations have also been active in promoting projects and, in some cases, have obtained financing from international lending agencies.

Those developing countries which enjoy abundant resources and large markets thus appear to face no serious problems in finding petrochemical project opportunities. But other countries which have small markets or few oil and gas resources undoubtedly find the diversity and versatility of petrochemical enterprises as strikingly attractive as do their more fortunately endowed neighbours. They will want the benefits of the "chemical revolution" as part of their industrial revolution.

The speed of growth of the petrochemical industry throughout the world, and the impact that some of its products such as plastics, synthetic fibres, and fertilizers can have on developing countries of all sizes, make it desirable for governments, financing institutions, and private companies to explore new configurations of petrochemical projects — or "petrochemical systems" — which might meet special problems of a country or a group of countries. These systems may be based on a petrochemical product market of several countries; or on a concurrent development of a cluster of related intermediate and end-user projects in one country; or on integration of a petrochemical facility with other kinds of activity. Because they are departures from customary country project development and because they may require inter-governmental action, it is likely that initial leadership, at least to explore these possibilities, is best suited for international financing institutions, including those agencies which finance the finding of projects. To the extent that these petrochemical project systems are technically feasible, new financing techniques may have to be devised to encourage and enable countries to embark on new kinds of ventures.

Economies of scale inherent in many industries have led to efforts to enlarge markets through association of several countries. A foundation has already been laid in the market association of Central American countries. The Inter-American Development Bank is sponsoring projects and studies looking toward sound forms and fields for Latin American economic integration.

It is possible to conceive of a petrochemical system covering a number of countries within which one or more primary products, such as polypropylene, are produced in one or two countries of a region with downstream end-user investments in several associated countries. The objective of this kind of association would be to make an efficient petrochemical production system feasible in an area probably years before individual national markets would justify such facilities. The multi-country project has been the subject of a considerable amount of discussion, but of few detailed studies to test the practical feasibility of the various types of arrangements possible under such a system.

The development of pretrochemical production associated with the operation of a refinery is well known. In Greece, for example, the projected production of ammonia for fertilizers is an integral part of the plan for a new refinery. It may be possible in some countries to encourage the establishment — as a group rather than a product-by-product, project-by-project approach — of various combinations of petrochemical products. In some cases, this may be a single firm producing related intermediate and end-products. In other cases, separately owned — although collectively planned and financed — enterprises may be feasible. This kind of configuration of producers and users of intermediates and end-products would be justified where concurrent development of each makes the others feasible — where the market for one project is being created by the establishment of other projects. It may be feasible also to encourage the creation of petrochemical projects in association with the expansion of an already vigorous textile or plastics fabricating industry. It is, on the other hand, also possible for a separate multi-product company in countries with small markets to make textile auxiliaries and chemical formulations for other industries such as paints, adhesives, paper and so on. The objective in examining petrochemical possibilities within a single country — even a small one — is to encourage imagination and pioneering to enter into the identification of opportunities and into the judgments as to their feasibility.

The potential importance of fertilizer deserves special attention by those seeking to identify petrochemical project possibilities. The problem in many countries is the absence of an organized market because of unfamiliarity with and limited use of fertilizer by farmers, and the lack of a credit system to facilitate purchases of fertilizer even where the demand and knowledge existed.

The lack of market discourages private companies interested in investing in fertilizer facilities. In turn, the lack of fertilizer production slows agricultural extension efforts to teach fertilizer techniques and makes somewhat academic the creation of fertilizer credit schemes. It would be of considerable importance to many countries to create a project system which integrates the actions required to create the basic components of a fertilizer market and justify an investment. This means, for example, participation by the potential fertilizer investment group from the outset in farmer education, farm credit programme, and rural co-operatives where necessary, rather than an *ad seriatim* approach. There are some private companies which would probably be quite willing to consider co-operating closely with governments during the years required for development of a market for fertilizer to be produced and sold by these companies. The chances are good that a fertilizer industry would be created far sooner through this multi-pronged approach than otherwise. This possibility of a fertilizer system project deserves extensive and detailed feasibility investigation in specific country or regional situations, especially in Africa.

3. FINANCING PETROCHEMICAL SYSTEMS

Judgments as to feasibility of new petrochemical project possibilities, including the foregoing, depend in part on the assumptions made in the study of the project regarding the amount and the terms of financing available. One financing arrangement can often make practicable what may be doubtful under some other financing arrangement.

A great deal of ingenuity has been exercised by private groups, governments, and investment lending agencies in developing financing mechanisms and techniques for economic development. Many of these are described in other Conference papers. They will no doubt continue to make possible the creation of new projects in the petrochemical field, as well as in other fields. Private groups have formed development banks in many countries. Most recently major American and European companies have joined together in ADELA, a company formed for the sole purpose of finding and investing in private ventures judged significant for the economic development of Latin American countries. Governments have formed international, regional, and national financing institutions which are by now well known.

Equipment suppliers, often with guarantees of their governments, offer equipment credits. One company offers to establish and operate a fertilizer plant to produce for sale at world market prices, but with an assured market within the country, and with the provision that after a specified number of years it would donate the plant to the government.

A number of major petrochemical projects have been financed by combinations of private and official sources of capital. The $68 million Coromandel fertilizer plant in India obtained its capital from two American chemical corporations, private Indian interests, and dollar and rupee loans, totaling about $44 million, from the United States Export-Import Bank and the Agency for International Development. The Inter-American Development Bank, the International Bank for Reconstruction and Development, the International Finance Corporation, and other lending agencies have joined together in financing various projects. Private foreign companies have worked out with private groups in developing countries patent rights and technical assistance associated with their financing. A carbon black plant in Mexico was organized on this basis, and with the financial assistance of the Inter-American Development Bank and Mexican banks.

The demonstrated ability of the foreign investor and of the private sector within developing countries to find and develop petrochemical projects as successful commercial enterprises, suggests that governments interested in encouraging the growth of petrochemical industries have active allies who should be permitted maximum freedom to exercise initiative. There is no reason why governments need to, or should, assume the burden of the high cost-of-looking and the heavy capital costs which private groups are willing to carry.

In the effort to identify possible new configurations of petrochemical projects regional, multi-project, and agricultural development systems there is some question whether private companies would or should proceed alone. Financing institutions national and international are in a position to help break new ground by encouraging if not actually sponsoring feasibility investigations, and by providing financing in a form which enhances feasibility prospects. For example, should the same criteria and loan terms (repayments over twelve years at six per cent interest) for a fertilizer project in a country with a well-developed market for fertilizer be applied in a country which is struggling to build a fertilizer market? It might be entirely justifiable to regard the building of a fertilizer system in such a country as analagous to the building of an irrigation system in another country. Projects of the latter type have received terms from the International Development Association of 50 years with repayment of principal beginning after a ten-year grace period and without cost except for a service charge of 3/4 of 1 per cent per annum on the amount withdrawn and outstanding. Such terms may be precisely the kind needed to make feasible a fertilizer system which will require years of farmer education to build a market, financing for a credit system covering fertilizer and other elements which will make fertilizer manufacture and sale eventually profitable and a vital factor in the country's economic growth.

For the same basic reason the consortium device of a number of countries or a number of private companies which now make possible huge projects in other fields, ranging from river valley development to communications satellites, may be what will make possible the large petrochemical project system covering several countries. Here, too, financing terms are needed which recognize the time required to create the system and build the market.

In effect, basic petrochemical facilities can assume the importance to the economy of a public utility or basic infrastructure, and financing mechanisms may soon be needed to respond to such situations with arrangements other than those now applied to conventional manufacturing facilities.

5. THE ROLE OF FOREIGN INVESTMENT IN PETROCHEMICAL MANUFACTURE

Business and Industry Advisory Committee to the Organisation for Economic Co-operation and Development

INTRODUCTION

It is obvious from the many papers presented at this Conference that the technical and economic factors that determine the viability of a petroleum chemicals manufacturing industry are being fully discussed. It is not the object of this paper to study these specific problems. Its purpose, rather, is to examine the situation that arises in a developing country when a particular project seems likely to be viable.

Without detailed local studies it is impossible to be specific as to the type of chemical likely to be involved and therefore the discussion will be in general terms with no more than a passing reference to any particular field of chemicals manufacture.

This paper will consider what, provided the technical and commercial prospects are attractive, are the requirements for investment in heavy organic chemicals manufacture, and how these can be met in a developing country. It will pay particular attention to the role that the foreign private investor can play in such a venture, and how he will compare the prospects it offers and those of alternative investments elsewhere.

CAPITAL

Size and technical complexity make chemical plants extremely costly to build. Initial investments for various plants located in western Europe, for example, have ranged from $8.5 million for ammonia manufacture to $17 million for a plant producing ammonia and complex fertilizers. These were for the most part plants that could be integrated with existing manufacturing units; built on new sites in developing countries they could cost much more. Nevertheless, the figures give an indication of the level of expenditure to be faced.

In any country there are three possible main sources of funds for such a venture.

The first is the State itself. In most developing countries the government has funds at its disposal, both from its own taxes and also from loans, credits, grants or gifts from other governments, international agencies and commercial or private sources. Nevertheless, most governments have found one key obstacle to the investment of public funds in a commercial venture of this magnitude: there are too many urgent calls on their resources for essential work that only a government can do. The infrastructure needs of the developing countries, and their bearing on the ability of these countries to sustain economic growth, are too well known to call for enumeration here. There will be little disagreement, therefore, with the proposition that a chemicals manufacturing venture whose cost had to be counted in terms of unbuilt roads, houses, schools and hospitals, for example, would be politically, socially and economically a poor investment so long as there were other ways of achieving the same ends.

The second potential local source of funds, the private investor, is also handicapped, but for rather different seasons. As a hedge against the risks of inflation and political instability, the bulk of such funds as are available tend to follow an investment pattern aimed at producing liquidity and a high rate of return. There is thus a preference for investment in land and livestock, which in addition carry traditional prestige in many countries, in housing and mortgages for high-income groups, and in short-term commercial loans and consumer credit. The local investor is also hampered by relative lack of access to technical skills and research upon which sophisticated investment projects depend. Such a situation inevitably tends to limit long-term productive investment.

It does not seem likely that, at least until a much higher level of domestic savings is reached, there will be a strong preference for chemicals manufacture among local investors.

There remains the third potential source of funds — the foreign investor. Private investment already plays an important part in the flow of long-term funds from the industrialised to the developing countries; it now contributes more than one-third of the total flow of some $8,400 million a year.[1] The General Assembly, in its programme for the United Nations Development Decade, has called for the flow of private investment capital to be stimulated.[2]

There is no doubt that chemicals manufacture could, where appropriate, become an important feature in the stimulation of this flow. Here, however, the limiting factor is, paradoxically, the growth of world trade in chemicals, which places so many alternative choices before the potential investor.

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[1] This United Nations figure does not include certain funds reinvested and understates the total contribution.

[2] *The United Nations Development Decade: Proposals for Action*, United Nations publication, Sales No.: 62.II.B.2.

Such obstacles are not prohibitive, however, and there is every reason to believe that, provided a project is technically and commercially viable, conditions attractive to a foreign investor in chemicals manufacture can be made to exist in one country as in another.

EXPERT KNOWLEDGE

The second main requirement is less tangible but no less important — skill based on highly specialized knowledge and experience. It is clear from other papers delivered at the conference that the chemicals business calls for a high degree of scientific, technical, managerial and commercial skill. These papers abound in examples of the complexity of its research and development work, its manufacturing processes and its products. It is easy to understand that the academic and technical qualifications of management and of research, manufacturing and marketing staff must be high indeed, and the practical day-to-day experience on which they base the exercise of their knowledge must be very wide.

The pace of change in the chemicals industry demands, moreover, that such qualifications can never be static. Yesterday's discoveries may be dated tomorrow, and success in the industry depends on a continuous process of keeping knowledge up to date.

Expert knowledge and experience are thus essential ingredients of investment in chemicals manufacture. At the same time they represent a valuable increase in any country's national resources. It has been shown that there is a close relationship between rising prosperity and the proper application of technical knowledge.[3]

The current world-wide shortage of such knowledge and practical experience, in chemicals as in other fields, is one of the major preoccupations of governments and industrialists everywhere; access to it on a continuing basis is therefore no less a problem than that of acquiring the funds necessary for the investment.

Each country's ultimate aim is to build up its own sources of technical knowledge. But this is a long-term process requiring on the one hand a firmly established and comprehensive educational system, and on the other extensive facilities and funds for scientific research, which in turn must be linked to existing industrial development. This must be supported by the managerial and commercial skills and experience essential to weld them into an integrated long-term enterprise. These are something that the entrepreneur, be he government or industrialist, must provide himself and it is here that the foreign private investor, either alone or in conjunction with local capital, has much to contribute. He brings an increment to the national resources of knowledge and skills that puts no charge on public funds. Nor is this limited to the qualifications of the imported expatriate specialist, since the foreign investor has every incentive to train people of the country to take the place of the expatriate as soon as possible, so that he can be transferred to another investment elsewhere.

This, in fact, suggests the key limitation to the employment of foreign private enterprise technology: it has as many alternative calls on its service as private enterprise money. The risks it runs and the rewards it is offered must be carefully compared with those of possible alternatives whenever any venture is proposed.

For the most part this process of comparison is closely linked to the parallel scrutiny of financial considerations. There is one field, however, of particular importance to the chemicals industry, where the technological considerations have their own scale of values: this is in the matter of patent protection. Manufacturing and product application know-how, the concentrated result of many years of costly research, may well be among the most useful assets a chemicals company can have. A company that introduces its technology to a foreign country is likely to make improvements in the light of experience and as local skills develop. For a technical industry such as chemicals manufacture to be established in any country, there should be in existence effective legislation that affords adequate patent protection both for inventions and innovations imported from abroad, and for those made in the country which can in turn be exported.

INVESTMENT, TECHNOLOGY AND GROWTH

At this point it is convenient to consider the subject of imported technology. After political stability, investment and technology are by general agreement the major factors in economic growth, but only if they are applied with discrimination. The productivity of an investment is the important element in determining the rate of growth.

The apparent correlation in the industrialized countries between heavy expenditure on research and development and a high standard of living may suggest that investment in research is an essential prerequisite to economic growth. In the studies referred to previously (see reference 3), it has been suggested not only that it would be more logical to find the correlation in the application of research work, rather than in the volume of research itself, but also that this application need not be based on one's own research. Countries like the United Kingdom and the United States, with the biggest expenditure on research and development, in proportion to their gross national product, have had relatively low growth rates in recent years. High growth rates are found among countries like France, the Federal Republic of Germany, Japan and Australia, which not only have a lower rate of spending on research and development, but also have brought more technological knowledge from abroad than they sell. Yet these are countries with their own plentiful resources of scientific manpower. If in the present state of the international trade in technological knowledge these countries flourish with an "adverse balance", it must be even more to the advantage of countries with limited resources.

PROFITS AND EFFICIENCY

If a chemicals manufacturing project in a country is viable, the foreign investor, with his unique combination of financial and technological resources and experience,

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[3] B. R. Williams: "Investment and Technology in Growth" *The Manchester School of Economic and Social Studies*, vol XXXII, No. 1, January 1964.

has excellent qualifications for undertaking it. Competition between foreign investors for an opportunity to do so will, moreover, ensure that the country concerned gets the best possible terms.

The factors that will lead a foreign investor to choose a given venture, in preference to whatever alternatives are available to him, therefore deserve some consideration.

The basic attraction is profit. The venture must promise to yield enough both to pay its costs, including the depreciation of its assets and a proper share of the high expenses of research and development, and to provide a profit that matches the size, difficulty and risk of the investment. And the venture that best meets these conditions will be the one most likely to be chosen.

While this Conference is no occasion for a detailed examination of the arguments for and against the profit motive, there is one point that must be mentioned, since it has a direct bearing on the needs of developing countries. Profits are an excellent yardstick for measuring the efficiency with which resources are employed. This has also been recognized by some authorities in the USSR; they have advocated the introduction of profit incentive to encourage Soviet plant managers to raise output and standards of quality and introduce new technology.[4]

The stringent tests applied by any foreign investor to the viability of any chemical investment he undertakes will ensure that such a venture, if it is worth his while, will be of true value to the country also, and not an uneconomic white elephant. If the prospects are sufficiently attractive, foreign capital will generally flow spontaneously, and it is within a country's power to induce such a flow of capital by creating conditions in which investors find it more rewarding to make the investment there than elsewhere.

Apart from the creation of an adequate infrastructure of transport and communications systems, power supply, education, housing, public health and the other essential pre-requisites of industrial development, this is largely a matter of fiscal and commercial policy.

The United Nations Development Decade Proposals referred to above pointed to the need for tax reform in many countries. They found that

> "Countries initiating planned development efforts often have tax systems that are structurally and administratively inadequate in their productivity, the range of taxes used, their elasticity and their social and economic impact. The objective of tax reform may be defined as a tax system which will produce increasing revenues on the basis of the rising productivity which in turn it helps to promote in the economy."

In developing this argument the Proposals outline the scope offered by tax reform for the encouragement of new industries of the right type.

To pursue this matter further would be to go beyond the terms of reference of the present Conference. Technical assistance in the field of tax reform is already receiving the expert attention of the appropriate agencies of the United Nations. We can here only emphasise our belief in its importance for economic growth, and suggest that, from the point of view of chemicals manufacture, while the profits and incomes generated by such an investment are a proper source of tax revenue, taxation should encourage, not penalise, that venture. Moreover, taxation needs to ensure that there are adequate personal incentives for the technologists and managers on whom the venture depends, and who cannot be expected to choose service away from home without adequate compensation.

THE NEED FOR CONFIDENCE

There is another area of fiscal policy that deserves mention in this connexion. This affects the right of the foreign investor to repatriate his capital, interest, dividends and profits. This is of course part of the broader environment in which an investor operates. We are also concerned here with the risk he faces that government policy may change after he is established in the country. Such risks are a source of the gravest apprehension to the private investor. The efficient firm can assess the commercial risks and decide whether the return on the investment is likely to be sufficient reward for facing them. But adverse conditions that might arise from the actions of governments represent non-commercial risks that can be neither predicted nor measured; no normal scale of profits can match these risks. It is not suggested that the foreign investor should enjoy a privileged position; merely that his rights and duties should be on a par with those enjoyed by the people of the country; to quote the Development Decade Proposals again:

> "Assurances to overcome these apprehensions may be provided through authoritative policy statements, through guarantees incorporated in investment laws, and through commitments incorporated in international treaties with capital-supplying countries or in concession agreements with individual firms.
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> "In all these cases the value of the assurance, and in effect the weight of the apprehension itself, will depend to a considerable extent on the stability of the government of the country offering the assurance and on the underlying political and institutional framework. A development plan clearly setting out, *inter alia*, the role envisaged for the private investor may form an element of this framework. So will the development of a modern commercial, financial, administrative, legal and institutional structure, which can greatly reduce the area of uncertainty in carrying on foreign business operations. The value of unilateral assurances and guarantees also increases with time, if the commitments are strictly observed."[5]

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[4] *Pravda*, September 20, 1964.

[5] *The United Nations Development Decade: Proposals for Action*, p. 95.

6. THE ROLE OF THE INTERNATIONAL FINANCE CORPORATION IN PROMOTING INDUSTRIAL VENTURES IN DEVELOPING COUNTRIES

J. Chanmugam, the International Finance Corporation

The industrial revolution now taking place in Asia, Africa and Latin America has emphasized the need for financial institutions capable of mobilizing resources for risk ventures in developing countries. Awareness of this need has grown more acute as many of these countries take stock in their development plans; of the opportunities as well as the gaps that exist in their economies. Specialized merchant banking institutions or *banques d'affaires* have had considerable experience in promoting new enterprises and facilitating the expansion of existing companies in Western Europe and North America. But the terrain is less familiar in the developing countries and the problems are likely to be correspondingly greater. Such resources as equity capital, as well as production, marketing, accounting and other management skills are relatively scarce. In addition, social and political factors – such as government policies regarding domestic control of industry or exploitation of natural resources – must be taken into account.

In this context, the International Finance Corporation, an affiliate of the International Bank for Reconstruction and Development, has a unique role in stimulating industrial enterprise in the private sector of developing countries. IFC came into existence in July 1956 when 31 member countries provided capital subscriptions totalling $78 million and thereby fulfilled the membership requirements of the Articles of Agreement. As of June 30, 1964, IFC's membership had risen to 78 countries and its paid-in capital to nearly $99 million.

To date, IFC has made over 90 commitments in 30 different countries in six continents. Its investments have centred on manufacturing and processing industries including steel, pulp and paper, textiles, chemicals, fertilizers and construction materials. Although IFC may consider agricultural or service projects in connection with manufacturing enterprises, it excludes such fields for investment as service industries (for example, tourism) as well as public utilities, real estate development or land reclamation. As of the end of September 1964, IFC's gross commitments totaled $122.7 million. Net of cancellations and terminations, the total was $111.5 million.

In order to accomplish its aim of spurring productive private enterprise in developing countries, IFC considers investment proposals in the light of whether a given project will make an effective contribution to the development of a country's economy. A project should not involve wasteful use of resources, nor should the costs be excessive in relation to the benefits that can be expected to result from the project. As guidelines for decisions of policy, IFC has established five basic criteria:

Is there an adequate market for the product?

Is the project technically well-conceived?

Is management capable and experienced?

Is the capital structure of an enterprise or project sound?

Is there a prospect of profitable operation?

In effect, the establishment of these criteria means that while IFC is called on to review a wide range of investment proposals, actual commitments are only made after careful selection and preparation of projects. In establishing the need for, and desirability of, an investment commitment, the Corporation acts as a lender of last resort: it must satisfy itself that sufficient private capital is not available on reasonable terms for a venture. Since its aim is to stimulate private investment, it requires that other investors put up a large portion of the funds required. In the case of a new enterprise, it expects its own participation to be less than 50 per cent of the capital cost although it is prepared to waive this condition in cases where an existing enterprise is expanding. As this indicates, IFC does not aim at acquiring the controlling interest in enterprises in which it invests, nor does it seek to provide management. Except when circumstances compel it to do so, the Corporation normally does not exercise the voting rights of the stock it holds.

In most respects, IFC behaves much like a private investor. It does not expect or seek special foreign exchange privileges. Nor does it ask government guarantees on its investments. Since it was formed to deal specifically with private enterprise, it does not, as a practice, invest in undertakings which are government owned or controlled. While this does not exclude enterprises in which some public funds have been invested, IFC's judgment in these situations is based on whether the enterprise concerned is essentially private in character.

There are several restrictions on where and how IFC may make investments. In the first place, its operations are confined to projects in its member countries and their territories. Under its charter, it is not permitted to make an investment in a member country if the government of the country concerned objects. IFC's practice is therefore to inform a member Government in advance of its intention to make a commitment in the country concerned. As a matter of operating policy, the Corporation does not invest in the more developed of its member countries – in the main, Western Europe, Japan, Canada or South

Africa, although it has made commitments in Southern Italy, Spain, Greece, Turkey, Finland and Austria.

While IFC's [illegible] preferences are wide as far as [illegible], it does not [illegible] in [illegible] export financing, [illegible] credit or mortgage lending. Initially, under the terms of its charter, the Corporation was permitted only to provide loan capital, usually with some form of equity feature — such as an option to acquire stock — which allowed it to share in the growth of a business. Experience showed that this policy had decided limitations, since the real shortage in many developing countries is equity rather than loan capital. Because of this shortage many new companies in developing countries find themselves burdened with heavy debt charges before they have built up earnings capacity. Over-dependence on short-term credit and shortage of permanent working capital can create stringencies for companies in the process of establishment or expansion.

It was the realization of these problems, and the desire to place the Corporation in a position where it could help meet them, which led to amendment of IFC's charter in 1961, permitting it for the first time to provide straight equity or a combination of loan and equity funds as the situation demanded. The record of operations during the last three years has shown the increasing number of opportunities opened up as a result. In its most recent fiscal year (1963-64), more than half IFC's investments were — for the first time in the Corporation's history — in the form of subscriptions to capital stock rather than in loans. At June 30, 1964 the proportion of its portfolio invested in equity stood at 40 per cent, compared with 17 per cent twelve months earlier, and this proportion is expected to rise in the years to come.

The commitment of its own resources is not IFC's only function in the area of financing. Its charter directs it to seek to stimulate the flow of private capital — both domestic and foreign — into productive investment. In meeting these conditions IFC has been able to assist in financing enterprises which have required as much as $80 million in capital funds to come into operation. One of the principal ways in which it has achieved this has been by working closely with other financial institutions. In the 1963-64 fiscal year, for instance, IFC's commitment of $21.8 million in 18 different enterprises was joined by commitments by other investors totalling more than $144.5 million — a ratio of $7 to every $1 committed by IFC. More than 60 different institutions, domiciled in France, Federal Republic of Germany, Hong Kong, Italy, India and Japan among other countries, joined IFC in these direct financing operations. On top of this, IFC has been successful in rolling over its funds by selling participations in its investments. This helps to account for the fact that IFC's total commitments are in excess of its subscribed capital. Although it had made net commitments of $111.5 million as of September 30, 1964, the Corporation still had over $51 million available for investment — representing $19.5 million in accumulated net earnings and $31.8 million from sales of investments and other sources in addition to its subscribed capital of $99 million.

The amendment to IFC's charter in 1961 has also extended the range of its financing activities in other ways. In the first place it has made it possible for the Corporation to take part in underwriting new share offerings and to make standby commitments. Its gross commitments in these respects total more than $16.7 million, including major participations in two offerings of stock by a well known Mexican steel company, Compañía Fundidora de Fierro y Acero de Monterrey, S.A. IFC's role in the underwriting field is, in addition, intended to assist the development of local capital markets.

In the second place the freedom to make equity investments has enabled IFC to assist in financing private development banks, many of which have been required to expand their equity base in order to increase their operations. The development banks in turn have been able to assist smaller or medium-sized companies whose requirements IFC itself cannot hope to service satisfactorily. In all, the Corporation has provided more than $17.1 million in capital to banks of this kind, often in conjunction with loans from the International Bank or credits from the Bank's affiliate, the International Development Association.

In several cases, IFC's decision to take part in financing industrial projects has proved to be of decisive significance in enabling companies to proceed with expansion and other plans. Since IFC funds are intended primarily to cover foreign exchange outlays, this financial assistance has been particularly valuable to companies in countries where there have been exchange shortages. But the provision of financing is not the only service performed by IFC. It is in a position to provide a package of services in helping to prepare a project, whether this involves starting a new industry in a country, helping to bring a new company into business or planning the expansion of an existing company. In many projects IFC is required to act not only as an investment bank or underwriter but also as industrial promoter and management and engineering consultant.

In order to perform these functions, the Corporation is in a position to draw on its own operating staff, on the resources of the International Bank as well as on outside consultants. IFC's staff consists of financial analysts (investment officers), engineers and accounting and legal advisers. Operating as a working party on a specific project, IFC staff are in a position to make a full analysis with the help of field trips to extend their acquaintance with project and sponsor alike. From this background it is possible to answer some of the basic questions. Are the estimated capital costs realistic? Has sufficient provision been made for possible overruns or delays in startup? How experienced is management? Does it need the assistance of a technical partner to get into a new line of business? How effective are the accounting procedures? These are only some of the questions to be considered. The staff appraisal, embodied in detailed financial and engineering reports, provides the basis for the decision whether or not to make a commitment. The end result may be recommendations for substantial changes by the working party, backed up by economic and marketing studies prepared within the Bank. By this stage, if a commitment appears likely, the outlines of an investment agreement between IFC and the sponsors of the project will have begun to firm up. All of this activity represents a considerable pre-operational investment.

This approach permits a high degree of objectivity in the appraisal of a project. The need is apparent since in many cases capital costs for machinery and equipment may be heavy. While many industrial projects in developing countries are financed by suppliers' credits with the purchase tied to the prices offered in a particular country by a particular supplier, it is not the policy of IFC to tie investment commitments to the procurement of specific equipment. Nor is there any requirement that the proceeds of IFC financing be spent in a specific country.

The same degree of objectivity is likely to be necessary in choosing a technical partner. A new industrial enterprise in a developing country may need to draw on a foreign company to obtain its technology and it may also require considerable management assistance in seeing a project through its teething stages. As a matter of operating policy, IFC has encouraged partnership arrangements. It has helped finance projects in which Japanese interests have teamed up with local entrepreneurs in the textile industry in Africa. It has made commitments to [illegible] projects initiated in India by local businessmen in partnership with French and German companies. The fact of partnership itself is important but the terms on which partnerships are arranged may still have a vital bearing on the success or failure of an enterprise. Generally speaking, IFC has argued that partnership is likely to be more fruitful if it involves a financial interest as an indication of willingness to share in the risks as well as the profits of a business.

No two IFC projects are identical but examples of the Corporation's commitments in the petrochemical field show some of the opportunities and problems likely to be encountered in promoting new enterprises in developing countries. IFC's first investment in the petrochemical field was in a Peruvian company, Fertilizantes Sintéticos S.A. (FERTISA), in 1960. The company was founded to produce synthetic ammonia from a petroleum feedstock and to convert it into ammonium nitrate and ammonium sulfate. FERTISA was originally organized in [illegible] by a group of Peruvian shareholders who in 1955 brought one of the world's largest chemical companies, Montecatini of Italy, into the project as a technical and financial partner. Construction of a plant with a capacity of [illegible] metric tons of ammonia per day was begun near Callao, with long-term debt financing of roughly $6.5 million being provided by two European banking institutions. The plant was still under construction in June 1959 when the project was brought to the attention of IFC. Because of higher than estimated costs and a delay in startup the company found itself short of working capital. IFC arranged nearly $10 million in new financing for the company including a commitment of $3.6 million.

Partly as a result of continued production problems, partly due to competition from imports, the company continued to experience problems and was obliged to default on its interest payments to IFC and its financial partners late in 1961. At this stage IFC was instrumental in arranging a reorganization of the company by conversion of a large part of its long-term debt, funding of some of its interest payments and short-term obligations and the provision of new capital. In [illegible] on the advice of a private consultant engaged by IFC, it was proposed that the capacity of the plant should be increased to [illegible] tons of ammonia per day in order to improve the company's earning capacity. These measures were instrumental in [illegible] the [illegible] the total capital [illegible]

A more healthy [illegible] now being [illegible] position [illegible] possibility of increasing [illegible]

IFC [illegible]

[illegible] petrochemical [illegible]

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[illegible]

In another case IFC [illegible]

[illegible]

Although IFC has greatly enlarged the scale of its activities in recent years and has begun [illegible] underwriting large blocks of capital for major investment projects, the fact remains that its resources are limited in view of the steady growth of the Corporation's commitments, there has been some reason to believe that additional funds would be required in the not-too-distant future. The importance of IFC as a unique international agency equipped to assist industrial ventures in developing countries has been acknowledged in the International Bank proposal to make extra resources available to its affiliate. Under the terms of the proposal, brought before the Boards of Governors of the Bank and IFC at the annual meeting in Tokyo in September 1964, the Articles of Agreement of the two institutions would be amended to permit the Bank to lend funds to IFC for re-lending to private industry without government guarantee. This would substantially increase IFC's available resources, with a limit on Bank lending of four times IFC's subscribed capital or surplus, or approximately $400 million.

The provision of resources on this scale would open up new possibilities of investment for IFC. There are many large-scale projects — in fields such as extractive industry (mining and smelting) as well as steel, petrochemicals and the like — where substantial blocks of long-term debt capital are required in addition to equity funds. With loan capital available from the Bank, IFC would be in a position to make bigger individual commitments in the form of straight loans or a combination of loan and equity. It would also be in a position to free funds of its own tied up at present in loans and make them available for equity investment. The proposal to expand IFC's resources is still in an early stage and has only recently been submitted to the Board of Governors of IFC and member countries of the International Bank for their approval.

B. Legal aspects (patents, licensing and know-how agreements)

INTRODUCTORY SUMMARY

The fundamental purpose of the patent system is to provide incentives for continued progress in research into, and development of, technological processes by ensuring that inventors or innovators shall reap the fruits of their own labour for a definite period of time. Patents are granted by governments and, naturally, differ from country to country as regards duration, patentable items, and legal circumstances. Licences which are legal permissions to engage in defined transactions can be granted either by governments or by patent holders. Since patents confer monopolistic power on their holders, the national patent laws are designed to forestall abuses. When a licence is granted by a patent holder, it becomes a "patent licence". Patents, "know-how" and "technical data" constitute the so-called "industrial property rights".

A patent licence is a formal agreement between the owner of a patent and the party interested in making use of the item for which the patent was originally granted in return for some periodic compensation (royalty). The licensee undertakes not to release the proprietary information thus obtained to other parties without the permission of the licensor.

It is observed that there are more patents granted in developed countries than in developing countries and it is conjectured that the reasons for this may be, on the part of the developing countries, minimal inventive capacity, inadequacy of legal protection and, in some cases, the greater importance attached to unpatented items.

Patent licensing involves the drawing up of formal licence agreements. Generally, the scope of a licence agreement, either in the same country or between countries, includes provisions with regard to definitions (of processes and rights), terms of licence (exclusive or non-exclusive), duration, compensation (royalties or lump sum), secrecy (exclusion of third parties), exchange of information, law (the country or state law to apply), assignability (in case of sale of assets or inheritance thereof) and ancillary services.

As a means of effecting the transfer of technology from developed to developing countries in the petrochemical field, patent licensing is considered very important.

It is relatively easy to obtain licences for petrochemical processes, mainly because of the high rate of technological obsolescence in the petrochemical industry. Usually, a patent holder would want to exploit it before new processes are discovered. However, a potential licensee from a developing country should make sure that his evaluation of a petrochemical process takes into account the heavy financial burden generally involved in licence agreements.

1. PATENTS AND LICENSING IN THE PETROCHEMICAL INDUSTRY

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Even the most superficial examination of the scope of the papers presented at this unique Conference reveals the wide variety and the extent of existing capabilities in the petrochemical field. The scope of available technology is probably already far greater than any one country can adopt and employ with advantage before technical obsolescence sets in.

The task of selecting a particular technical route for the establishment of a petrochemical industry, with its interacting complex problems relating to the availability, of raw materials, manpower requirements, and economic and governmental relations has been dealt with in other papers at this meeting. Whatever the course of the development programme undertaken, the technology available in the more industrialized countries will, in almost all instances, be made available through a patent and licensing agreement. Such an agreement sets out the mutual rights and obligations of the signatory parties, namely the licensor and the licensee, and is entered into in order to establish a working arrangement between them which will effectively operate over a period of years.

Viewed in historical perspective, the problem of introducing more advanced technology to a developing country from abroad is not new, and was indeed one of the major factors in developing the patent system as we know it today. Thus, as early as the 15th century, patents were granted to protect skilled crafts imported from abroad, and not necessarily invented or first conceived by the one to whom the patent was granted.

This historical aspect of patents as a tool for promoting the introduction of already existing knowledge to developing countries is reflected today in certain aspects of the patent law. For example, in certain countries, a publication is not a bar to a patent of invention unless publication occurred in that country itself. Many countries provide for a patent of importation by which an inventor can obtain a local patent based on a published foreign patent, generally, provided the invention is actually worked in the country of importation.

In these few examples, and others can be given, the incentive for the grant of a patent lies not in the stimulation of the creative art of generating new knowledge but, rather, in the encouragement of the economically valuable act of introducing technology available in some part of the world to a local economy.

It is well recognized that today patent rights represent only a portion and, indeed, sometimes a small portion, of the technology necessary for the effective adoption of a new technical process or for the production of a new product. In the transfer of technology by means of licensing agreements, patents constitute one form of "industrial property" which may be conveniently defined as those intangible property rights relating to the conduct of a business enterprise which are protected by physical documents issued by a granting country. Industrial property rights are distinct from real or personal property rights, which are tangible physical entities, and which, upon sale or transfer, are actually physically placed in the hands of the new owner or licensor. Industrial property rights, to the degree that they can be thought of as intellectually available, are available to the world at large, and the property right lies not in the physical possession of the knowledge incorporated therein, but rather in the exclusive right to use, or prevent others from using, knowledge of which they are aware. Industrial property rights include, in the broadest sense, patents of all types, including patents of invention, patents of importation, patents of addition or improvement patents, utility models, and design patents, as well as registered trade marks and designs.

As distinguished from "industrial property" rights, there are those other rights not specifically defined by government deed or document which are commercially valuable to the adoption of new technology, and which may be broadly classified as "intellectual property". In this category are included "know-how" and "technical data", both of which terms will be met time and time again in any patent licensing agreement. "Intellectual property" while distinguished from "industrial property" in that no government deed or document sets forth the rights of the possessor thereof, is nevertheless an intangible asset, in that its value lies in the ideas and concepts incorporated therein, rather than in the physical document which may describe such concepts and which document, in the final analysis, is merely a form of personal property.

Since "know-how" is such an important term in patent licensing agreements, it may be useful to set forth a more comprehensive definition thereof. One writer has stated that know-how includes,

> "... inventions, processes, formulae, designs which are either unpatented or unpatentable; it may be evidenced by some form of physical matter such as blue-prints, specifications or drawings; and it may involve accumulated skills which can best, or perhaps only, be communicated through the medium of personal services."[1]

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[1] J. F. Creed and R. B. Bangs *Know-how Licensing and Capital Gains*, P. T. C. J. Res. and Ed., vol. 4 No. 1 (Spring 1960)

Thus, know-how is an intangible property asset, distinct from patents, which may be embodied for the purpose of transmission from one party to another in documentary form. It is helpful to distinguish the ideas and concepts called "know-how" from the actual physical documents in which "know-how" is embodied and, for this purpose, the term "technical data" is often employed. Technical data have been defined as follows:

> "Technical data shall mean all physical material furnished by the licensor to the licensee such as specifications, blueprints, photographs, plant lay-outs, catalogues, sales books, engineering data, standards and the like."[2]

While there is no such thing as a standard licensing agreement in the petrochemical industry, it will be found that all licensing agreements concern themselves primarily with defining the mutual rights and obligations between the parties arising out of the transfer of rights in these three forms of property — patents, know-how, and technical data — from the licensor to the licensee. This package of rights and information enables the new enterprise to adopt existing technology, and to undertake the installation of new processes or the production of new products.

Fundamental to any understanding of the patent licence agreement is an appreciation of the role of patents in the modern technically oriented economy. The underlying economic assumption in the grant of a patent is that the monopoly power given to the patent owner is essential to the stimulation of invention and investment. As stated by one writer:

> "The patent system provides a protected market with the opportunity for universal profit necessary to justify the heavy investment in time, effort and capital necessary to bring the improvement to the public. This same protected market provides an entering wedge by which a business enterprise entering a new field can overcome the obstacles that otherwise discourage entering into an industry already overpopulated. Finally, the ever-present threat of new firms with exclusive rights to new technologies compels existing enterprises to explore avenues of improvement upon pain of sudden obsolescence."[3]

The value of a patent system to the economy is thus twofold. First, it guarantees that time and money invested in developing a new product or process, which can represent a substantial investment, will be protected from competition by imitators as soon as the product or process becomes public knowledge. It can be readily seen that without such protection, any enterprise undertaking substantial research and development, if required to compete with an imitator having no such investment to recoup, would be placed in an untenable market position. Secondly, the mere existence of patent protection in a given technical area, barring others from adopting the patented process or selling the patented product, leads in a competitive economy to development of alternate processes or equivalent products which are outside the ambit of existing patent protection. The resultant stimulation of competition provides the economic advantage to the public which, in those countries which have adopted strong and effective patent laws, justifies the grant of the patent monopoly.

It must be recognized that the patent law has been developed on a national basis, and that patent laws vary from country to country. The basic concept of the patent grant, to the extent that it is common to all countries, is that as a condition precedent to the patent grant, the inventor must provide the public with an intellectual contribution capable of use by the public at large after the expiration of the monopoly grant provided in the patent. The term of such monopoly varies from country to country, being as little as five years for so-called "petty patents" to as long as twenty years. It is interesting to note that the early English law fixed the term at fourteen years, this being equivalent to the training of two successive groups of apprentices (the custom then being to serve a seven-year apprenticeship). In principle, the monopoly grant was to expire when the new technique had been sufficiently disseminated to be practised independently by the public. National concepts differ further in the degree to which the patent owner may exercise his monopoly. It has often been stated that a patent confers no right on the patentee to practice his invention but, rather, that the patent only prevents others from so doing. While this is certainly true of the United States patent system, it must be recognized that in most countries the continued right to exclude others may, in certain circumstances, depend upon positive action on the part of the patentee to exploit his monopoly. Failure to do so within prescribed time limits results in circumscription of the monopoly right by virtue of compulsory licence provisions of national patent laws which seriously limit the exclusive privilege granted to the patentee.

National patent laws further differ in the extent to which certain products or processes may be eligible for patenting. In many countries, specified products or processes are not eligible for patenting, in particular, foodstuffs, pharmaceuticals, medicinal and chemical products, on the grounds that the grant of a patent, which may result in unreasonably high prices for certain necessities, is detrimental to the public interest.

The provision of monopolistic power by way of the patent grant can lead, and in fact has led, to the abuse of the power by those seeking to garner more economic gain than may be justified by the public interest in extending the monopoly. For example, patents have been employed, by purchase of competitor's patent assets or by restrictive licence practices, so as to concentrate the economic power of entire industries in the hands of a single enterprise. Attempts are made to pool the patent rights of competitors, and to establish trade practices based on such concentrated control of the patent structure of an industry, so as to bar any competition. Patent owners have sought, by means of a patent, to force licensees to purchase unpatented or even unrelated

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[2] L. J. Eckstrom, *Proceedings of the 1960 Institute on Private Investment Abroad*, South Western Legal Foundation, 2 251 (Publisher, Matthew Bender and Co., 1960).

[3] George E. Frost, "The Patent System & the Modern Economy", Study No. 2, Committee on the Judiciary, U.S. Senate (Washington, 1957).

products from the patent owner as the price for the grant of rights under the patent. And the pooling of patent rights among ostensible competitors in conjunction with a division of world markets and price fixing to the detriment of the consumer is a common direction in which patent owners seek to establish economic privilege not justified by the limited monopoly granted under the patent law.

Such misuse of the patent right for the purpose of concentrating economic power in the hands of a few at the expense of the public has resulted in a substantial body of national law by means of which such abuse is kept under control. National laws directed at control of such restrictive business practices may be contained either in the national patent law itself or in laws applicable to restrictive business practices generally, such as the anti-trust laws. It is perhaps sufficient to state that in any consideration of a patent licence agreement, cognizance must be taken of the applicable national law to avoid unwarranted extension of the patent monopoly by price fixing, patent pooling, compulsory package licence provisions, and the like.

While patents play an important role in any licensing consideration, it must be recognized that in the undeveloped countries no significant patent position has been established by the petrochemical industry. This is evident from the tremendous disparity between the total number of patents granted in the developed countries as compared to the under-developed countries. For example, in 1962 the United Kingdom of Great Britain and Northern Ireland issued 27,721 patents, Canada 21,225 patents and the Federal Republic of Germany 18,508 patents; whereas Morocco issued 363, Ceylon 104 and Iran 312 patents. Various reasons have been ascribed to the lack of interest in establishing patent positions in the under-developed countries including, for example, the following factors, to which attention is called in the interim report of the Secretary-General of the United Nations on the role of patents in the transfer of technology to under-developed countries (E/C.5/35):

(*a*) Lack of inventive activity on the part of the nationals and residents of the under-developed countries;

(*b*) The unimportance of the country as a market for the patented product;

(*c*) Economic and legal factors militating against the establishment within the country of any enterprise producing or selling the patented product or utilizing the patented methods and processes;

(*d*) The absence or inadequacy of the legal protection which patents afford inventors and investors;

(*e*) The relatively greater significance of unpatented, as contrasted with patented, technology.

It is perhaps worth noting briefly that while the cost of establishing and maintaining a patent office operation is a governmental expense, the financial investment necessary for a patent applicant to establish and maintain a world-wide patent position can only be justified if a reasonably rapid return on the investment can be realized. Because of the time limitations inherent in a patent, there is little interest in establishing a patent portfolio in a country where the technical capability of producing or using a product is at least five years away.

Where, however, a country is opened to entrepreneurial activity, and there are immediate prospects of economic return, there is no hesitancy on the part of inventors and investors in establishing a patent position. The resurgence of industrial activity in Italy after the Second World War has, for example, led to a twofold increase in the number of patents applied for yearly in the period 1951-1961, and in Japan the increase in this period has been more than threefold. Spain, which has only recently begun to encourage foreign investment, has experienced an almost twofold increase in patent applications filed between 1958-1961, whereas the number of applications was substantially static in the prior seven-year period. While increased patent activity in developing countries first occurs by reason of the filing of patent applications by foreign nationals, experience has shown that domestic inventors, stimulated by local economic opportunity, soon make a substantial and rapidly increasing contribution to the patent activity of a country.

It is doubtful that the legal strength of the patent law in any particular country affects, to any great extent, the decision to obtain patents. The mere existence of a patent system, with its potential for protecting the patent owner from competition, appears to be sufficient justification for filing, given the economic incentive to do so. Patent owners rarely resort to court action to enforce their patents, possibly because of the great expense of litigation, but more probably because patents are generally respected by others. For example, in the United States where corporations receive in excess of 50 per cent of all patents granted annually, the 500 largest patent-holding corporations were involved in only 878 patent law suits in the period 1949-1958, an average of less than two law suits per corporation for this ten-year period. The infrequency with which patents are actually challenged in the courts can be realized from the following statistics concerning certain selected United States companies having extensive patent holdings.[4]

Company	*Patents received 1939-1955*	*Law suits 1949-1958*		
		As plaintiff	*As defendant*	*Total*
General Electric Co.	10,757	4	14	18
Radio Corp. America	7,894	2	14	16
Du Pont Co.	6,338	3		
Esso Standard Oil	4,899	1		
Eastman Kodak Co.	3,784	5	6	11

In other highly industrialized countries, where the incidence of patent law suits is even less than in the United States of America similar statistics would doubtless show that patent owners rarely resort to judicial action to enforce their patents.

One must conclude that while the extent of patenting in under-developed countries is limited, the interest in

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[4] "An Analysis of Patent Litigation Statistics" U.S. Senate Committee on the Judiciary, 86th Congress, 2nd Session, (Washington, 1961).

patents will grow as the under-developed country provides the economic incentive for modern industrial activity.

From these general considerations, I should like to turn to the more specific question of the availability of process licences in the petrochemical field.

Because of the major participation of the petroleum processing industry in the development of petrochemicals, it is worth noting that in the petroleum industry, a very liberal patent licensing policy has always existed. The number of commercial petroleum refining processes are limited, the markets for basic petroleum products are vast, and petroleum markets are stable as compared with chemical markets. All of these factors have led to a willingness on the part of petroleum companies to grant licences. Such licences are generally of the "field" definition type, broadly covering all patents coming within a defined field, and providing for an exchange of know-how. Cross-licensing arrangements which provide for licensing of third parties are common, and royalties are in general reasonable so as to enable each party to market a competitively low-cost product in a relatively small geographical area. As a result of liberal cross-licensing policies, the petroleum industry economically employs at an early date the most up-to-date developments of the research efforts of competing research organizations.

To the extent that the basic raw materials and intermediates of the petrochemical industry, e.g. olefins, aromatics, and the like, share the characteristics of large volume and low price of petroleum products, petrochemical licensing follows the pattern of the petroleum industry. But, as the dollar value of petrochemical products goes up, and the size of the market decreases, licensing practices tend to reflect the attitudes of the chemical industry. Chemicals are ordinarily higher priced commodities than petroleum products, and many chemical markets can be satisfied by one or at most a few producers. Chemical markets are not stable since individual products may be displaced rapidly in a developing technology. In the chemical field, there is a real incentive to use chemical patents and proprietary know-how to exclude competition and to realize profits from individual market exploitation rather than through licensing.

There are, however, real pressures on the owner of proprietary petrochemical know-how to engage in licensing. The establishment of proprietary patent positions, coupled with a reluctance to license, has led to the development in many instances of alternative processes for the manufacture of particular petrochemicals. Because petrochemical technology has advanced so rapidly, owners of proprietary processes realize that, if their know-how is not exploited promptly, it will probably be outmoded and replaced by newer processes. Faced with the demand by local governments for local production facilities, the patent owner cannot rely on foreign patents to protect his export market, because this can be defeated by application of import duties, generous government assistance to local producers, and the compulsory licensing provisions of the local patent law.

Assuming that the owner of proprietary know-how is willing under prevailing circumstances to make his technology available in a foreign country, the further question arises as to the form of enterprise to establish in order to exploit the technology. The new technology can be introduced by (*a*) establishment of a wholly owned subsidiary in the foreign country, (*b*) establishment of a joint venture in partnership with local business interests, or (*c*) licensing a local enterprise under patents and know-how.

An analysis of the advantages and disadvantages of these means of participation in establishing a new enterprise is beyond the scope of the present discussion, but it may be helpful to list some major benefits which licensing offers:

Licensing:

(*a*) Minimizes the capital involvement of the licensor;

(*b*) Eliminates involvement in labour and social legislation of the foreign country and legal exposure in that country;

(*c*) Reduces the hazard of exchange controls and restrictions, since royalty remittances are generally looked on with more favour than dividends;

(*d*) May leave the door open for future joint ventures if the licensee performs satisfactorily, but at a later date requires financial assistance not locally available;

(*e*) Protects patents in countries where working is required;

(*f*) Provides for know-how return from the licensee;

(*g*) Provides a means of exploitation of know-how where local economies and/or import restrictions prevent direct sale of products from abroad.

On the other hand, it must be recognized that licensing, as opposed to some form of equity participation, limits the extent to which the licensor may share in profits of the enterprise and creates competition with future imports and/or future domestic production by a jointly owned or subsidiary company.

In recent years there has been an increase of interest in equity participation in conjunction with licensing and it would seem that this might be even more desirable in the introduction of new ventures in the under-developed countries. In such countries, patents presently play a relatively minor role, and the licensor is required to provide not only technological know-how, but assistance in training personnel, developing sales techniques, undertaking market evaluation and development, and directly assisting in the establishment of an integrated petrochemical operation. As an equity holder, the licensor develops a closer relationship with the local management, and shares as a partner in the establishment and economic development of the venture. Since a given petrochemical process may only be licensed to one party in a given country, the failure of the licensee to properly exploit the licence would severely limit the licensor's return and it would thus be in his interest to be a part of the management of the enterprise and thus to have some direct responsibility to ensure its success.

Finally, I should like to focus attention on the patent licence agreement itself. The licence agreement is an arrangement whereby the licensor undertakes to grant or make available to the licensee proprietary rights during the term of the agreement pursuant to specified conditions and limitations in return for some periodic compensation.

The agreement may be prefaced by a series of recitals which set forth in general terms that the licensor is prepared to grant rights under his patents, trade marks and know-how, and that the licensee desires to obtain such rights in order to establish a commercial enterprise. Mutual assurances of benefits expected to accrue to each party by virtue of the agreement are common. Whether or not such recitals provide any significant legal value is questionable and, at best, might be relied upon as showing a failure of consideration in the event the licensed process cannot be commercially used.

Commonly, the petrochemical licensing agreement will contain a series of definitions specifically setting forth the meaning of particular expressions employed in the agreement. While such definitions, for the most part, are a matter of convenience in establishing clearly and with particularity, the meaning of licensing provisions, special attention should be given to the definition of the "field of agreement" and of "patent rights".

The petrochemical licensing agreement is usually of the defined-field type, and the core of such an agreement is the establishment of a field definition which will adequately express the scope of subject-matter to be encompassed by the agreement. The defined field licence agreement is not usually limited to particular enumerated patents or patent applications, although these may be recited as exemplary of the intended field. Rather, the field definition sets forth a technical statement of the process, product and/or apparatus with respect to which proprietary rights are granted. The field definition should be drawn so as to cover adequately all of the patent rights and know-how which the licensor expects to provide, and which the licensee deems necessary to the establishment of the contemplated enterprise. Negative limitations may be resorted to in order specifically to exclude areas not intended to be covered.

The definition of the field of agreement automatically establishes the scope of the "patent rights" and "know-how" in terms of subject matter to be included in the licence. However, it is rarely desired to make all patent rights and know-how of the licensor available to the licensee during the entire term of the agreement, since the royalty charge established at the time of entering the agreement may not reflect in any way the value of improvements made at a much later date. It is recognized, however, that the licensee is entitled to improvements made within a reasonable time after entering into the agreement, i.e., those flowing from current research and development efforts of the licensor. It is customary to provide a cut-off date of two to five years after the agreement date, and to limit the licensee's rights to inventions and know-how made or developed prior to such date.

The patent licence agreement must set forth in the form of a grant, the type of licence which is given to the licensee under licensor's patent rights and know-how. Depending upon circumstances, the grant will be

(*a*) Royalty-free or royalty-bearing;

(*b*) Exclusive or non-exclusive;

(*c*) Transferable or strictly limited to the licensee's use;

(*d*) World wide or limited to a single area.

In establishing the licence grant, care must be taken to avoid restrictions that may violate anti-trust laws of the licensor's country or of the country covered by the licence. Thus, while it may be deemed desirable business-wise, to be able to restrict the licensee's sales to a particular territory, such a restraint can raise serious legal questions. It is far better to grant a right to manufacture in a given territory, and to use and sell throught the world; and to depend on the economics of shipping, import duties, etc. to effectively limit sales to the area where the product is manufactured, and avoid competition with other licensees in other parts of the world. Similarly, price fixing, production quotas, tie-in sales, and/or agreements not to compete are all dangerous from a legal standpoint and best left out of the agreement.

The licensee may be expected to develop patent rights and know-how which would be useful in the licensor's operations, or in connexion with operation of other licensees. The agreement will normally provide for a reciprocal grant by the licensee with respect to licensee's patents and know-how co-extensive in scope and time, with the licensor's grant. Such reciprocal grants of patents and know-how are usually royalty-free for the benefit of the licensor and its other licensees and, customarily, non-exclusive. A grant-back of exlusive rights under patents may require that the licensor undertake the burden of obtaining and maintaining patents in other jurisdictions.

The immediate purpose of the agreement is to place such know-how and technical data in the hands of the licensee as will enable him to begin plant construction and manufacturing operations. The licensor will normally undertake to provide necessary process information within a few months of the signing of the agreement.

The problem of protecting the proprietary know-how, trade secrets and technical data of the licensor from un authorized disclosure of the licensee is handled by way of a more or less conventional clause directed toward confidentiality. Such a clause will state that the licensee cannot use proprietary information given him by the licensor except in connexion with the exploitation of the licensed process, and cannot disclose same without the written consent of the licensor. Generally, the licensee protects himself from unreasonable confidentiality terms by providing that those items of know-how which are in the public domain, or which become part of the public domain, are not subject to confidentiality obligations. The licensor will normally be entitled to receive know-how developed by the licensee, and such information, to the extent it is confidential, will require an undertaking of confidentiality by the licensor.

Since know-how is not ordinarily adequately protected by patents, the obligation of confidentiality should survive any termination of the agreement, and should be effective for a sufficient number of years to protect the licensor from unlicensed use thereof until the technology is of relatively little value because of technical advances or outmoding of the licensed process. Normally a period of ten years from the date of delivery of know-how is provided for but, in special circumstances, this period may be even longer.

The licensor will often undertake to provide such services to the licensee in the form of engineering assistance, training of personnel, installation of equipment and the like, as may be necessary to establish the new process on a commercial basis. The terms and conditions for giving technological assistance will, of course, vary from case to case, but the agreement customarily makes provision for compensating the licensor for such services. The licensor may not have the manpower available to provide unlimited on-the-spot technical assistance, so that licence agreements will often limit the number of man-hours the licensor is expected to provide. Technical training in the licensor's plants can be provided for.

With respect to royalty provisions, each licence agreement will vary. In general, some lump-sum payment by the licensee may be required, primarily to compensate the licensor for the cost of transmitting technical data, including preparing pamphlets and instruction materials, sending personnel abroad, developing process conditions for specific needs of the licensee, etc. Such payment might be replaced by equity participation in the venture, and may or may not be credited against future royalties.

The determination of the proper amount of royalty is difficult, and one in which the Government may itself be involved. Royalties will be generally on a paid-up or running royalty basis, and if a paid-up licence is provided for, the amount will often be based on the equivalent running royalty for production over a five-to-ten-year period. Paid-up licences entitle the licensee to continue practising the licensed process after termination of the agreement, whereas running royalty is collected only while the agreement remains in full force.

The licence agreement will often provide for the defence of the licensee from patent suits brought against it by others, but the licensor will rarely undertake such an obligation except under strictly defined conditions. Thus, the licensee is expected to follow the design, specification and procedures set up by the licensor, and failure to do so will usually relieve the licensor from liability to defend and hold the licensee harmless. Further, the licensor's obligation will in general be limited to a part or, at most, the total sum collected by way of royalty.

From the licensor's viewpoint, the purpose of the agreement is to generate royalty which can be transmitted to his home country, and the licence will ordinarily provide for payment of royalty in hard currency. There is always the possibility that changes in exchange regulations will prevent the licensor from getting his royalties out of the country and, in such case, the licensor may desire to terminate the agreement, and this will often be provided for.

Another question that has to be considered fully in the licence agreement is the question of taxes and governmental charges. Generally, the licensee assumes all charges arising in his own country, including initial filing fee, stamp taxes and the like. Local income taxes must be taken into consideration, and the general practice is to have the licensor assume local income taxes and take a credit on the royalty income for domestic tax purposes.

Whatever the good intentions of the parties, no agreement can be expected to define the relationships of the parties over a period of years so clearly as to make unnecessary some recourse to a legal interpretation, and the agreement will set forth the jurisdiction whose laws will apply. Where the law of the licensor's country and that of the licensee's country differ markedly, recourse may be had to such principles of law as may have been applied by international tribunals. In the event of a dispute arising, provision is most often made for arbitration in accordance with the rules of some independent, internationally recognized organization, such as the International Court of Arbitration or the International Chamber of Commerce.

Finally, particular mention should be made of the laws of the United States of America governing export of technical data and know-how. The regulations of the Bureau of Foreign Commerce and of the Treasury Department of the United States set forth certain restrictions on export of unpublished technical data and know-how in the petrochemical field. These regulations can have a serious effect on the commercial exploitation by the licensee of the licensed process since the controls not only extend to re-export of such technical data by the licensee to other countries, but may also affect the right to sell articles made by use of such controlled data to other countries without clearance. In view of these regulations, the licensee cannot expect to receive know-how from the licensor free of such restrictions, and this should be specifically set forth in the agreement.

Time does not permit detailed discussion of all of the other factors which are taken into consideration in the patent licensing agreement, including, for example, the term of the agreement, the effect of bankruptcy, insolvency, sale of the business, *force majeure* or governmental confiscation or nationalization, payment for special services, minimum royalties, production quotas, favoured nation clauses, etc. Suffice it to say that the objective of the parties in entering into the agreement is to establish a mutually advantageous working relationship to which in most cases the Government of the licensee's country must give the stamp of approval, and that the licence agreement if carefully thought out and properly drawn will minimize the misunderstandings and avoid any conflict between the parties over the course of years

2. LICENCE AGREEMENTS IN THE PETROCHEMICAL INDUSTRY

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INTRODUCTION

Whenever one human being generates a useful new idea and begins profitable exploitation of the idea, or demonstrates that it can be profitably exploited, he is ultimately confronted by the question of licensing, i.e., divulging his idea to others and permitting them to utilize it in return for some consideration. He may attempt to protect his idea by complete secrecy and thereby run the risk that someone else may independently generate the same idea and reap the benefits thereof. He may seek to protect his idea for the period of time legally provided by patents. If so, he faces several questions. Is his idea patentable? Is the expense of obtaining and maintaining patents justified by his potential income? Should he seek patent protection only in his own country? The development of a patent system has helped all inventors to establish and protect, for a period of time, their exclusive right to enjoy whatever profit may be derived from their inventions. Unfortunately, the patent systems differ greatly from country to country and do not give equal rights to the inventor.

The progress of civilization has both complicated and simplified the inventor's licensing problems. Technological progress everywhere has made necessary the combining of individual efforts into partnerships and companies, not only to better exploit current inventions but also to finance and foster the research and development activity that will lead to further advancement of knowledge, more inventions and better profits therefrom. These factors make steadily more complex the licensing problems, because the organization must protect an ever-growing number of inventions, and each new commercial development is usually a combination of many inventions conceived by various members of the organization. At the same time, however, licensing problems and practice have been simplified by competition. Licensing of processes within the petroleum industry was a well-established practice before the birth of the petrochemical industry. The combining of chemical and petroleum technologies, particularly in the United States of America and in Europe has brought about the so-called petrochemical industry in which many different companies have developed good and competitive processes. This competition has naturally caused such companies to establish generally similar terms and conditions in the licence agreements seen today. In this sense licensing practice is being simplified while technology and its problems become increasingly complex. This paper discusses briefly some of the basic provisions common to most licence agreements in the petrochemical industry; sets forth some general observations on the benefits and risks to licensor and licensee; and, finally, offers some suggestions that a prospective licensee should keep in mind.

BASIC PROVISIONS OF THE LICENCE AGREEMENT

There are probably no two licence agreements that are identical in all respects. However, the typical licence agreement will, or should, contain certain basic provisions. Among these are the following: 1. definitions; 2. grant of licence; 3. grant-back; 4. payments and reports; 5. exchange of information; 6. secrecy; 7. law; 8. assignability; 9. term of agreement.

The comments given below refer primarily to the licensing of processes for the manufacture of various petrochemicals, which licences usually include the right to use and sell the products made by such processes.

1. *Definitions*

The agreement should define as clearly as possible the nature of the process being licensed, regardless of whether the licence is intended to be broad or narrow in scope. The process definition should include any desired limitations as to nature of feedstocks, catalysts (if any), operating conditions, or products to be made. These limitations will determine the scope of information and rights that will flow to the licensee. Payments by the licensee will often be affected by the scope of the process definition.

If the agreement includes any licensing of patent rights, these will normally be defined in two ways, by reference to the process and by reference to time. The reference to process will simply provide for inclusion of all patent rights relating to the process (and perhaps also relating to the products thereof). The reference to time will provide for inclusion of all patent rights existing prior to some fixed date (such as date of agreement or end of agreement term or often as an arbitrarily chosen intermediate date). Patent rights should be further defined to make clear whether they inlude only patents issued, patent applications filed, or inventions conceived prior to the fixed "cut-off" date. Depending on the intent of the agreeing parties, patent rights may be only those rights of licensor or may include the rights of both parties.

2. *Grant of licence*

This provision will show that the licensee is granted a manufacturing licence (i.e., a right to practise the process)

In addition, the licensee may be granted a licence to use the products of the process, or to sell such products, or to do both. A grant of licence to make, use and sell appears to be most common in petrochemical process licensing. However, there are instances, for example, where the process being licensed is for manufacture of a product for which the only or principal commercial use is in some other operation controlled by a third party. In such an event, the process licensor must be careful that any hold-harmless provision of the licence does not cover use of the product, though he may be entirely free to grant a licence to make and to sell the product.

3. *Grant-back*

This provision will set forth whatever rights may be granted by licensee to licensor, hence the term "grant-back". In some instances, the licensee may already possess some patent rights or technical information, or both, as a result of his own work relating to the process for which he is acquiring a licence. More often, however, the licensee is obtaining the right to use a process entirely new to his experience. In either situation, it is reasonable to assume that the licensee's personnel, after having obtained full information on the process being acquired and after practicing it commercially, may develop useful new improvements. Such improvements, whether patentable or not, would probably not have been developed by licensee's personnel had they not been directed to work on the process because of the rights and information acquired from the licensor. This is the theory that accounts for the "grant-back" to licensor. The grant-back may also extend to other licensees using the same process, provided those other licensees have a similar grant-back provision; such an arrangement permits each licensee to enjoy the benefit of possible new developments by many other companies.

4. *Payments and reports*

Payments may be in the form of a fixed sum of money (to be paid on completion of the agreement or in stipulated instalments) or in the form of a royalty or fee based on production of sales, or any combination of these forms. If a fixed sum of money is required, it will usually be designated as a consideration to cover use of the process for manufacture of not more than a certain annual amount of product. During any year that the licensee makes or sells more than the certain annual amount of "paid-up" capacity, he may be required to pay licensor for the excess, either by a fixed sum to cover excess annual capacity or by a periodic royalty or fee based on the amount of excess. Payments may be made monthly, quarterly or annually, and must normally be accompanied by certified reports of licensee's production or sales for the period covered. Payments of periodic royalty or fee may be expressed as a percentage of product sales price, but often are expressed as an arbitrary amount per unit of product. Licensee's obligation to pay will normally relate to the magnitude of his use of the process, and the obligation may exist either for the full term of the licence agreement or for some lesser fixed number of years. Unless the licensor has investments or operations of his own in the licensee's country, the licensor will expect to be paid in the currency of his own country.

5. *Exchange of information*

In an important sense, this provision is related to and should be consistent with the scope of any patent rights licensed. If, for example, the two parties agree to exchange process information for a period of five years, the patent rights licensed should be only those developed during the same period. If the information to be exchanged includes research or pilot plant information not yet utilized in commercial practice, then the patent rights licensed should be any patents ultimately issuing from inventions conceived during the period covered by information being exchanged. Otherwise, either party may find himself in the inconvenient position of having received full information on the other party's useful new development but not having a licence under the patent covering that new development. Many licence agreements, however, provide for exchange of information only on commercial practice, and the information exchanged is limited to that being practised as of the date of agreement. Other licence agreements provide for information and rights to flow between the parties for as much as twenty years. The limits placed on information exchange can also determine the extent of licensee's enjoyment of information developed by other licensees of the same process.

6. *Secrecy*

It is generally important to both parties that information exchanged between them should not flow to any third party except as may be necessary and proper in the conduct of licensor or licensee's business. Any such third party should then be allowed to obtain information only under adequate secrecy restrictions. The only third parties to whom process information is normally allowed to flow are (1) contractors retained by either party for the design and construction of a plant to practice the process involved, and (2) other licensees of the same process. Licensor and licensee have a common interest in maintaining secrecy, i.e., neither desires that an unlicensed third party be enabled to compete in the same business by using information intended to be kept secret from him. The licensor has other reasons for insisting on secrecy, among them being the potential profit from additional future licence agreements.

7. *Law*

In order to avoid all possible misunderstandings as to legal interpretations of the licence agreement provisions in the event of any argument between the parties, it is important to specify the laws under which the agreement shall be construed. Each party will of course be inclined to prefer that the laws of his country should prevail. However, the licensor is not usually willing to disclose information on a process he has developed except under the terms of an agreement that will be subject to laws well-established by legal experience and court proceedings in such matters. Many United States companies, for example, regardless of the particular State in which they may be located or incorporated, desire that any licence agreement be construed according to the laws of the State of New York. Such companies take this position both as licensee and as licensor. The principal reasons again for having an agreement construed under the laws of any given country relate not to any unfavourable features of such law but simply to: (1) legal structure insufficiently defined by past practice, and (2) absence of or uncertainty of the country's patent system. In some instances, particularly it seems with European companies, the parties prefer to resolve any conflicts by arbitration rather than to place the conflict before the courts.

8. *Assignability*

A licence agreement can usually be assigned by either party to the successor of its entire business and goodwill, i.e., a company to whom the party has sold its entire assets. However, the licensor will normally want to protect himself by means of assignability provisions against two potential risks. First, as the developer of an important commercial process, the licensor may wish particularly to prevent certain competitors from obtaining information and rights to his process merely by purchasing a licensee plant and having the original licensee assign to him the licence agreement that was not otherwise available. Secondly, the licensor will wish to prevent assignment of the licence agreement to any person or organization that is not clearly capable technically and financially to fulfil the agreement obligations and successfully practice the process. Another risk sometimes encountered is that an organization of not quite reputable stature may by means of the assignability provision, obtain a licence agreement not otherwise available. This latter risk, however, is one which both licensor and licensee would probably recognize readily and avoid if at all possible. With these risks always in mind and with adequate safeguards against them, the licensor may permit assignment of the licence agreement to any party. The usual safeguard against such risks is that the licensor's prior consent must be obtained if the licensee wishes to assign his licence agreement to any party other than the purchaser of licensee's entire assets. The licensor will usually commit himself not to withhold his consent unreasonably.

9. *Term of agreement*

The term of a licence agreement may be for any period of time, depending on the nature of the process or subject matter being licensed, the payments desired or required, or the duration of patent rights involved. The term often extends for a fixed number of years of commercial plant operation, with royalties or fees payable on such operation. A term fixed in this manner will ensure to the licensor that his enjoyment of potential income will not be affected by delays in design or construction of licensee's plant. If patent rights are involved, some of the potential important patents may not have issued as of the date of agreement consummation. In such circumstances, which often apply to new processes, the term of agreement may be for a fixed period of years, that is the sum of patent life plus the number of years estimated to elapse before issuance of principal patents

BENEFITS AND RISKS TO LICENSEE

The potential benefits that lead one into any business venture must always be considered in balance against the risks that could cause failure of the venture. Many of the benefits and risks to be considered by a prospective licensee are apparent in my earlier remarks. Let us look briefly, however, from the licensee's viewpoint at some of the more important factors he should keep in mind. First, consider the benefits that you as a licensee might evaluate when deciding to sign a licence agreement enabling you to use a new process.

1. If you want a new process or its equivalent, you must either acquire it from others or develop your own. To undertake your own research and development may require many men for several years. The probable costs of your own development programme will be saved by your obtaining a licence to use a process already commercially developed by others. If you attempted to develop your own process and were successful after only four or five years in bringing your development to a commercial status, you might then find that competitive processes had been so improved, as a result of commercial experience, that you are still several years behind the advanced technology.

2. The benefits of saving time and money by acquiring licence are manifested in several ways. You can expect to have your plant designed and built in shorter time by utilizing the experience of others, and you can expect the plant as designed to cost less than you might have achieved on your own. The benefit of saving time is even more important in terms of plant operation, however, than it is in plant erection. The sooner you can begin plant operation, the sooner you can begin selling product and deriving income. If you might normally expect two years to be needed for plant design and erection, and you can instead build the plant in eighteen months, the benefit from the first six months of product sales is obvious, but such a time saving may also mean the difference between capturing and losing a potential market.

3. Once having chosen a process, you may then immediately be able to organize and begin your sales and technical service efforts with the specific product or products of the process you will employ. Such efforts, where appropriate, can be undertaken with product purchased from the licensor or another user of the same process while your own plant is under erection, thereby enabling you to train your sales staff, fulfil any existing market demand, and orient such market toward your product and its merits.

4. You can arrange with your licensor for training of your own personnel who will be responsible for building, operating and maintaining your plant. Such training can be by oral and written instructions and may most usefully include visits to a licensor plant that is in commercial operation.

5. The successful commercialization of any process involves much "trial and error" work. Sometimes, your greatest benefit seems to be the knowledge you gain of what not to do. You can profit not only by the successful experience of others but also by avoiding the methods

that your licensor and other licensees have tried and found to be undesirable, in all phases of the business.

6. You may obtain advisory help from your licensor, in the form of experienced personnel, in the design, erection and startup of your own plant, as well as of guidance in maintenance procedures and control laboratory operations.

7. You may arrange an agreement whereunder you can receive for several years a continuing flow of information from the licensor as to any new process improvements, procedures or modifications.

8. If patent rights are involved, you may resolve any potential conflict with the licensor by obtaining licence under his rights. In instances where the licensor's patent position and his potential income together justify it, you may obtain protection against possible action from third parties.

Some of the risks that may confront a licensee are not always properly appreciated, except in retrospect.

1. The process being licensed may not be commercially developed or in commercial operation. In such instances, the licensee should consider most carefully the stature and reputation of the licensor, his ability and past record of performance, and the assurances obtained under the proposed licence agreement as to help that the licensee will receive during further development work on the process.

2. The process may be fully commercialized, but the licensor may not provide any or adequate assistance during the licensee's plant design, erection and startup; or the licensor may not be able to provide for the licensee's personnel to receive training in commercial plants actually using the process.

3. The licensee may not obtain his government's co-operation and approval to import licensor advisory help when and as needed, or to expedite through customs and transportation authorities such items as are imported. These are risks that can critically hamper and delay completion of a project and, in fact, entirely eliminate its chances for success. There have been instances where a country's government was wholeheartedly in support of a project but where the actual progress of the project was unreasonably hindered by the above-mentioned factors. The spirit and the essence of government co-operation at all levels are often needed and too often not obtained.

4. The licensee who is planning to erect a plant must consider always the risk of competition from other domestic plants or from product imported by other domestic concerns.

5. Inadequate quantity or quality of feedstocks, failure in supply of any materials or utilities needed from others — such factors as these are risks that may be encountered. If a licensee is dependent on someone else for feedstock supply, he may complete his plant and only discover that the feedstock is not available unless the company has taken all steps necessary to assure such supply.

6. Where patent rights are involved, the possibility of an infringement suit by others is a risk that must be considered and evaluated prior to [illegible] licence agreement.

GENERAL SUGGESTIONS TO A PROSPECTIVE LICENSEE

Aside from the usual considerations of investment, operating costs, royalties or fees, etc., there are several factors that every prospective licensee should consider. Any or all of these factors, if not properly considered, could mean the difference between the success or failure of a new venture.

When considering a new process and once it has been determined that it is being commercially and successfully practised in another plant, you can assume that your own people will also be able to operate and maintain such a plant, if they receive good training and technical advice. You cannot expect your licensor to share all the responsibilities for you, because eventually you will want to handle the plant and its business entirely on your own. Therefore, you should pick good key men to handle your responsibilities of plant design, erection, operation and maintenance, and you should ensure that these key men fulfil their jobs, including intensive training of all personnel under their supervision. You should expect your licensor to provide thorough training of your key men *via* oral or written instructions; such training should include whenever possible a few weeks of training in a commercial plant operated by licensor. Your key men cannot, of course, be allowed to participate in actual operation of the licensor's plant, but they can observe in detail every aspect of such operation, including maintenance, safety and laboratory problems relating thereto. After such training and observation of successful practice by others, your own key men will be well prepared to handle their tasks. You should then be able to obtain and need only advisory assistance from the licensor during your plant startup period; normally a maximum of four skilled operators from the licensor for a period of perhaps thirty days will suffice for you to begin successful operation.

You will encounter with any process occasional problems that are alien to your experience but not to that of the licensor. For this reason, and also to obtain the benefit of future new developments, you should seek a licence agreement arrangement that will provide for information exchange between you and licensor at least through the first few years of your plant operation. Such an arrangement could also permit you to make periodic visits to the licensor's plant for review and discussion of common operating problems.

V. LICENSING OF PROCESS KNOW-HOW

Jerry L. Jenkins, Manager, Licensing and Chemical Development, Cosden Oil and Chemical Company, United States of America

[illegible] Cosden Oil and Chemical Company. In March [illegible] when the first [illegible] know-how was signed the [illegible] and itself is a new [illegible] had always been the [illegible]. Since that day thirteen other [illegible] know-how [illegible] the United States of America and [illegible] other countries [illegible] have been [illegible] ethylbenzene recovery from mixed [illegible] production polystyrene [illegible] butadiene manufacture. This paper [illegible] development of the Cosden licensing [illegible] of the more interesting aspects of licensing process know-how.

The first [illegible] contract by Cosden covered the ethylbenzene recovery and styrene monomer processes. [illegible] was filled with [illegible] the problems encountered [illegible] licensing programme. The [illegible] company which [illegible] ownership by a major oil [illegible] product. Prior to creating the [illegible] established organisations wanted [illegible] data so that they [illegible] the processes to be employed [illegible] company, the licensee company [illegible] then called [illegible] Company Y. Following the [illegible] of the licence agreement such as royalty rate [illegible] information exchange and process guarantees. It was during this period that Cosden established a basic philosophy toward licensing that is still practised today. The part of this philosophy is that each licence represents a different situation. The things that are of paramount importance to one licensee may be minor in the case of another. For example, the joint venture company was not at all concerned about process guarantees since they felt the engineering staffs of the parent companies were capable of doing a thorough job of process design review. They were disturbed, however, over the technical information exchange provisions of the agreement. Since one of the joint owners was a styrene producer, therefore a Cosden competitor, they were quite intent on preventing any exchange of technical data. Cosden felt that feedback of operating data was extremely important to continuous process improvement. The agreement was [illegible] worked out to the mutual satisfaction of all concerned and the first milestone on the way to becoming a successful licensor was passed.

A second valuable lesson was learned a short time later during the negotiation of another licence for the use of the ethylbenzene recovery process. During a discussion of the proposed agreement, the potential licensee stated that Cosden's royalty rate was too high and was not justifiable. This statement came as a surprise and left only two possible choices for Cosden. One was to defend the royalty with only words and take the chance of losing the sale. The other was to compute a return on the paid-up royalty to determine its justification. The latter course of action was chosen and out of that study came one of the best selling points that a licensor could have. That is an accurate engineering evaluation showing that the royalty could be fully paid out by savings in plant investment. Upon presentation of this data, the licence was promptly executed and another chapter was completed.

Actually, the chapter was just beginning although Cosden did not know this at the time. The agreement referred to above called for a process performance guarantee which was to be determined by a plant test. Cosden personnel were to be present during the test as well as during the initial plant start-up at the option of the licensee. At one time two engineers, two shift operators and one foreman were on duty at the licensed unit. Only minor operating difficulties were encountered and the performance test was waived because of excellent unit operation. However, the licensee wanted these people for round-the-clock coverage. For a small company with a limited number of technical personnel, it was indeed disquieting to find that a significant number of people were required on licensing and start-up. This also was a valuable lesson and Cosden now realises that competent start-up assistance is essential to a sound licensing programme.

In the interim between the two domestic licences, Cosden had its first experience in negotiating licences with overseas companies. During [illegible] two licences for use of the Cosden [illegible] process were successfully executed. One of these was for a plant in France and the other for a plant in Japan. As was the case with the ethylbenzene process, each of these licensing negotiations presented problems which were new and different. The licence agreement with the French company did not present any real difficulty; however, the design of the plant unit was a very enlightening experience. Not only was [illegible] necessary to educate the licensee in the process but it was also imperative that the engineering contractor be advised of the many special engineering features. Since the process design was done by a United States contractor, the process details were easily resolved. The detailed mechanical design was done by the [illegible] office of the United States firm and it was this phase of the project which proved to be a problem. [illegible] Cosden engineers were not familiar with the [illegible] equipment. This [illegible] extremely difficult. The [illegible] engineers [illegible] the special [illegible] equipment [illegible] a great deal of time was spent in attaining [illegible] understanding of the problem. [illegible] after the licence agreement was signed.

The Japanese licence [illegible] different from the preceding one. The [illegible] using imported technology [illegible] of the Japanese Ministry of International Trade and Industry is required. This necessitated [illegible] special features in the licence agreement and required considerable amount of time. After the licence agreement was approved and executed, Cosden learned that the licensee was required to [illegible] in the market development area. Although the project had an excellent raw material situation, markets for the polybutylene were not developed to a point which justified the construction of a plant. To explore and develop this market required samples of all the various grades of polybutene. This is where Cosden entered the picture. From the output of its plant in Big Spring, Texas, Cosden supplied sample [illegible] market [illegible]. This [illegible] and [illegible] has proven to be [illegible] in promoting the use of the Cosden [illegible] polybutene process on a world-wide basis.

In the summer of 1961, the first polystyrene process licence was signed with a Japanese company. Since a [illegible] licence had been granted in Japan, the form of the agreement presented no new problems. The licensee [illegible] wanted its own staff to perform the process design. It was therefore agreed that a group of engineers from the staff of the licensee should come to the United States for the design work. Ten engineers came to Big Spring, Texas, for a period of six months, during which time the process design for the licensee's plant was completed. This procedure was extremely successful. By working in close contact with the Cosden staff, the licensee obtained a far greater amount of know-how than would have been obtained by having the design done by a contractor. In addition, Cosden engineering personnel became thoroughly acquainted with the equipment and other design features of the licensee's plant, which made the start-up conditions much easier. Basically the same method of design was used on a subsequent polystyrene unit licensed in France. The exchange was equally successful in this case.

In the second half of 1961, a total of six licences were negotiated, including the polystyrene licence in Japan. Included in this group were three [illegible] company [illegible] and [illegible] was added to the [illegible] know-how was [illegible] cost and [illegible] United States [illegible] companies [illegible] Cosden [illegible] period. Since [illegible] been granted [illegible] England and [illegible]

[illegible]

[illegible] When the [illegible] the [illegible] and [illegible] research and development [illegible] the same [illegible] of potential profit [illegible] development stages of a new process must be taken into account. If the competitive processes [illegible] also have [illegible] royalty rates [illegible] difference in royalty must be compared with the [illegible] advantages of the processes. A higher royalty [illegible] lower capital and decreased operating requirements or [illegible] improved product quality.

The next three items shown in the list are just as important as the [illegible] economic factors [illegible]. The status of development of a process is of primary importance in process selection. In the process licensing [illegible] evaluation of pilot plant data [illegible] supply one that some engineer has put on paper? Commercial application of the process should also be investigated if possible. One highly successful way of doing this is for a prospective licensee to visit other plants where the process is used. In this manner, first-hand information regarding the operation of the process can frequently be obtained. The background and prior record of the licensor can be of the utmost importance. This is particularly true if the process is new and has had no proven commercial operation. In any case, the licensee should ask the following questions:

(1) Does the licensor have experience in this specific field of processes or chemicals?

(2) Does the licensor have a successful record or has there been a series of failures?

In addition to the above items, there is another very important point to bear in mind when selecting a process for licence, namely, how much the licensor can contribute to the success of the project in terms of service. All companies offering know-how for licence can and will furnish basic process design data, but this is only one essential part of a successful process installation. To be a profitable venture, the process unit must be erected with a good mechanical design, must be placed on stream in an efficient manner, and must be staffed with well-trained operating personnel.

The potential help which can be obtained from the licensor in each of these three areas should be seriously considered. In many instances, good mechanical design is based on experience with the process. The licensor should either operate a unit using the licensed process or have complete access to the records of an operating unit in order to be of maximum benefit in the mechanical design phase. This is also true with respect to start-up assistance and operator training. A well-qualified start-up engineer or operator must know the licensed process in great detail. This can be learned from books and drawings, but not nearly as well as it can be learned from actual plant operations. The training of operating personnel can take the form of classroom instruction, but, once again, there is no substitute for field training in an operating unit.

Following the selection of a process, a licence agreement must be entered into between the licensee and the licensor. In many respects, licensing of process know-how is equivalent to a partnership or joint venture. A licensor obtains earnings through royalty payments, which are directly related to the production of the licensed unit. The licensee earns profit through the sale of plant production. It is, therefore, important to both parties that the licensed unit operates as efficiently and profitably as possible. A good licence agreement merely outlines the responsibilities of each party to the other and defines the terms and conditions under which the loosely formed partnership shall operate.

Although there may be wide variations in the actual format of a licence agreement, there are certain provisions which should be included. Clear stipulation of these points is of equal importance to both the licensee and the licensor. A summary outline of the more important provisions is given below.

A. *Definitions*
   1. Definition of process
   2. Definition of patent rights
   3. Definition of proprietary information
B. *Terms of licence*
   1. Exclusive or non-exclusive
   2. Disclosure of technical information
C. *Exchange of technical data*
   1. Method of exchange
   2. Period of exchange
D. *Secrecy*
   1. Period of secrecy
   2. Information covered
E. *Royalty*
   1. Rate of royalty
   2. Method of computation
   3. Payment schedule
F. *Patent indemnification*
G. *Engineering services*
   1. Design consultation
   2. Start-up assistance
   3. Fee for engineering services
H. *Process guarantee*
   1. Performance test outline
   2. Basis of guarantee
   3. Liability of licensor
I. *General provisions*
   1. *Force majeure*
   2. Arbitration procedure
   3. Assignability

A clear definition of all special terms used in the agreement is highly beneficial. The licensed process should be defined as well as the licensee's patent rights and proprietary information. By this technique, the agreement can be shortened considerably and is much easier to understand. In the section outlining the terms of the licence, the licensee can see exactly what is to be received. This article should so state if the licence is exclusive and should clearly define the geographical area covered. The technical information to be received by the licensee may also be stipulated in this part of the agreement. Exchange of technical data is another important provision. Does the licensee get the benefit of process improvements of other licensees and, if so, for how long? This is usually a give-and-take proposition; therefore, the licensee is normally required to allow others to use his improvements in return. The licensor merely acts as the clearing-house for this information. The secrecy provision should outline the information which is to be maintained in confidence and stipulate for what period of time.

Royalty has been discussed at some length earlier in this paper; however, the royalty clause in the licence agreement warrants further discussion. In addition to defining the royalty rate, this part of the agreement should clearly present the basis for the royalty and the method of computation. For running royalties, a report period should be set forth and for paid-up royalties, a payment schedule should be outlined. There are many possible options for crediting either all or a portion of the running royalty to a paid-up licence. This is another point which should be included in this part of the agreement.

Patent indemnification or "hold harmless" clauses are also quite commonly found in licence agreements. This provision gives the licensee some protection from legal action brought by a third party for patent infringement. The licensor normally assumes a share of the cost of settling such a dispute, therefore he must be sure of his patent position before agreeing to a patent indemnity provision.

Although, frequently, a separate agreement is prepared covering engineering services, this is not a necessity. The services provided by the licensor can be easily included as a part of the basic licence agreement. In either case, the responsibilities and obligations of the licensor should be clearly outlined. The more important points to be covered are consultation services during design of the licensed unit, start-up assistance to be provided, and the fees charged for engineering services. Once again, a wide variation can be encountered in this area. However, some engineering is normally included in the licence fee and charges for additional service are usually reasonable. Process guarantees should also be an important consideration. Not only is it important that the guarantee basis be clearly defined, but it is equally important that the performance test method be set forth. The duration of the test, the obligations of the licensee and the responsibilities of the licensor must be outlined in detail. A substantial portion of this section should also be devoted to the liability of the licensor in the event of failure of the unit to meet the prescribed guarantee.

Lastly, there are general provisions which are common to most contracts. Included among these are *force majeure*, arbitration procedures, and assignability. The licence agreement provisions outlined above are not necessarily the only ones which are needed. Special cases may dictate the need for others. Each provision is negotiable and Cosden's experience has indicated that the best agreements are those which were negotiated by both parties in good faith in an effort to develop a working agreement ensuring a mutually profitable relationship.

During the past few years, licensing has become big business. Royalty payments made by United States chemical companies to companies overseas were estimated at $70 million in 1962. Payments by overseas firms to United States companies amounted to $140 million, bringing the total flow of royalty dollars in and out of the United States to $210 million in 1962.[1] This was an increase of over 80 per cent based on the estimated royalty payments in 1958. By 1970, the total annual royalty payments exchanged between United States and overseas chemical industry should reach $800 million. There are several reasons for this trend. Among these are the rising cost of research and the increasingly greater number of chemical products on today's market. Product demands are changing rapidly in our modern world. It is not economically feasible for even the larger chemical companies to do adequate research on the technology needed to make all the products required by this growing demand. Faced with this problem the chemical industry has chosen licensing of process know-how as a solution. In this way, research effort can be concentrated on new products and new processes, where the economic return on research expenditures is greater.

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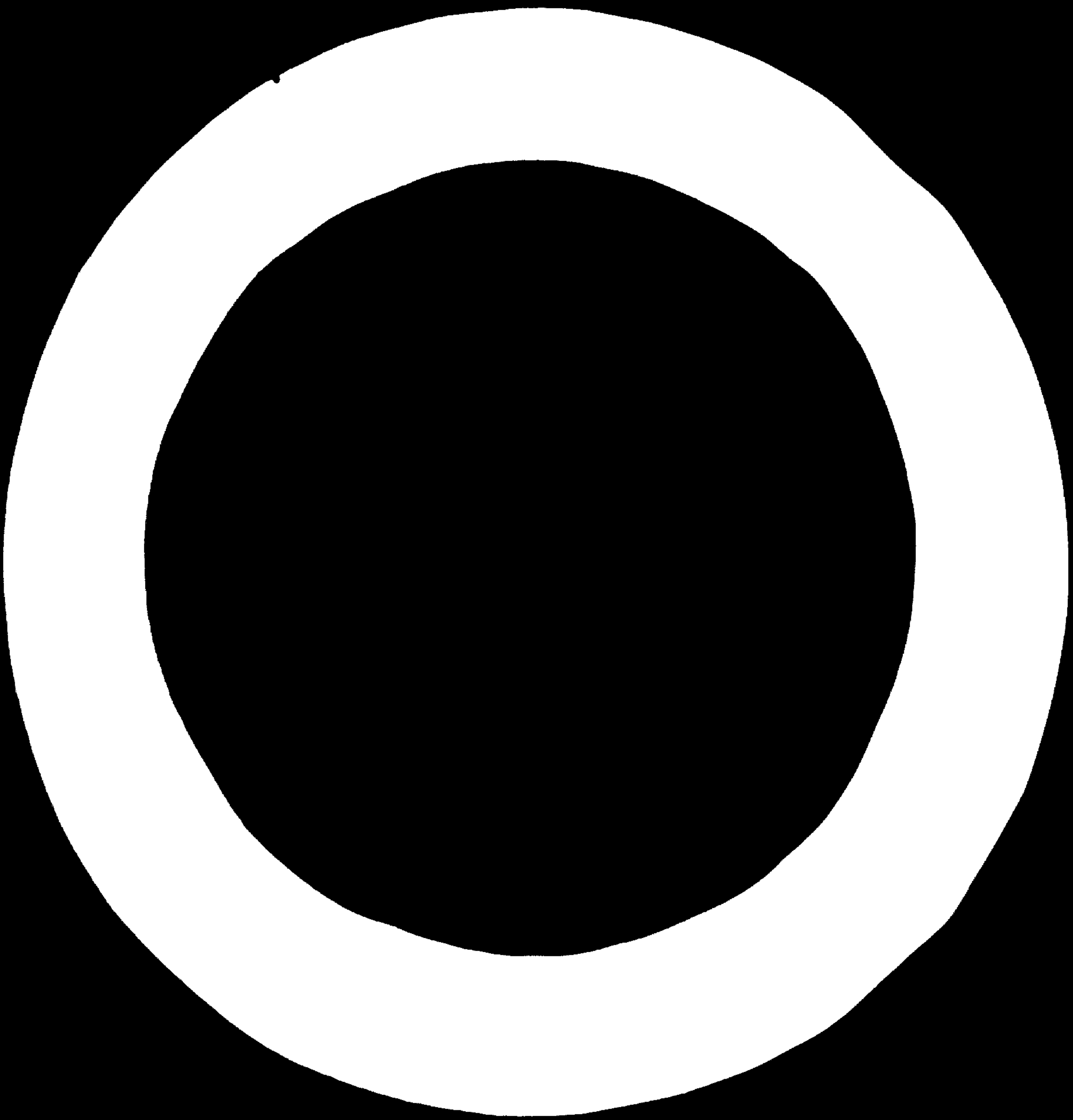
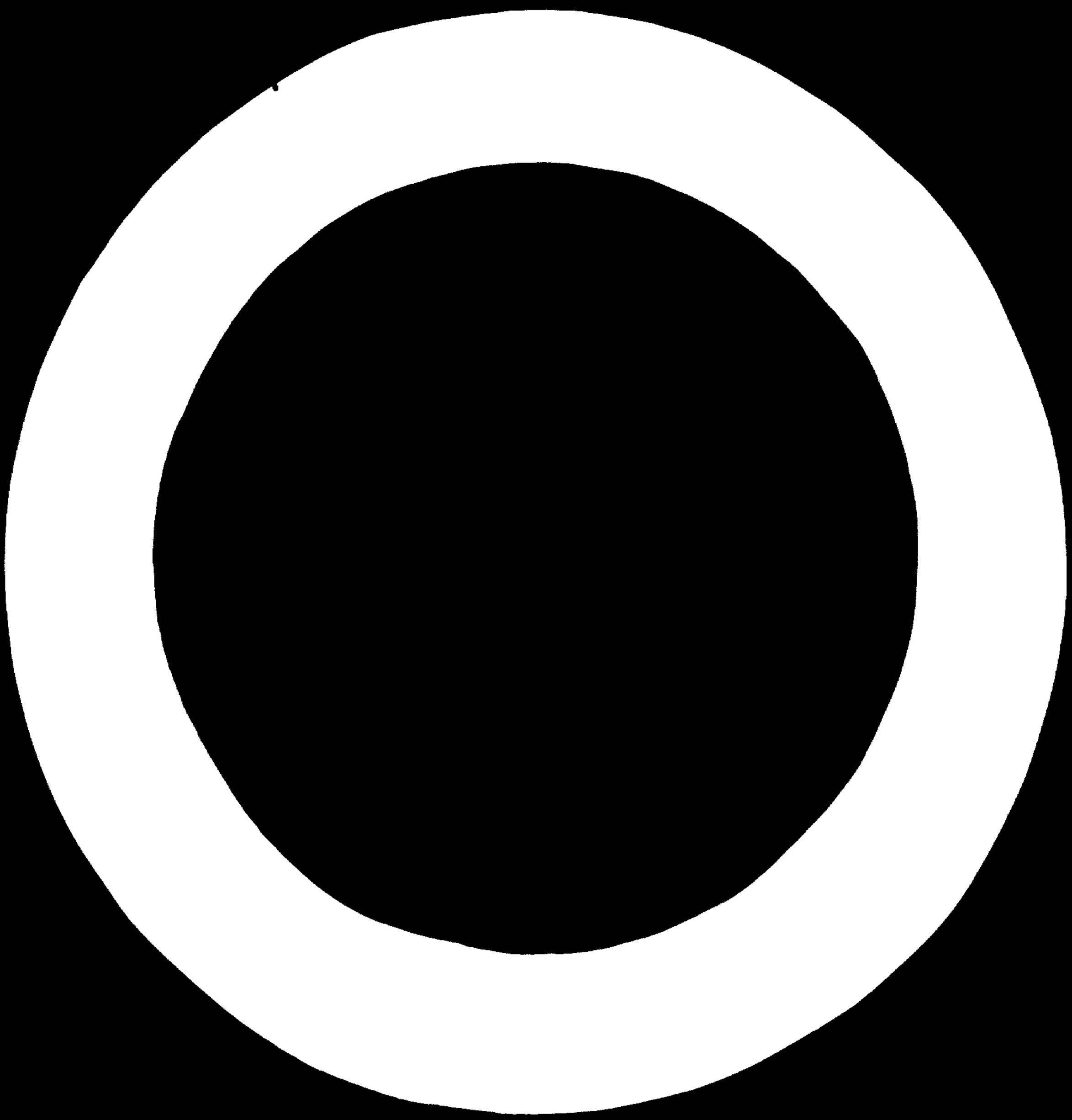
[1] *Chemical Engineering*, July 20, 1964, p. 98.



Chapter VIII

LOCATION FACTORS IN THE PETROCHEMICAL INDUSTRY



INTRODUCTORY SUMMARY

There is no doubt that for the development of the petrochemical industry the geographical location of the *core* plant will often make the difference between subsequent success and failure of the entire industry. Developing countries can, therefore, benefit from the experience which other countries have acquired in the location of petrochemical establishments.

The experience of some countries with petrochemical projects highlights the relative importance of the following factors in the location of petrochemical plants.

(*a*) The local availability and accessibility of the basic raw materials such as oil and natural gas: it is argued, however, that the existence of crude oil and gas might not be reason enough to embark on a petrochemical project. The importance of this factor should, therefore, not be overestimated.

(*b*) The cost of exploitation of the local raw materials: opportunity costs are considered the best criterion for the evaluation of domestic raw materials. A comparison should be made between the value of the raw materials in domestic use and their alternative value as an export.

(*c*) The prospects for growth by "vertical integration" and utilization of by-products: growth by vertical integration occurs when the output of one establishment immediately becomes a raw material for another. This is the case with many petrochemical complexes.

(*d*) The cost of transportation of either the finished product or the raw material to the consumer and the factory respectively: the greater the cost of transportation, the nearer to the destination the establishment should be located. In this respect, it is important to observe that improvements in the transportability of a given raw material might diminish the need to locate a plant near it.

(*e*) Availability of infra-structure and skilled labour.

(*f*) The effect of location on the scale of operation: it is argued that restricted markets are apt to inhibit the development of large-scale operation.

(*g*) Tax environment: this factor is often considered by foreign firms interested in setting up petrochemical establishments in a developing country.

In general, the problem of the appropriate location for the petrochemical industry, as well as for any other industry, can be resolved into that of making a choice between location on the basis of "nearness to the market" and "nearness to the source of productive resources", that is, if non-economic criteria can be safely ignored or regarded as a datum. "Productive resources" is defined in this context to include not only raw materials but also human and non-human services which are either directly required in the production process or are indirectly conducive to the growth of the industry in a particular location. The term "market" is also defined not only in terms of the volume of demand but also in terms of its geographical distribution.

In regard to location near the source of raw materials, some observation about specific cases is informative. In North Africa, there is the problem of what to do with the flare gas and the question that arises is whether an ammonia plant should be built to utilize the waste gas. In this case, market considerations have been found to be of paramount importance. Given the accessibility of the European and Mediterranean markets, favourable tax environment, and provision of infrastructure at low cost, the location of a 150,000 ton/year ammonia plant in North Africa would appear to be economically feasible. Similarly, an ammonia plant in the Persian Gulf would need the Indian market for its survival. In Mexico, the petrochemical centres of Pajaritos, Coatzacoalcos and Reynosa are overwhelmingly based on the availability of ethylene [illegible] petrochemical intermediate as "raw material".

As has been hinted above, growth by vertical integration is most pronounced in the petrochemical industry. Consequently, if markets are assured or can be [illegible] a petrochemical complex is almost certain to [illegible] rapidly once the core plant is commercially established. The commercial establishment of the core plant presupposes the existence of an increasing demand or an expanding market. For the development of the petrochemical industry, the importance of an expanding market cannot be over-emphasized. In fact, the petrochemical experience of the United States emphasizes the [illegible] "accessibility to the market" in the rapid development of a petrochemical complex. Being [illegible] petrochemicals grow at a rate considerably higher than the growth rate of the other sectors and [illegible] can pull up the rate of aggregate [illegible]. This is so because there is hardly [illegible] standard of living in which petro[illegible] in one form or another.

Given the availability of the basic petrochemical raw materials and good transportation routes, what should the core petrochemical plant be? There is no standard route to the development of a petrochemical industry, but, for developing countries, [illegible] starting core petrochemical project [illegible] the ultimate aim of maximizing the product [illegible] bearing in mind the ever-increasing [illegible] growth. A fertilizer plant might be set up [illegible] the domestic agricultural need. Accordingly, the manufacture of synthetic ammonia [illegible] possible starting point for a petrochemical industry in a developing country. Another possible starting-point is the manufacture of ethylene, as is the case in Mexico where the growth of its petrochemical industry is heavily based on ethylene production.

In regard to continued growth, once the core petrochemical plant has been established, the experience of Japan is noteworthy. The reasons given for the success of Japan's petrochemical industry are as follows :

Adequacy of timing: the project was launched at a time when Japan's over-all economic growth was considerable;

Introduction of up-to-date techniques based on continuous research and development and initial importation of technical know-how from more advanced countries;

Location to exploit existing infra-structure and nearness to major centres of consumption;

Favourable assistance of the Government and co-operation with other industrial concerns and financial institutions.

In Mexico, success is credited to the following:

Favourable tax and pricing policies: petrochemical products may be sold at home at a price 15 per cent above international prices;

Vigorous promotion of exports to Latin America;

Effective co-operation between the Government and private sectors; introduction of modern techniques based on importing know-how through licensing from the industrialized countries;

General economic growth.

In Mexico, the petrochemical industry already accounts for 3.2 per cent of the national output (G.N.P.). While the Mexican and Japanese successes are not necessarily typical, they point out an interesting feature of the petrochemical industry: if the "correct" core plant is established, the industry will subsequently contribute to increase the rate of over-all economic growth which, in turn, induces further growth of the industry so long as markets are not too restricted.

In conclusion, the development of the petrochemical industry in any place may be conceived as being heavily dependent on three major factors as follows: Availability of petroleum or natural gas, the existent level of industrial technology, and access to consumer markets.

1. LOCATION FACTORS FOR THE CHEMICAL INDUSTRIES IN DEVELOPING COUNTRIES

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The introduction of a chemical industry is an important step in the industrialization of a developing country. Countries that traditionally have been exporting raw materials and importing finished products will begin their own consumer products industries. In the production of organic chemicals, the trend today is overwhelmingly in favour of a petroleum feed-stock — natural gas, crude oil, or refinery by-products — replacing the traditional coal base. In the United States at the present time, approximately 90 per cent of the organic chemicals produced are based on petroleum feed-stocks; in Italy it is also about 90 per cent; it is over 60 per cent in the United Kingdom; over 40 per cent in the Federal Republic of Germany and climbing rapidly. The newly developing countries need not start with or change over from an industry based on the chemistry of coal, but rather they have the unique advantage of being able to establish their chemical industry by using the newest and latest techniques which are associated with the petroleum-based chemistry. Nor need they modernize obsolete plants — obsolete because of age or changing technology or both. Matching the latest and newest technological developments of the petrochemical field have been the rapid growth of consumer demands in many areas of the world, the increasing necessity for the creation of internal industry, and the generation of additional capital. In addition, the recent discoveries of oil and natural gas in such areas as Libya and the Sahara Region broaden the availability of raw materials.

With all these advantages, the developing country still must study the many factors which affect a specific enterprise. Among these factors are: what to manufacture, where to locate the facility, what process to use. We shall adhere strictly to a discussion of the factors affecting location of a petroleum-based chemical industry. We shall assume that a decision has been made for the creation of a petrochemical plant or of a petrochemical complex.

I. LOCATING THE PLANT

The selection of an area or site for location of a petrochemical plant in any country is a problem complicated by interwoven technical and economic relationships. The enumerating of the major considerations is simple: site, availability of raw materials, markets, labour, transportation, utilities and fuel, water and air, and social considerations (living conditions, etc.). However, the weights assigned to each of these factors can vary tremendously when considering the type of plant or plants to be built, industrialized nations *versus* developing nations, and even from country to country within either of the categories.

The importance of the choice of a location is second only to the original decision to build. The success of a venture that is otherwise technically sound and market-proven depends on the geographical and practical manufacturing factors that are largely responsible for determining manufacturing costs. What has been predicted to be a highly successful venture can fail totally if any one of the factors involved in plant location is found to be inadequate. We are all familiar with plants that have experienced difficulties because the proposed raw material source did not materialize or was insufficient to sustain production, or because the distance from the market place was too great.

The problem of selecting a site in an industrialized country is not too difficult, since considerable information is available. The specific site requirement factors can be listed and the various suggested sites can be compared. Raw material availabilities and transportation costs can be easily compared, so may shipping rates of either chemical intermediate or of finished product, and by-products. The known economics of operation of similar industries in similar locations can be taken into account. Largely, the decision depends on a choice of location near the product market, at the raw material source or somewhere in between. In the United States the petrochemical plant is usually located near the source of raw material. More than 80 per cent of these plants are actually in Texas and the Gulf Coast Region. This is, of course, where the major oil and natural gas deposits are located. The most desirable petroleum raw materials are, generally, the light hydrocarbons associated with natural gas. They are also the most difficult to transport, because of their high vapour pressure. Secondly, much of the United States' petroleum refining capacity is located in this region, and the light hydrocarbons and olefin by-product streams from such operations as catalytic cracking and hydrocracking have also given great impetus to locating petrochemical plants there. Again, this is largely because of the difficulty in handling and transporting such raw materials. However, as cheaper raw material transportation methods are developed — such as pipelines, tank cars, etc. — petrochemical plants may be located closer to the market place. In the industrialized countries the location of the plant is considered important in relation to the general surrounding areas, which may be highly commercialized already or may be large consumer areas, for reasons of urban beauty, tax benefits to the community, provision for utilities, air pollution problems, etc. Thus, in Europe, where naphtha has always been a far more important petrochemical raw material than light hydrocarbons (due to the lack of natural gas and oil), the easy transportation of naphtha has resulted in locating petrochemical centres much closer to population centres.

In the newly developing nations, the problem is more acute. The various outside factors that come into play must be seriously studied. Above all, location should be selected with the utmost care on the basis of economic and social considerations. Whenever possible in the determination of a site, the various factors should be expressed in quantitative terms by using local cost data. The comparison of the figures obtained for all sites considered will be one of the best measurements to be used toward the final decision. The choice which is next is to use plant location as a means of determining the future growth and expansion of an area. Instead of locating the plant in relation to present surroundings, the future surroundings can be located in relation to the plant.

In all of the developing countries, industry, especially new industry, is closely controlled or guided by the government. This is understandable because of the numerous problems facing countries that have not yet been able to obtain large capital incomes and have not been able to build adequate capital reserves. Then, too, in the absence of an organized industry, the government determines what is to be built up first to fit in with the country's long range economic and industrial plans.

It is to the nation's advantage to accelerate industrialization as a basic means of increasing employment opportunities and as a spur to build up the small- and medium-sized industries generated by the heavier industrialized plants. Although considerable capital must be available to initiate new plants, local production will eventually decrease foreign exchange expenditures. It may also lead to an increase in national income through the possibility of future export of goods. If capital can be generated from private industry, the government can offer many incentives to help the industry get started. Among the incentives currently employed locally or nationally in many countries are those of tax exemptions, low cost loans, tariff concessions and assistance in marketing. Other incentives that could affect site location will be discussed later — those of government-supplied facilities such as power, water, transportation, housing etc. The tax incentives could include tax holidays wherein taxes are suspended completely, usually for a specific length of time, partial tax exemptions, wherein the rate is considerably reduced, or any combination which could be a gradually increasing tax over a period of time. Tariff concessions could include lowering of duties on raw materials or raising duties on competing goods, or preferential margins for import and export among certain groups. Marketing assistance would include a quota system of regulating imports under licences. The tax and tariff considerations would be used to adjust calculated costs for a given site.

II. SITE SELECTION

One of the initial factors to be considered is whether the new petrochemical facility should be located near the source of raw materials or whether it should be located near the point of consumption. Location near a raw-material source would be influenced largely by whether a refinery exists in the country, whether one is contemplated in the immediate future, or whether the raw materials must be imported. If a refinery exists, one must consider whether transportation of raw materials is inexpensive enough to justify placing the plant near the consuming area, in comparison with the transportation costs if located near the refinery for shipping plant product to consumer areas. For example, in the industrialized countries, the development and improvement of inexpensive systems for transporting raw materials is starting a trend toward location away from the sources of raw materials. The network of pipe lines being set up to carry petrochemical raw materials is the leading trend. It is, of course, a tremendous advantage that petrochemical raw materials are for the most part liquid or gases because of the simplicity of transportation, loading and unloading. A network of pipe lines is now being installed throughout Europe, some emanating from Algeria, and these will have a pronounced effect in further use of petroleum feed-stock as well as a lowering of raw material price.

This is a general discussion and the conclusions to be drawn from it will be strongly influenced by the type of plants considered. If there are several plants, and there is any interdependence of raw materials, then the grouping as a complex is desirable. Scattering related plants, or putting up two similar small plants in different areas instead of one large plant, are both undesirable. In the case of fertilizer plants, the large-volume, low-cost product, would be expensive to deliver over long distances, suggesting location nearer consumer areas. Again, to use the United States as an example, it has been determined that ammonia plants must be located close to the large users to achieve the best economics. This has led to a rash of farmers' co-operatives in the middle west and a current boom in California. On the other hand, other petroleum-based plants produce a disproportionate volume of by-products, which must usually be sold or otherwise disposed of in order to make over-all operation economically competitive. Thus, transportation of by-products to a potential user must be considered along with shipment of principal product to the consumer. Only in the case of these large-volume, low-cost product industries would two smaller plants each closer to widely separated consumer areas be considered practical.

If a refinery is not available, imported basic raw materials transported inexpensively over water routes would be an excellent source of supply. This would require that a plant be located at or near a port of suitable size to accommodate tankers. It would be well to remember that a refinery must ultimately be built if a country is to become industrialized. Crude oil could then come over the same route. Here, too, the development of large-scale transportation methods have justified the practice of building refineries nearer the areas of large consumption. This is justified by the development of super tankers that can move large quantities of oil or other raw materials at a relatively low cost; this saves on eventual transportation costs of products from plant to consumer areas. In an article in *World Petroleum*, January 1964, entitled "Refineries in Smaller Consumer Countries" by Newton, a table is presented that shows the comparative costs of shipping bulk oil as volume increases. Assuming that the costs of moving oil in a T2 tanker is 100, the cost factors for other tanker sizes are as follows: in a 25,000 dead-weight tonnage tanker (DWT), 79; in a 38,000 DWT tanker, 67; in a 45,000 DWT tanker, 59; in a 69,000 DWT tanker, 51; and in an 80,000 DWT tanker, 47. The conclusion is that it is much cheaper and simpler to transport crude oil instead of petrochemical products, provided of course, that the super tanker can be accommodated in the port and the refinery is of adequate size. It is well to remember that the products, as distinguished from raw materials, are more specialized and numerous and are shipped in smaller, harder-to-handle lots. This again often dictates a location closer to the consumer.

The cost of land in most countries is quite small compared to the total cost of the proposed plant. Therefore, comparative land costs are rarely deciding factors. Some of the factors that govern site selection — accessibility to the site, the availability of services, and the physical suitability of the land — are the same factors that have long been considered in connexion with the development of industrial estates. A considerable amount of literature on industrial estate planning is available from the United Nations' conferences that have been held in the past. However, the scale and consideration of these factors is considerably greater for the chemical industry. The industrial estate is usually considered as a collection of quite small industries, no single one of which would impose heavy demands on facilities. A petrochemical plant on the other hand is a comparatively large and highly complex industrial property. The capital costs involved, as well as the facilities included, are quite large.

It is important to emphasize at this point, that the major initial considerations for the location of a plant involve the availability of raw mtaerials and the existence of a transportation system able to handle raw materials and the products of the plant. If these conditions cannot be met, the site cannot be given further consideration. To summarize further, it is important to recognize that the location of the refinery will have a predominant influence on the location of the petrochemical complex — thus the case should already be kept in mind when locating the refinery.

III. ACCESSIBILITY

The factors of accessibility are usually given as transportation, raw materials, markets, related industry and labour forces. The first three listed are of prime importance.

Transportation has already been discussed briefly in our consideration of location with respect to the sources of major raw materials. Not only must it be possible to get raw materials to the plant, but it must be possible to get equipment, services, supplies and, of course, construction materials to the plant as well as manufactured products from the plant either to other plants or [illegible] to the consumer. Then, too, there is, in many petrochemical processes a large volume of by-products that must be sold or otherwise disposed of in addition to [illegible] desired products. Where the plant is located near [illegible] convenient to the consumer areas, a transportation system is usually available. Where the plant [illegible] located in a rural area or one that is scheduled for [illegible] then the problems of transportation [illegible] considered.

For the most part [illegible] system [illegible] system of transportation in [illegible] course, permits the shipping of very [illegible] and materials. However not all [illegible] served by railroads so that road and [illegible] for truck transport must be thoroughly [illegible]. Among the latest developments in the [illegible] nations is the combination rail and road [illegible] in the United States is called [illegible]. It [illegible] a special truck trailer built to be carried [illegible] on a flat car to a convenient location where [illegible] transferred to a truck for final delivery. [illegible] involves only one packing and one unloading [illegible] and the standardization of trailer types and [illegible] a high degree of flexibility in their use and operation. A variation of this procedure is the modular [illegible] unit which can be transported on flatcars [illegible] so-called "tote bin").

For any international transport which [illegible] export, transportation by water [illegible]. Bulk transport is simplified, and tankers [illegible] expensive form. Air transportation for the [illegible] of people and materials, while not a controlling [illegible] tion, must eventually be provided.

Where an adequate transportation [illegible] problem of supplying raw materials [illegible]. Fortunately for the petrochemical [illegible] materials to or from a refinery destined for [illegible] chemical plant are largely in the liquid state and [illegible] easy to load, unload and transport. [illegible] where the plants are to manufacture [illegible] raw material supplies (which are usually [illegible] are also largely in the liquid state [illegible] that are usually solids. Here again is [illegible] towards closer location of plant to the [illegible]

The accessibility of markets [illegible] by locating the plant near the market [illegible] chemicals, the market could be another [illegible] plant if the initial product is an intermediate [illegible] when considering petroleum-based chem[illegible] newly developing countries, we rarely [illegible] single isolated plant but rather the beginning [illegible] chemical complex. The inter-relation [illegible] polymer manufacture, the number of products that [illegible] stem from a common raw material [illegible] usually require that plants be grouped for the sake of economy and convenience. Thus, in considering the size to build, considerable thought should be given to planned and possible expansions to be sure that adequate land and facilities will be available when needed. It should be further recognized that chemical plants, although intrinsically fairly self-sufficient must be backed up by a variety of general services such as machine shops, equipment suppliers, technical and scientific assistance, and other outside help, which make the location of a plant far away from such services a very questionable matter.

Industrialization generates further industrialization. Many related industries follow in the wake of a petrochemical plant. These vary: there are industries related to finished and consumer products and industries that supply the necessary plant services and equipment needed for the [illegible]. This in turn, of course, poses a problem now faced by the industrial estates: is this industrial growth best located near a community area or should industrial centres be located some distance away? The problem has no immediate answer. It is, to a large part, dependent on municipal planning, and the greatest abuses arise through lack of such planning.

Except for actual construction, a petrochemical plant does not require a large number of people for successful and adequate operation. Those employees required, however, must be skilled, and in some countries it will probably be necessary to provide the training programmes to teach the skills needed. It must be recognized that the petrochemical industry is a capital-intensive rather than a labour intensive industry. In a recent study conducted on the initiation of a practical-sized petrochemical complex, in this case one costing $40 million, the investment per employee was found to be of the order of $100,000. For this same complex, the number of permanent operating employees would be approximately 400. In contrast, the construction of this complex would require about 5,000 skilled and unskilled workers during periods of peak activity. In selecting a site, thought must be given to the availability of this size labour force during the initial or construction stage, and the social conditions resulting with the permanent employment of a greatly reduced number of people in the operation of the plant.

Other modifications in what would be best practice for developed nations may be made to suit conditions in developing nations without sacrificing the competitive strength of the petrochemical plants. But too much should not be expected, a modern industry cannot be built with too high a requirement for labour. It is the ability of modern industry to generate jobs in subordinate and satellite industry that is important here. The petroleum based products to be manufactured would have major outlets in the plastics, textiles, and synthetic rubber industries and involve all types of consumer goods production, from fabrication through finishing. These are all labour intensive applications.

IV. AVAILABILITY OF SERVICES

The utilities most necessary for the operation of a petrochemical plant are electricity, fuel, water, waste disposal systems and communications. These may all be taken for granted in any of the industrialized nations, but one or all could pose a considerable problem among the newly developed nations. The chemical industry requires large quantities of the various utilities.

Electrical power is generally generated by either hydro- or thermal-electric plants. The location of the site is strongly affected by the availability of power, as the chemical process industries are large users of energy. Power must not only be available in large quantity but must be highly reliable with all possible provisions made to prevent temporary break-down or discontinuation. For this reason, a petrochemical complex in a developing nation may consider building its own independent power supply, and not rely on existing systems. The absence of an adequate power supply is not a controlling factor in the location of a large petrochemical complex because by-product fuel from the complex will satisfy energy requirements. On the other hand, if cheap (i.e., hydro-electric) power is available, this may be an overriding reason for establishing a chemical complex. In the United States, the heavy concentration of industries in the Tennessee Valley Authority Region and around Niagara Falls, N.Y., testify to this fact.

Fresh water of sufficient and continuing high quality is also important to the chemical industry. The manufacture of chemicals uses large volumes of water. We have proven that the manufacture of polyethylene uses 6 cubic metres of water per metric ton of product; ethylene oxide uses over 40 cubic metres per metric ton and synthetic rubber uses over 100 cubic metres of water per ton. In one of the industrialized countries, the lack of a satisfactory water supply would be ample reason to disqualify the site. In many of the developing nations, however, it is recognized that the general lack of fresh water may be an extremely serious problem. Therefore, means must be found to resolve this water problem rather than conclude that the site is unacceptable for industrialization. The quality of the water is important not only for reasons of health but because of the possibility of corrosion of equipment. Where water is of low quality, additional facilities and equipment would be necessary for purification. Sea water, when available, can be, and is being used. Special precautions must be taken when using sea water to prevent excessive corrosion of equipment. Another means to conserve water is to employ air cooling methods. Any water supply should be adequate for sanitary demands and fire protection. Consideration and planning must also be given to the future as well as to present water needs.

In a petrochemical plant with many possible waste by-products, an adequate sewerage and drainage system must be made available. This material waste must be removed not only because of its volume but also for health reasons. Drainage systems usually do not exist or cannot be installed and the open-plant-waste type of system installed drains into lakes and rivers. This method can be tolerated for a short period of time, after which a waste treatment system must be installed. This is not only for health and safety, but economic reasons. Other industries dependent on the purity of surrounding water are affected, such as fishing, light manufacturing etc. Air and water pollution must be thought of in terms of the future; accumulation of even small unsanitary situations can create havoc in later years with growing population and urbanization. Another physical consideration relates to the prevailing winds and atmospheric conditions. Effluent from petrochemical plants is heavier than air and, at times, toxic. Thus, it becomes important to locate in an area where vapours are readily dispersed and carried away. The industrialized nations have learned this lesson through bitter experience; the developing countries need not make these mistakes.

Without the availability of each of these items, no petrochemical plant can operate. Every single one of these services and facilities must be ready by the time the plant is ready to begin operations. It is of no advantage whatsoever to have an excellent water and sewerage system if the power cannot be turned on. Therefore, the timing of the availability of all the utilities is a major part of plant location and planning. In too many cases over-optimism in drawing schedules and in guaranteeing services has resulted in plants that are unable to function because not all facilities were available simultaneously. This unfortunately has also occurred in the industrialized nations; it is, however, considerably more prevalent among the newly developed nations where the natural enthusiasm over the prospects for a developing industry may be stronger than realism in the consideration of money, man-power and time.

V. Physical conditions

The actual physical condition of a site is important. If all other factors of accessibility and availability of services are met, the cost of leveling a site, or piling, or of coping with foundation problems would be minor as compared with the entire project. While the levelness of a site is important, and the factors of drainage, rockiness, etc. must also be taken into consideration, these can all be corrected at some cost. It would, for example, be much less expensive to level a site than to attempt to build a power supply or bring power to an area where none exists. Nevertheless [illegible] recognized that chemical plant equipment [illegible] and needs good foundations. Since [illegible] add 10 per cent to the over-all project cost [illegible] to look for a site that has good earth bearing properties, if such can be found.

In many developing countries [illegible] extreme. Conditions such as heat, [illegible] monsoons, earthquakes, extremes of temperature [illegible] exist. Proper precautions must [illegible] these inherent problems.

One extreme site development [illegible] bility of flooding. In most countries [illegible] and expensive problem [illegible]. Another [illegible] must be recognized is the possible [illegible] atmosphere. This is particularly [illegible] locations and the prevailing wind [illegible]. The moist salt-laden air can wreck [illegible] equipment and structures. However, [illegible] not insurmountable and [illegible] precautions and design can be [illegible] to minimize the effect. This would [illegible] physical phenomena such as sandstorms and [illegible]

Social services such as housing, health, [illegible] and commutation will not be considered [illegible] with the problem of building the petrochemical [illegible] these are relatively simple. These [illegible] when a plant is located near the consuming [illegible] they can also be readily installed in [illegible] It is only necessary that the requirement [illegible]

As can be seen from the foregoing, [illegible] answer to the question of where [illegible] Rather there is a combination [illegible] on the type of plant, the country in which [illegible] installed and the existing economy of that [illegible] advantage or disadvantage of one [illegible] into consideration and weighed against [illegible] tions of other sites, always keeping [illegible] riding importance of [illegible] accessibility to market.

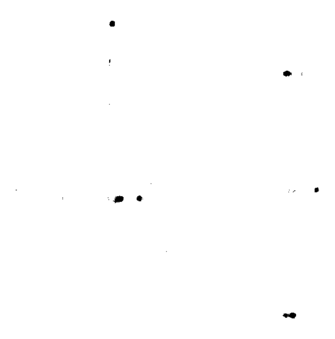
2. FACTORS INFLUENCING THE LOCATION OF A PETROCHEMICAL PLANT

P. C. [illegible], American Oil International Co., United States of America

A. INTRODUCTION

B[illegible] of the [illegible] factors involved in [illegible] location for a chemical plant [illegible] consider [illegible] effected the character of a private [illegible] and the petrochemical industry.

A[illegible] accept that there are major groups [illegible] interests affecting [illegible] company. The goals of these groups [illegible] considered in making the decisions of a private [illegible]. H[illegible] are going to discuss a private [illegible] by individual shareholders although [illegible] other types of companies. The concept [illegible] of a corporation in choosing [illegible] location and therefore the information I will [illegible] make this all important decision a sound one. A [illegible] of a corporation and eight of its major [illegible] would look something like this.



[illegible] Ma[illegible] affecting [illegible]

In general, all except perhaps the competitors are [illegible] stability and growth for the corporation [illegible] to assure continuation of the benefits they expect [illegible] from its operations.

The owners, both local and foreign, seek profitable operation adequate to pay them for the risk of long term investment of their money plus providing for future growth expansion to assure protection of their principal.

The customers seek lower product prices for products, constant improvement in quality with increasing supporting services and a reliable source of supply for their needs. The suppliers want a higher price for their raw material resources and a reliable growing market for their materials. The employees seek higher wages and improved working conditions plus the opportunity for promotion as abilities and new skills are acquired.

Competition exerts a powerful influence, seeking weakness in the corporate position in hopes of capturing a share of the market. The most effective technique is to establish a significant economic advantage.

Creditors seek to recover payments due for the monies or materials they have agreed to let the corporation use. National and local governments seek a larger income from taxation, encourage growth of worthwhile industry, and establish laws to prevent any one interest group from taking unfair advantage of the others. Society, having the best interests of the people in mind, seeks help from the corporation in improving their well being and encourages the corporation to produce a product which best serves the people's needs.

The most important duty of corporate management is to maintain a dynamic balance among the demands of these interest groups so as to assure perpetuation of each worthy corporate activity. Members of these interest groups are for the most part local people. Therefore, with each new plant location the corporation comes in contact with a new set of interest groups.

Management goals on entering business in a new area are designed to maintain support of the present and potential new interest groups. In general the goals would be to establish a viable commercial operation yielding adequate profit while serving an established but growing market with minimal threat of adverse moves either by competitors, employees, society or government.

It will be noted that between the corporation and the interest groups there is unanimity on the one hand as both seek to gain benefits through their community of interest. However, there is a dual relationship here in that both the corporation and all interest groups have competing claims as to what their proper share of the benefits might be.

It is important for any private corporation to recognize that in other countries there may be a somewhat different social and political philosophy. In considering an area basically oriented to government-owned plants, all parties should discourage a doctrinaire attitude and consider the potential possibilities of a compromise in ownership. Joint ownership with local people offers many ancillary advantages.

B. THE [illegible] OF THE PETROCHEMICAL INDUSTRY

Now let us turn our attention to the petrochemical industry in search of insight bearing on its choice of plant location. This is a business based on the chemistry [illegible] approaching [illegible] of [illegible] or [illegible] products [illegible]

There are four important factors which influence the petrochemical industry. These are shown in table 1.

Helped by the experience of petroleum refiners, the industry has learned to harness the most modern and highly efficient process technology. However, as noted by other speakers, the economy of size or scale is a significant factor which demands attention in this business when building a new process plant. As an example, to double the capacity of a small process plant on the drawing board requires only a 50 per cent increase in capital investment and 15 to 30 per cent more people to operate it. Therefore a plant built too small is vulnerable and may fail for lack of adequate profit or through competitive pressures from larger plants serving the same market area. Fortunately, there is a limit to the advantage of increasing size. It levels some[illegible] at each point where major items of equipment can be made no larger and duplication of items is needed for any further capacity increase.

This problem of scaling suggests that it certainly would not be desirable for each country to have its own fully fledged petrochemical industry. To do so would impose on local customers the unnecessary penalty of high prices supported by protective tariff barriers to keep the venture from being an economic failure.

The importance of the factor of raw material availability is illustrated by the ammonia segment of the fertilizer industry which has shown rapid growth as a phase of the petrochemical industry. The basic ingredients are hydrocarbon gases and air, and very recently there has been a technological improvement in the process which makes it possible to build smaller and yet competitive plants of around 300 tons a day if adequate raw materials are available locally. Here transportation cost is important.

The third item in table 1 is *market availability*.

Encouraged by its current interest groups, management of petrochemical companies are continually seeking new growth opportunities, and many firms have been attracted by the markets developing around the globe. The key to success and survival in the long run is to identify a market which, even though scattered over a broad area, is large enough to support an economic size plant. In early years much of the production may have to be exported to adjacent markets which are served competitively by [illegible]. With the passage of time [illegible] point how increasing demand [illegible] profitable market.

The last factor listed is transportation [illegible]

The [illegible] certain parts of the [illegible] are good examples of how transportation [illegible] of a location.

Transportation [illegible] ammonia production at a point not [illegible] economically feasible. The transportation of [illegible] phosphoric acid as against [illegible] is an example of a saving [illegible] weight of raw material.

The effect of physical form [illegible] ramifications. It is usually [illegible] rather than a solid [illegible] transport a solid rather than [illegible] either under high pressure or refrigerated.

Let us now [illegible] a location for a new plant [illegible] of discussion [illegible] of well defined stages [illegible] One way to define these stages [illegible] questions which management [illegible]

TABLE 1. FACTORS [illegible] THE PETROCHEMICAL [illegible]

1. Scale of operation
2. Raw material availability
3. Market availability
4. Transportation factors
   (a) Raw material transportation
   (b) Weight of raw material versus weight of final product
   (c) Physical form of raw material and final product

TABLE 2. WHERE [illegible]

Stage *I* In what region [illegible]
Stage *II* In what [illegible]
Stage *III* [illegible]
Stage *IV* The [illegible]

The reason for making this distinction of stages [illegible] the information requirements [illegible] important tend to shift [illegible] stage.

The primary consideration of the first stage [illegible] locate a market [illegible] run to support a [illegible] the petrochemical industry [illegible] of industrial [illegible] other industries whose business [illegible] chemical conversion, blending [illegible] marketing information sought [illegible] both current and historical information on the production, imports and consumption by end use of specific petrochemicals and likely substitutes. Since the existence of a market is the major key to success, accurate forecasts of this type is very important. As to the future potential market, management will be most interested in any firm plans which may affect the supply or demand situation. Both current and historical information is needed concerning the prices of these chemical commodities and it would be most helpful to know the point of manufacture for the material now serving this market area, if any.

I am presuming here that the market, at least in the early stages, extends beyond the boundaries of any one country so that information of the type mentioned (prices, production, consumption and origin of supply) would be desired from each of the countries, and preferably by industrial areas within each of these countries.

Other factors which will receive attention in this initial phase bear on the economic soundness of the contemplated venture. The availability of a convenient raw material source is self-evident; however, even more important is the availability of low-cost transportation for distribution of the finished product over a large market area.

Even at this early stage thoughts on plant location will begin to crystallize since usually it has to be on one of the main transportation arteries joining the raw material supply with the market. Economic incentives involving transportation costs of raw materials and products will tend to influence plant location either toward the raw material source or toward a central point relative to the market area. One peculiarity of the petrochemical industry is the value of by-products. Some processes require large volumes of raw material, converting only a small portion to finished products, and the remainder must be returned to an oil refinery to realize its best value. In this case, it is important that the petrochemical plant be closer to the refinery than to the market.

In this initial stage management faces the problem of convincing itself of the existence of a market it can penetrate without competitive disadvantage. These factors we have been discussing will continue to be influential in subsequent stages of the decision process used by management in selecting a plant location.

In the second stage let us consider the factors of importance in choosing between the countries within the marketing region as shown in table 3.

TABLE 3. FACTORS INFLUENCING THE CHOICE OF COUNTRY

1. Political and economic stability
2. Freedom of entry and repatriation of capital
3. Government policies on property rights and ownership of businesses and real property

Since stability is an important consideration to most interest groups, the economic and political stability of the countries will be considered. The second factors encouraging to private enterprise are the freedom to bring in and repatriate capital. The third factor is adequacy of government policies regarding property rights and ownership of business.

Next most important after the factors in table 3 is the relative size of the potential market within one country versus the others. In the interest of a strong competitive position in the long run, it is logical that the plant should be located as close as possible to the major market concentration. Where two adjacent countries offer the same level of demand today, the judgment may rest on the indicated future potential or the general growth of industrial development during recent years.

In order to have a basis for judgment, it is desirable to have the following data indicated:

1. Domestic production, if any
2. Imports
3. Exports

The petrochemical industry is often dependent to a large degree for its raw materials on either sources of natural gas, LPG, or selected streams purchased from petroleum refiners. Therefore, information will be needed on these sources and particularly the location of refineries, their crude run capacities, and the types of unit operations in use. Statistics on the chemical and related industries would also be helpful, indicating their location, the products made, and installed capacities.

In order to select the country in which to locate the plant, information on the following points will also be sought:

TABLE 4

1. Data on the work force
2. Employment practices
3. Availability of local capital
4. Availability of secondary resources

In order to select a country, it is desirable to know the size of the work force and its distribution in agriculture, government employment, etc. It is also important to be informed on wage rates, benefits expected and other employment practices.

The availability of local capital can be important if downstream industrial growth is needed to sell a product. For example, it is proposed to install a 5,000-ton per year polystyrene plant in an area. One question to answer is whether there is enough local capital to finance the fabrication facilities. It may also be important if it is desirable to have the participation of nationals of that country in the business.

Secondary resources such as the abundance of water (potable and process) and the availability of adequate electrical energy are also of importance.

Since so much depends on the accuracy of forecasting future demand within each of the countries, there will be a tendency for management to bring in specialists or consultants to help them in this area. This group would be vitally interested in the general economic trends for each of the countries. Helpful information would include such items as the value of national production *per capita*, industrial production statistics, and even information on the national fiscal policy as it relates to inflationary trends.

By the time the third stage has been reached the question will be, "In what area within the country shall the plant be located?" If economy requires the plant be near a refinery, this could be a dominant factor

However, if such a dominant factor is not present then the factors shown in table 5 will be important

TABLE 5. FACTORS INFLUENCING PLANT LOCATION

1. Convenience in serving the domestic and export markets
2. Adequacy of labour force
3. Cost of raw materials
4. Availability of secondary resources
5. Availability of industrial sites
6. Climatic conditions

The area chosen must offer convenience in serving the domestic market while still retaining the ability to reach the export market with low-cost transportation. The product volumes involved in petrochemical plants are far smaller than most people realize – many times less than for an oil refinery. Separate port facilities and long pipelines simply cannot be justified. The movements of petrochemical products must therefore rely on convenience to existing port, rail, and highway facilities. For most petrochemicals, the largest shipment might be a bargeload for inland water shipment, or about 150 tons. It is a rare case that involves a significant load either for a ship or a tanker. For some products, which are corrosive or require insulation, special transportation equipment will be required. Almost without exception, purity of chemical products requires careful handling to prevent contamination with other material. To store exported product near the customer, tankage terminals and warehouses will either be rented or built at central points throughout the market region.

By this stage, some weight must be given to the availability of skilled labour since most of the workers in a petrochemical plant are hired for the skills they bring or their ability to acquire new skills. Beyond their immediate availability, consideration might be given to existing training facilities and qualified instructors. Local services such as hospitals, schools and churches will also be considered. A new consideration at this point would be the availability and cost of secondary resources such as water supply, fuel and power. Petrochemical operations normally require significant quantities of fresh water, which may be an important consideration. Fuel is usually not a serious problem since the basic raw material sources as well as some of the by-products can provide fuel. Where the process requirements call for large volumes of steam, the economics [illegible] provide its own power at a cost competitive with outside sources.

Climatic conditions will have an impact on the cost of the plant and doubtless the efficiency of the operation. As a final point, there must be some industrial sites available within the area.

In the fourth and final stage, a specific site is chosen weighing all criteria previously mentioned plus a few new ones. Primary factors will be the cost of the land and the cost of doing business at each of the sites. The site must be accessible to a potential pool of employees. It also should permit construction of a low-cost plant. Factors involving plant investment include the land, water, the soil characteristics, the need for dykes to protect against floods, the cost of tying in to the transportation system and secondary resources (water, fuel and power), any requirements relative to disposal of waste product and sewage, and finally, the security requirements for the plant.

This completes our discussion of the factors we consider important to understanding what influences selection of a plant location. But let us review it briefly. First, we attempted to emphasize the people involved and their goals relative to the corporation seeking a new site. In describing a private corporation and its management, we have attempted to pass on to you a better understanding of their motivation and thinking. In dwelling on the problem of plant economies of scale as a characteristic of the petrochemical industry, we have attempted to suggest its impact on company strategies. Finally, we followed a step-wise analysis leading to the selection of a specific plant site, and in so doing placed emphasis on why certain key information is sought at each stage along the way.

In conclusion, our major point is that the problems of finding a market for the product are dominant for the petrochemical industry because of its large scale process technology. It is concise information pertaining to the advantages of serving a specific market that will receive the broadest attention. We willingly admit that the collection of these and the other data requested presents a major effort on the part of any country. However, we believe that a well-documented, carefully prepared set of facts will attract attention [illegible] a desirable place to locate new petrochemical [illegible]

3. THE LOCATION OF PETROCHEMICAL PLANTS IN IRAN

The Iranian Participants, Iran

I. Introduction

The relative desirability of possible plant locations hinges upon two considerations: the cost or difficulty of production itself at any given location and the cost or difficulty of bridging the distances between any given location and its sources of materials and markets. Thus the choice of a desirable location for any type of business is determined by weighing the relative advantages of possible sites in terms of differences in operating costs plus differences in the transfer costs that may be involved in collecting the necessary materials and in marketing the products. In some operations, a single consideration may turn the balance, while in others the same factor may not apply at all.

It should also be remembered that cost alone is not the only or even at times the most important plant location consideration. Besides company policies, many tangible and intangible items, such as type of community and climate, may become important.

Selection of a spot for a petrochemical plant (or plants) requires the careful weighing of a number of interrelated factors. Production and distribution costs involve consideration of the sources of materials, fuel and power; availability of labour; transportation facilities and costs; and the nature, location and extent of the market. Organizational factors can be important, especially as to the extent to which operations can be integrated with related processes. It will be realized from the foregoing that Iran's petrochemical plants should either be located in the South, where there is an abundance of raw materials, or in the North where the markets are centred.

II. Discussion

In considering the location of the petrochemical plants it is necessary to:

(*a*) Select several specific regions which would be economically desirable;

(*b*) Make a detailed cost study of these locations and determine the most advantageous one.

The procedure employed in selecting specific regions for intensive location study is essentially a negative mechanism, its prime aim is to eliminate areas from consideration by successive exclusion. For example, locations unsuitable because of topography may be eliminated. From the remaining areas, one may discard those with inadequate access to transport facilities. Various other requirements can be imposed and the eligible areas further restricted on each examination until there emerge sites which have passed all requirements.

A study carried out recently proposed that Iran's petrochemical plants should be located near one of the following places:

(*a*) Tehran;

(*b*) Abadan;

(*c*) Ahwaz;

(*d*) The Agha Jari area.

A further possibility which could be considered for social reasons is to locate the plants near one of the depleting oil fields — for example Masjid-i-Suleiman — and so provide employment in these areas when the fields cease production.

The problem of selecting one of the above locations can best be treated by listing the advantages and disadvantages of each location, then listing the various cases to be studied in the light of a number of other factors associated with each location. Finally, the economics of each location can be evaluated and compared.

A. *Ahwaz*

1. *Advantages*

(*a*) It is situated on the Khorramshahr-Tehran railway and road;

(*b*) It is a sizable town to which it would be desirable, for social reasons, to attract more industries;

(*c*) The real price of fuel gas would be very low as the units would be near the Ahwaz oil field;

(*d*) Electricity could be obtained from the Dez Dam installations, which are capable of producing much more electricity than can be used in the South;

(*e*) Ahwaz is sufficiently near to the southern ports to enable excess products to be exported economically. Even for ammonia plants designed to export all their production, the difference between the feasibility of a plant at Bandar Mashur and a plant at Ahwaz is negligible, because the effect of the cost of piping gas to Bandar Mashur is almost the same as the effect of the cost of transporting the finished products from Ahwaz to the coast;

(*f*) The cost of installing the plants will be less at Ahwaz than at Tehran due to the shorter distance over which the imported equipment must be transported. However, this will be offset partly by the fact that due to the higher wet bulb temperature at Ahwaz the coolers, condensers and compressors will be larger and more expensive;

(*g*) Transportation by barges on the Karun river is possible;

(*h*) Water is abundantly available;

(*i*) Housing facilities are available;

(*j*) It is important not to concentrate all new industrial developments in Northern Iran;

(*k*) Natural gas which would otherwise be wasted would be utilized.

2. *Disadvantages*

(*a*) The major part of the products would be consumed in Northern Iran, the cost of transporting (finished products) being approximately $ T 26. This has a marked effect on the profitability of the complex as far as the output for the home market is concerned;

(*b*) The disagreeable climate;

(*c*) Butane and propane are required for the process feed, and the cost of separating these from Ahwaz gas would be more expensive than from refinery gas at Abadan or Teheran unless a market could be found for the condensate which would unavoidably be produced at the same time.

B. *Abadan*

1. *Advantages*

(*a*) Presence of existing facilities for utilities production, and of housing and other facilities.

(*b*) Availability of certain hydrocarbons not available elsewhere in Iran and notably

(i) Propylene and butylene from the catalytic cracker,

(ii) A C_6 cut coming from the superfractionators which is extremely well suited to benzene production.

(*c*) Presence in Abadan of well-qualified operating personnel.

2. *Disadvantages*

(*a*) For products for the internal market, there are even greater transport disadvantages than in the case of Ahwaz,

(*b*) The very disagreeable climate.

(*c*) It may not be considered desirable to expand the already enormous operations at Abadan. In view of this, production at Abadan could only be recommended for those products in respect of which advantages due to the availability of certain hydrocarbons were preponderant.

(*d*) The absence of rail and road connexions.

C. *Tehran*

1. *Advantages*

(*a*) Low transport cost for end-products, most of which are consumed in the Tehran area and Northern Iran;

(*b*) If a refinery is installed near Tehran, this could result in a diminished investment, as facilities such as some of the drainage, fire protection, etc. could be common to the refinery and the petrochemical plant.

2. *Disadvantages*

(*a*) Desirability of encouraging industry in parts of Iran which are less developed than Tehran.

(*b*) Need to install electricity generation facilities.

(*c*) Difficulty of operating a large scale export venture based on Tehran.

D. *Agha Jari area*

1. *Advantages*

(*a*) Proximity of port facilities (Bandar Mashur)

(*b*) Availability of housing facilities and social services.

2. *Disadvantages*

(*a*) Need to construct a railway linking the plant to the Bandar Shapour Tehran railway.

(*b*) Increased transport costs for products intended for the home market.

(*c*) Arduous climate,

(*d*) Water would have to be piped from a long distance.

III. VARIANTS STUDIED FOR EACH LOCATION

Such items as the price to be charged for fuel are affected by the question of whether the fuel is of virtually zero value because it is unsaleable, or if it is being diverted from a use where it could normally be sold. Similarly, the question of whether electricity is generated at the complex or purchased from the existing facilities can have a significant effect. The following cases have been separately considered:

Case 1 Plants installed at Tehran assuming that excess fuel will be available.

Case 2 Plants installed at Tehran but with no excess fuel available.

Case 3 Plants installed at Abadan with electricity purchased instead of being generated.

Case 4 Plants installed at Ahwaz.

Case 5 Plants installed at Ahwaz with electricity being purchased from the Dez Dam installations.

Case 6 Plants installed at Agha Jari.

Case 7 Plants installed at Agha Jari with electricity purchased from the Dez Dam Authorities.

The relative merits of the above cases are summarized in tables 1 and 2 below.

TABLE 1. IRAN'S PETROCHEMICAL COMPLEX
EFFECT OF LOCATION ON OVER-ALL INVESTMENT
(Hypothetical case)

Location	*Case 1, Tehran*	*Case 2, Tehran*	*Case 3, Abadan*	*Case 4, Ahwaz*	*Case 5, Ahwaz*	*Case 6, Agha Jari*	*Case 7, Agha Jari*
				(in US dollars)			
Basic investment	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Reduction for purchased electricity			8.55		8.55		- 8.55
Cost of electricity supply lines		—			—	—	1.32
Investment for installing railway						13.20	13.20
Investment for Housing		—	7.02	7.02	7.02		—
Investment for gas plant				3.89	3.89	3.89	3.89
TOTAL INVESTMENT	100.0	100.0	98.47	110.91	102.36	117.09	109.86

TABLE 2. IRAN'S PETROCHEMICAL COMPLEX
EFFECT OF LOCATION ON CASH FLOW AND PROFITABILITY
(Hypothetical case)

Location	*Case 1, Tehran*	*Case 2, Tehran*	*Case 3, Abadan*	*Case 4, Ahwaz*	*Case 5, Ahwaz*	*Case 6, Agha Jari*	*Case 7, Agha Jari*
				(in US dollars)			
Income	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Expenses							
Basic expenses	74.70	74.70	74.70	74.70	74.70	74.70	74.70
Additional cost of fuel		5.5	0.21	0.63	0.31	0.63	0.31
Effect of purchased electricity			2.01		0.68		0.68
Annual housing costs			1.02	1.02	1.02		
Net effect of gas plant				0.36	0.36	0.36	- 0.36
Additional transport costs			1.74	1.1	1.1	2.38	2.38
TOTAL EXPENSES	74.70	80.20	79.68	77.09	76.09	77.35	76.35
Profit	25.3	19.8	20.32	22.91	23.91	22.65	23.65
Cash flow	50.0	44.6	46.7	48.6	47.5	48.3	47.1

Note (*) Cases 3-5 and 7 are based on purchased electricity. (*) [illegible] and benzene producing units are excluded.

IV. CONCLUSIONS

In considering the relative investments shown in table 1 it will be noted that although the Abadan location appears to be the cheapest, the difference between Tehran, Abadan and Ahwaz (without electricity generation) is not large. This is particularly true if one considers that, even if in theory no gas plant is needed at Tehran or Abadan, some investment will be necessary for separating the gas streams at these locations, and this will be reflected in the price at which these streams would be sold. If housing is not charged to the project at Ahwaz, or if it is charged to the project at Tehran, the profitability situation would tip in favour of Ahwaz. It may very well be argued that it is not justifiable to charge housing which is an increase in the country's [illegible] to the cost of a petrochemical project. Whatever view may be taken of this, over-all investment, except in the case of Agha Jari, does not appear to be a determining factor.

It is seen from table 2 that Abadan and Ahwaz show relatively favourable cash flow, compared with Tehran and Agha Jari. In this respect Ahwaz is rather more favourable than Abadan. In considering the relative merits of locations at Abadan or Ahwaz, despite the similarity of investment and profitability of both places, other factors, such as the complete independence of an Ahwaz operation from existing industrial plants and other social factors, would tend to result in preference being given to Ahwaz.

In considering Ahwaz over Tehran, it should be noted that although on the surface Tehran might appear marginally more attractive on a strictly profit basis, this is only true if:

(*a*) Housing is not charged to the project at Tehran;

(*b*) Fuel is available at a very low cost;

(*c*) Rail transport charges remain at their present level.

If it were possible to negotiate lower transport rates this would materially affect the problem. Moreover, if export possibilities are taken into consideration for certain products, it will be easier to export them from Ahwaz than Tehran.

If the closeness of the timing that will be necessary to complete a major refinery and a large petrochemical complex at the same time and on the same site is considered, together with the financial consequences which would result from failure in this respect, then it appears that the Ahwaz location is more favourable than the Tehran one.

4. THE EVOLVING PATTERN OF THE PETROCHEMICAL INDUSTRY IN INDIA, WITH PARTICULAR REFERENCE TO THE GUJARAT AND BOMBAY REGIONS

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[*Summary*. This is a review paper which gives an outline of the present and future trends of the petrochemical industry in India, with particular reference to the Gujarat and Bombay regions.]

The petrochemical industry, meaning thereby the large-scale production of various primary and derived organic chemicals starting from petroleum feed-stocks in well defined, modern plants, has not yet commenced in India. No doubt, there are industries in the country such as polyethylene, SB rubber, PVC etc. which are based on fermentation alcohol, coal tar benzene and carbide.

Shortly, we may have a naphtha-based 33,000 tons per year capacity methanol plant in Bombay operating as a part of a fertilizer project. This unit, perhaps, will be the first truly petrochemical unit in India. An Indian affiliate of a foreign company operating in Bombay is busy putting up a naphtha cracker unit to meet the requirements of ethylene for its own polyethylene plant as well as for other requirements. This unit then is likely to be the second truly petrochemical operation. All the other petrochemical projects both in the private and the public sector are in various stages of planning.

However, bulk organic and inorganic chemicals are being made in the country, either from Indian raw materials like fermentation alcohol, carbide coke oven by-products etc., or by importing the intermediates. The following table shows the position regarding some of the important organic and inorganic chemicals that are being produced in the country.

TABLE 1

S. N.	Article	Accounting unit	Third plan targets	Production figures in the years			Fourth plan targets	Total licenced capacity mid '63
				1961	1962	1963		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	*Alcohol and organics*							
	Acetic acid	Tons	29,000	3,659.0	4,767		57,000	18,186
	Acetone	Tons	9,500	759.0	560		18,000	11,460
	Acetic anhydride	Tons		3,188.0	2,525		..	5,220
	Alcohol, etayl	Tons	200,000	117,280.0	127,120	131,656	315,000	...
	(a) Absolute	Mn litres		53.8	53.6	25.3	..	...
	(b) Rectified	Mn. litres		50.7	58.0	84.61	—	..
	(c) Denatured	Mn litres		42.1	47.3	55.66		
	Butyl acetate	Tons		152.0	1,060			4,000
	Butyl alcohol	Tons		252.0	893			1,600
	Ethyl acetate	Tons		356.0	300		..	900
	Formaldehyde	Tons			1,401		..	13,200
2	*Insecticides and plastics chemicals*							
	BHC (Tech.)	Tons	15,000	4,631.0	4,659		25,000	—
	DDT (Tech.)	Tons	6,000	2,824.0	2,448		9,000	—
	Ethylene dibromide	Tons		46.0	—		—	369
3	*Moulding powder-resins*							
	(1) Phenol formaldehyde	Tons	6,000	2,111.0	2,283	2,994.1	12,000	—
	(2) Polyethylene (high and low density)	Tons	36,000	5,[illegible].0	7,777	7,[illegible]	120,000	37,500
	(3) Polystyrene	Tons	20,000	3,404.0	3,734	4,900	50,000	..
	(4) PVC resins compositions	Tons	30,000	917.0	2,563	3,100	110,000	62,000
	(5) Urea formaldehyde	Tons	3,000	433.0	631	975	6,000	2,000
	Phenolic laminates	Tons	—	[illegible]	1,657	1,700	—	—
	Plastic moulded goods	Mn. lb.		[illegible]	903.1	...	—	—
	Polythene films and flat tubings	Tons		1,975.0	2,013	—	—	—
	PVC sheets (unsupported)	Tons	—	1,400.0	1,725	—	—	—

TABLE 1 *(continued)*

Sl. No	Article	Accounting unit	Third plan targets	Production figures in the years			Fourth plan targets	Total licenced capacity, mid.'63
				1961	1962	1963		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
4.	***Dyes and explosives***							
	Azodyes	Tons	—	1,243	1,315	846.9	–	
	Basic dyes	Tons	...	89	63			038
	Fast colour dyes	Tons		391	350	—	..	
	Fast colour salts	Tons	—	46	21	...		1,535
	Naphthols	Tons	—	993	967	613.7		
	Optical bleaching agents	Tons		177	151.2	223.2		1,550
	Organic pigments	Tons	—	218	260	—		453
	Rapid fast and rapidogen colours	Tons	—	129	163	—	—	1,058
	Solubilized vats	Tons	...	75	73	109.6	—	310
	Sulphur black	Tons	–	1,235	1,316	1,716.5		320
	Vat dyes	Tons	-	510	475			2,575
	Benzene	Kilo-litres	30,000	9,729 (12,645 tons)	7,120 (9,000 tons)		174,000 tons	2,258
	Creosote oil	Kilolitres		8,145	4,606			
	Crude coal tar	Thousands of tons	..	249	276		.	16.5 (Durgapur only)
	Motor benzol	Kilolitres		2,116	4,408			
	Naphthalene refined	Tons	20,000	719	936			-
	Solvent naphtha	Kilolitres	..	532	598		40,000	
	Toluene	Kilolitres	—	850	1,098			.
	Industrial explosives	Tons	—	9.0	14.2	...	...	...
5.	***Acids, fertilizers and other chemicals:***							
	Sodium hexa meta phosphate	Tons		638	645	696		
	Alum	Tons	..	4,495	4,210*			
	Aluminium sulphate							
	(*a*) Ferric	Tons		52,677	52,120			
	(*b*) Iron free	Tons	—	2,097	3,360*			150,000 approx
	Ammonium chloride	Tons	—	19,716	15,430*			
	Bichromates	Tons		5,237	6,640*			81,900
	Calcium chloride	Tons		684	940*			
	Hydrochloric acid	Tons		15,385	15,400	16,809		61,175
	Nitric acid	Tons	—	56,463	44,170	200,517		600,000 approx
	Phosphoric acid	Tons	—	2,238	4,470	8,320		14,000
	Sulphuric acid	Tons	422,400	445,000	568,296		2,000,000	1,200,000 approx
6.	***Synthetic fibres***							
	Rayon yarn							
	Acetate	Tons		2,034	1,640	4,306	15,000	
	Viscose	Tons		21,478	25,175	68,830	88,000	
	Cellulose film (cellophane)	Tons		2,974	1,877	..		
	Viscose staple fibre	Tons		25,997	32,068	70,809	150,000	
	Viscose tyre cord	Tons		.	610		21,000	2,100
	Nylon							
	Nylon (filament and staples)	Tons	•			1,410	28,000	6,000
	Nylon tyre yarn	Tons					13,000	
	Polyester	Tons					20,000	
	Polyacrylonitrile	Tons	-				10,000	4,000
	Polypropylene and poly-vinyl alcohol	Tons	6,000				20,000	
	Caprolactam	Tons	12,000				20,000	9,900
	Man-made fibre fabrics	Mn. yds.				712.0		
7.	***Plasticisers***	Tons	—	139.2	867.0	865.7		1,850
8.	***Synthetic detergents***	Tons		2,306.0	3,574.0		...	12,400

* Actual for nine months and estimated for three months.

It will be observed from this table that in almost every case there has been a shortfall in performance compared with the Third Plan targets. The Fourth Plan targets are also indicated, figures for which should be taken as tentative.

In order to meet the growing demand for the various organic chemicals, plastics and synthetic fibres, ambitious plans are under way to produce the basic and derived products from various existing and projected refineries as sources of basic raw materials.

It may be argued from the point of view of the cost of production that only one or two big complexes should be planned to meet the country's requirements. However, there have been several considerations which have made it desirable to plan a number of smaller complexes, dispersed regionally. India is a vast country measuring 2,500 miles from North to South and equal distance from West to East. Transport, therefore, constitutes an important factor in the ultimate cost of the product to the consumer, especially when products are classified hazardous.

Therefore, in locating complexes, proximity to markets has been borne in mind so that transport costs are kept low, resulting in lower ultimate cost to the consumer of the products. There have also been other considerations like balanced region-wise industrial growth in the country which will result in equal opportunities of employment throughout these regions. Connected with the petrochemical complexes will be the conversion plants of large, medium and small scale, providing vast opportunities of employment in the regions.

In Bombay, in the private sector from a 225,000 tons naphtha cracker, the following are proposed to be produced:

Item	Installed capacity in tons/annum
Ethylene	60,000
Ethylene dichloride	3,000
Vinyl chloride monomer	[illegible]
Polyvinyl chloride	30,000
Polyvinyl chloride products	5,000
Ethylene oxide	17,000
Ethylene glycol	10,000
Diethylene glycol	[illegible]
Polyethylene glycol	1,000
Propylene	15,000
Isopropanol	1,500
Methyl-isobutyl ketone	3,500
Acetone	11,000
[illegible] alcohol	[illegible]
Butanol	8,000
2-ethyl hexanol	8,000
Butadiene	[illegible]
Dicyclopentadiene	[illegible]
Benzene	14,000
[illegible]	2,500
High density polyethylene	20,000
Processed polyethylene products	5,000
Ziegler catalysts	[illegible]
Chlorine and related inorganic chemicals	[illegible]
Vinyl acetate monomer	8,000
Polyvinyl acetate	12,000

In addition, as already mentioned, another naphtha cracker in the private sector is being constructed to supply the raw materials required for the derived products already under production.

In Gujarat, associated with Gujarat refinery at Koyali, it is proposed to establish petrochemical units (A) linked with the refinery proper and (B) linked with the 200,000 tons/year naphtha cracker, respectively. The details, as far as is known, are given below.

A. Schemes for manufacture associated with refinery

Product	*Tons/year*	*Date of availability*	*Investment in Rs. crores*
Benzene	33,000	Mid 1966	
O-xylene	10,000	Early 1967	4.0
P-xylene	8,000	Late 1967	..
Dimethylphthalate	10,700		3.0
Cyclohexane	21,000	1967-68	0.45
Caprolactam	15,000		
Styrene			
Isobutane	30,000		
Isobutylene	22,690		
Butyl rubber*	30,000		..

* Based on 30,300 tons a year of isobutane to be separated from oil field gas and refinery gas plus isobutylene from naphtha cracker. Alternatively, a hydrocracker for 30,000 tons of isobutane, isobutylene dehydrogenation unit and butyl rubber plant.

B. Schemes linked with naphtha cracker—200,000 tons/year

Product	*Tons/year*	*Date of availability*	*Investment in Rs. crores*
Ethylene	75,000 to 80,000		9.7
Propylene	40,000		
Polyethylene	40,000		19.0
Vinyl chloride	32,000		3.0
Polyvinyl chloride	30,000		1.0
Styrene	25,000		5.2
Polystyrene	10,000		3.9
Polyacrylonitrile	15,000		5.2
Propylene tetramer	15,000		1.4
Butadiene	9,000		1.2
Normal butane	[illegible]		
Polybutadiene (isoprene)	30,000	[illegible]	15.4
Benzene	17,000		1.1
Dicyclopentadiene	10,000		0.3
Dodecyl benzene	15,000		0.8
Isobutane	[illegible]		
Butyl rubber	[illegible]		

The Gujarat scheme is expected to cost Rs. [illegible] crores, the investments being spread over as follows:

	Rs. crores
1967	[illegible]
[illegible]	[illegible]
1971	[illegible]

In the Calcutta region, the following is contemplated. The complex is recommended to be planned along with the Haldia Refinery and commence operations by 1970. Definite plans and locations have yet to be finalised.

Product	*Capacity in tons per annum*
Ethylene	110,000
Propylene	6,000
Normal butylene	14,000
Polyethylene	50,000
Ethanol	30,000
Ethylene oxide	30,000
E.P.T. Rubber	20,000
Polypropylene	15,000
Methyl-ethyl ketone	10,000
Polybutenes	7,000
Butadiene	12,000
Benzene	23,000

At Madras the following tentative phased programmes are contemplated: the complex is to be built in two stages, the first phase to commence operation by 1969.

Phase 1

Product	*Capacity in tons per annum*
Partial oxidation of naphtha	100,000
Acetylene	30,000
Vinyl chloride	64,000
Polyvinyl chloride	30,000
Methanol	40,000
Formaldehyde	40,000 to 50,000
Chlorine plant	
Oxygen plant	

Phase 2

Product	*Capacity in tons per annum*
Ethylene	100,000
Propylene	44,000
Polyethylene	64,000
Vinyl chloride	64,000
Styrene EPT rubber	
Polypropylene	
Oxo-alcohols	

In the following table are summarised the projected figures for the year 1970-71 for some of the important petrochemical-derived products.

It will be seen from what has been said above that the petrochemical industry in India is developing both in the private sector and in the public sector. However, in years to come, the public sector undertakings are likely to dominate the field. The public sector undertakings are stated to operate under bipartite and tripartite agreements. The bipartite agreements will be between the Government body and the foreign collaborator who offers technological know-how and financial participation in the basic units such as the naphtha cracker and its products. In the tripartite agreements, an Indian partner and the government body and its foreign collaborator will participate in units producing derived products, which are penultimate for the production of consumer goods. In other words the public sector will maintain interest in the operations right down the line. At least this is the likely pattern envisaged in Gujarat. This is in sharp contrast to the pattern that is evolving in Bombay, where the entire complex is privately owned and managed by multipartite agreements. This sort of pattern will have repercussions on the existing and pioneering manufacturing units based on non-petrochemical raw materials such as carbide and fermentation alcohol, which merit serious consideration.

Although not connected with the subject matter, an opportunity is taken here of referring to a point which is thought to be of cardinal importance to the developing countries. This is the need for the developing countries to export their products. The need of developing countries for foreign exchange is great and will grow as their programmes of industrialization expand. It is therefore logical that they should give attention to exporting their products to meet their growing need for foreign exchange. Some developed countries have at present regulations which prevent importation of products at prices lower than those prevailing domestically. In addition because of several unfavourable factors, costs of manufacture of some products in developing countries are higher, which also prevents them from exporting to the developed countries.

It is therefore felt that [illegible] the need of the developing countries for earning foreign exchange [illegible] regulations, wherever they exist, should be abolished.

TABLE 2

Product (thousands of tons)	[illegible] Internal	[illegible] Export	[illegible]	[illegible]	[illegible]
Polyethylene	[illegible]	20	120	5	[illegible]
Polypropylene	5				[illegible]
PVC Resin	94	1	100	62.0	[illegible]
Vinylchloride for PVC	[illegible]		115	[illegible]	[illegible]
Nylon	[illegible]		[illegible]	[illegible]	[illegible]
Polyester	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]		[illegible]
[illegible]	[illegible]		[illegible]		[illegible]
Synthetic rubber	1[illegible]		1[illegible]		[illegible]
Ethanol	[illegible]		[illegible]		[illegible]
Benzene	[illegible]	[illegible]	1[illegible]	[illegible]	[illegible]
Detergent alkylate	[illegible]		[illegible]		[illegible]

5. DEVELOPING THE PETROCHEMICAL POTENTIAL OF NORTH AFRICA AND THE PERSIAN GULF

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I. SUMMARY AND CONCLUSIONS

Access to markets on a duty-free or, at least, non-discriminatory basis and the ability to operate at competitive cost levels are two key factors in the development of the petrochemical potentials of producer nations.

The logical markets for a North African-based petrochemical complex would be largely the countries bordering on the Mediterranean and the East Atlantic, those for the Persian Gulf, the markets East of Suez. Many of these countries are either already industrialized or are in the process of building up their own industries. For this reason, a petrochemical enterprise in North Africa or on the Persian Gulf could most usefully be directed, at least initially, towards the manufacture of basic intermediates, such as synthetic ammonia, rather than finished products. The latter would directly conflict with existing interests in the very markets on which such a venture would have to rely for most of its outlet. A properly conceived project for the manufacture of intermediates, on the other hand, could complement pending industrialization programmes of the consumer nations.

The mutuality of interest it would hold for producer and consumer country alike could provide a sound basis for an intra-regional arrangement. It would make possible considerable savings in over all cost. In certain cases, foreign currency requirements might also be reduced. This could be a particularly important consideration for such developing countries as India.

Burgeoning world fertilizer demand coupled with new concepts in the manufacture, handling and transportation of anhydrous ammonia would pave the way for the petrochemical upgrading of a sizable volume of natural gas, which is today being flared. Once a start has been made with a synthetic ammonia plant, the addition of other basic petrochemicals at later stages becomes a far easier proposition.

The price at which ammonia can be supplied from any given point is greatly affected by the magnitude of the investment called for and by the financing methods. Where ammonia manufacture is a pioneering industry, considerable investment may be needed not only for the processing units proper but also for utilities, auxiliaries and infrastructure. In developed industrial regions, such facilities and services are generally already available on a low-financing cost basis. Programmes to build up the infra-structure and low interest loans offered to attract new industry to lesser developed areas in Europe, as well as the use of municipal bonds to finance utilities, housing, site development etc. in the United States, are typical examples of what is being done elsewhere.

Tax environment and cost of available financing methods for off-sites and infra-structure are far more important parameters for the economic feasibility of a petrochemical complex in North Africa and the Persian Gulf than they are in industrialized nations with large and established home markets. These two elements could affect the price at which ammonia could be supplied from a plant located in a developing country by as much as $40 per metric ton, as is shown by various analyses of the principal cost factors of ammonia manufacture presented in the paper.

These studies demonstrate that, under the proper conditions, the economic feasibility of a 150,000-ton-per-year ammonia plant in North Africa looks promising, and that of a larger capacity even more so. It presupposes that access to European and Mediterranean markets can be gained on a duty-free or non-discriminatory basis, by virtue of treaties or membership in trade blocs. In the case of the Persian Gulf the feasibility of such projects would seem largely to hinge on the possibility of coming to an understanding with a country like India.

Estimates presented in the paper suggest that there is a basis for a potential mutuality of interest which merits further serious exploration. Such an intra-regional arrangement could become an important factor in the implementation of India's fertilizer programme and in achieving its targets at worthwhile savings in both time and cost.

II. INTRODUCTION

The gas flares that can be seen in the oil fields of the Middle East and North Africa point up a paradox of our petrochemical age dependent as it is upon low-cost energy and raw materials. Equally paradoxical is the fact that the availability of increasingly large quantities of such surplus gas notwithstanding, the industrialized nations of Western Europe and Asia are largely turning to light naphtha and other crude oil fractions to provide feed-stocks for their rapidly expanding petrochemical industries.

For the producer nations and for all who have a stake in their welfare, these paradoxes are of far more than academic interest. Indeed, they are burning questions in every sense of the word. The urgency of the problem how to turn such wasting resources into assets through petrochemicals, or otherwise is widely recognized, but, so far at least, progress towards a practical solution has been modest, at best.

The difficulties are certainly formidable, but hardly insurmountable. It is the intended purpose of this paper to contribute towards an understanding of the nature of the problems involved and to point the way to a positive and realistic approach towards their solution.

Much of the material presented herein is based upon numerous detailed feasibility studies including market surveys, engineering and locational studies carried out over a period of years for various projects in many parts of the world. The permission of the sponsors to use material relevant to the subject of this paper is gratefully acknowledged, as is the assistance received from other companies and individuals.

Although every care has been taken to ensure that the figures reflect, as nearly as is possible, practical conditions and the most up-to-date state of technology, individual cost items will obviously vary from case to case. The data are sufficiently representative, however, of conditions at most locations on the Persian Gulf and North Africa to provide a basis for producer nations to decide upon positive policies for the realization of their petrochemical potentials.

Wherever used in this paper, tons are metric tons of 1,000 kilos (about 2,200 pounds) rather than the short tons (2,000 pounds) commonly used in United States publications. Certain abbreviations employed, on the other hand, follow standard United States practice for example, M for a thousand and MM for a million. Thus, MCF stands for thousand cubic feet, $MM for millions of dollars etc.

III. SIGNIFICANCE AND CHARACTERISTICS OF THE PETROCHEMICAL INDUSTRY

There are today more than 1,000 petrochemical plants operating in the world. In addition, at least 315 new projects are known to be in various stages of planning. The number of existing units reflects a remarkable rate of growth; just five years ago a survey by *The Oil and Gas Journal* listed only [illegible]. What is more, capacity at many locations is being increased rapidly. The United States has 319 plants operating today, compared with [illegible] in 1959. The Canadian total mounted from [illegible] to 64 during the five-year period. Elsewhere, the number of facilities more than doubled, from 190 to [illegible] with Western Europe accounting for much of the gain. That area alone accounted for 130 plants in 1959; it now has [illegible] (1).

It is estimated that there are presently well over [illegible] different chemicals that can be made from petroleum hydrocarbons, and the number is increasing almost daily. These chemicals range from laboratory curiosities with such impressive names as 3,4-dihydro-2H-Pyran-2-carboxaldehyde to many of the now commonplace commodities, such as methanol, glycol, polyethylene, [illegible], styrene, butadiene etc.

Petrochemicals are different from other chemicals only in their raw material source, which is, as the name implies, of petroleum origin: crude oil, its fractions, natural gas liquids, LPG or natural gas. These petroleum raw materials can be converted into a relatively small number of basic building blocks from which, in a series of successive conversions, the abundant variety of chemicals and consumer products can be fashioned. The principal petrochemical building blocks are listed below.

Synthesis gas, which in its turn is the key to such products as ammonia, nitrogenous fertilizers, methanol and resins.

Acetylene, which is the origin of many well known chemicals, including acetaldehyde, plasticizer alcohol, polyvinyl chloride, and other plastics and synthetic rubbers.

Ethylene, which today is the largest volume basic petrochemical next only to ammonia. Current installed capacity in the United States exceeds nine billion pounds a year (2), a figure which is expected to be doubled if not tripled within the next decade. An equally impressive expansion of ethylene capacity is underway in Western Europe, and elsewhere. Ethylene is the starting material for innumerable chemicals, including the well known polyethylene plastics, ethyl alcohol, ethylene oxide, acetaldehyde, polyester fibres, and polyvinyl chloride plastics. It is also the principal component of du Pont's "Surlyn A" resins, the latest family of ionically cross-linked ethylene copolymers.

Propylene, which is the precursor to such well known plastics and chemicals as polypropylene, propylene oxide, isopropyl alcohol, acetone, acrylonitrile, detergents, etc.

Butylenes, which are known for their use as intermediates for butyl rubber, butadiene and butadiene based rubbers and plastics, secondary butyl alcohol, MEK, Nylon 66, etc.

Normal paraffins, which have gained recent attention as starting points for biodegradable detergents and as plasticizers for PVC.

Aromatics. The main members of this family are benzene, toluene, the xylenes and naphthalene, all significant base products for the manufacture of synthetic rubbers, plastics, synthetic fibres etc.

There is hardly a phase of modern life on which petrochemicals do not enter either directly or indirectly. The food we grow, the houses in which we live, the clothes we wear, the means of communication and transportation we use, all have clear petrochemical associations.

There are many factors which have contributed to the success of the petrochemical industry and its phenomenal growth, such as: abundant availability of raw materials, high and uniform standards of product quality and technological advances which have resulted in a series of process improvements and new products. However, the two that are perhaps most germane to the subject at hand are:

(a) The dependability and virtually unlimited expandability of supply of basic petrochemical intermediates at predictable prices. This has freed the industry from its former dependence for basic intermediates upon the vagaries of nature or the unrelated activities and growth rates of other industries. For example, the world was long dependent for its alcohol and acetone supply upon the fermentation of molasses, a natural product, and for its aromatics upon the activity of the steel industry. The attendant "feast or famine" supply situations and "prince and pauper" prices were not conducive to the programming of production or the commitment of many millions of dollars for new facilities by the consumer industries. The firm basis for programming of these customer industries which the advent of petrochemicals made possible produced a chain reaction multiplying manifold the impact on the economy.

(b) The low cost at which a wide variety of basic petrochemical "building blocks" can be provided. Such low cost levels, however, are possible only if operations are on a very large scale. Unit sizes have increased consistently. For instance, the average annual capacity of ethylene plants on the United States Gulf Coast, which was 150 million pounds in 1950 and 260 million pounds in 1960, is today almost 400 million pounds. Plants with capacities of over 900 million pounds a year are known to be in advanced stages of planning. Europe, where ethylene plants of 50,000 metric tons a year were once a common sight, is now building several three and four times that size. In synthetic ammonia, units of 50,000 tons a year, which once were considered adequate, are now confronted with several 150,000 tons per year competitors [illegible] which in its turn is dwarfed by that of other units now on the drafting board.

If one were to sum up the fundamental characteristics of the modern petrochemical industry, the picture would look somewhat as follows:

(a) Petrochemicals depend upon a sophisticated chemical processing industry for their outlets. In this respect the petrochemical sector is no different from the chemical industry as a whole, which is its own best customer. Numerous "downstream" conversions are needed and many transformations involved before petroleum-derived olefins, paraffins, aromatics or ammonia can reach the consumer as a garment, rubber tire or detergent, or the farmer as a fertilizer, plastic mulch or pesticide. Indeed, some chemicals never reach the ultimate consumer at all but are used up as solvents, cleaning agents and auxiliaries in industrial operations.

(b) The petrochemical industry is highly dynamic. Changes in process and product technology are frequent and often revolutionary, creating an unusual complexity of competitive forces and a high obsolescence factor in that:

(i) The same product can be made by different processes from more than one alternative raw material or basic building block. For instance, synthesis gas for ammonia or methanol can be made by partial oxidation, cracking, the methane-steam process, naphtha reforming etc. PVC and acetaldehyde can be derived from either acetylene or ethylene; acetylene and propylene compete in the manufacture of acrylonitrile etc.

(ii) A chemical may compete with many other chemicals or with natural products or in different markets for different uses. For instance, various synthetic rubbers, which compete with each other and with natural rubber, and oxo alcohols, which compete with Ziegler and other synthetic alcohols, as well as with the alcohols from coconut and tallow. Ethylene glycol competes with methanol in the anti-freeze market, with several polyols in the field of humectants and surface active agents and with nylon in synthetic fibres etc.

(c) The petrochemical industry is highly capital-intensive. For example, a conventional crude oil refinery can be built for $6 to $10 per annual ton of product. Even a more complex, so-called "complete refinery" would barely cost twice this much. By comparison, a synthetic ammonia plant will involve an annual investment of upwards of $50 per ton, even for a large (i.e. relatively low unit cost) plant erected in a highly industrialized country. The figure would be appreciably higher for smaller plants, especially if built in faraway locations. An ethylene plant will easily call for $150 to $200 per annual ton of productive capacity, even under favourable circumstances. Downstream investment to up-grade such ethylene to polyethylene, ethylene glycol or alcohol, moreover, would easily double this figure.

(d) The capital-intensive nature, high obsolescence factor, as well as the trend towards ever larger unit sizes combine to make petrochemical manufacture a high risk industry calling for a better-than-average rate of return. These factors also make unit cost of petrochemicals highly sensitive to the level of capacity at which a plant can be operated. This, in its turn, points to the vital importance of assuring sufficiently large markets to support an economically sized plant. For example, the plight in which the Australian petrochemical industry finds itself is too well known to need much elaboration. The special problems inherent in a small market were underrated and, more important, the quickening tempo of far-reaching modifications made overseas virtually outdated small facilities almost before they were off the drawing board (15).

IV. ALTERNATE USES OF NATURAL GAS AND CRITERIA FOR SELECTION OF BASIC PRODUCTS

Despite the fact that the United States boasts the world's largest natural gas based petrochemical industry, only a minor portion of the country's output of natural gas is consumed in this area. The overwhelming bulk is accounted for by the energy sector.

Petrochemical usage of natural gas is not reported separately but can be estimated fairly closely. On the basis of such estimates, it is calculated that about 270 thousand million cubic feet of methane were consumed as feed-stocks and fuel for petrochemicals in 1963. Close to 80 per cent of this amount was used for synthetic ammonia. In addition, about 117 thousand million cubic feet of natural gas were used in the manufacture of carbon black in that year, a use which has been declining with the trend towards oil blacks.

One must also take into account the quantities of ethane that were diverted to petrochemicals. Although ethane is non-condensable, the United States Bureau of Mines includes it under its classification "Natural Gas Liquids." According to the Bureau 990 million gallons of ethane, equivalent to 37 thousand million cubic feet, were extracted from natural gas in 1963. The Tariff Commission reports petrochemical use of a little over one billion pounds of ethane or about one-third the quantity extracted. There is reason to believe, however, that the Tariff Commission figure may be incomplete, due to the practice of some refiners and chemical plants to report finished petrochemicals rather than feedstocks. If the entire quantity of extracted ethane is considered to have gone into petrochemical channels, we thus arrive at an estimated total 1963 petrochemical usage, including carbon black, of 424 thousand million cubic feet of natural gas, or less than three per cent of the total consumption (see table 1).

The above leaves little doubt that the true impetus for growth of the natural gas industry in the United States has stemmed from the energy-hungry homes and factories of the populous North and North East more so than from petrochemical demand. An extensive network of pipelines has been built up to supply these markets, where gas must compete with other forms of energy, such as oil and coal. The cost of gas transmission, however, is appreciably higher per unit of energy than is the shipment of crude oil by pipeline or tanker. Depending upon pipeline diameters, tanker sizes etc., it may be from two to three times as expensive.

TABLE 1. END-USE PATTERN OF NATURAL GAS IN THE UNITED STATES IN 1963

Thousand million cubic feet

	Quantity	Per cent of total
Non-industrial		
Residential heating	[illegible]	24.5
Commercial heating	1,2[illegible]	8.7
TOTAL, above	4,847	33.2
Industrial		
Field use	2,0[illegible]	14.2
Refineries	7[illegible]	5.4
Pipeline fuel	424	2.9
Electric utilities	2,14[illegible]	14.6
Cement	180 (est.)	1.2
Other industrial	4,1[illegible] *	28.4
TOTAL, industrial	[illegible]	66.7
SUB-TOTAL, as reported by Bureau of Mines	14,601	99.9
Add		
Ethane extracted and reported by Bureau of Mines as "natural gas liquids"	37	.1
GRAND TOTAL	14,6[illegible]	100.0

Source: United States Bureau of Mines and Chemical Projects Associates estimates.

* Of which:

Petrochemical (non-fuel) [illegible] and feed	270
Carbon black	117
Sub-total	387
All ethane	37
Grand total, petrochemical uses	424

In order to be able to sell at a parity with oil in these consumer markets, therefore, natural gas must be priced at its point of production well below oil. For instance, in 1963 the average cost of natural gas and heavy fuel oil supplied to the electric utility industry in the New England States was 34.2¢ per MMBTU and 34.7¢ per MMBTU respectively. The corresponding figures for the Mid-Atlantic States were 33.9¢ per MMBTU for gas and 32.1¢ per MMBTU for oil.[4] By comparison, the average value of natural gas at the wellhead for that year as reported by the Bureau of Mines was 15.8¢ per MCF (or per MMBTU assuming an average of 1,000 BTU/CF), and of domestic crude $2.89 per barrel or 49¢ per MMBTU.

The availability of gas at prices considerably below oil parity has understandably proved a powerful attraction to locate petrochemical basics plants (and other industries) in such areas as Texas and Louisiana. Today about two-thirds of the petrochemical capacity of the United States is to be found on the Gulf Coast.

The situation on the Persian Gulf and in North Africa is in some ways reminiscent of that which existed on the United States Gulf Coast before a practical solution was found to bring the gas or its products to market. As in the case of the Gulf Coast, there is a considerable geographic distance between hydrocarbon resources and the potentially large-volume energy and chemical markets. However, access to these markets is far more costly, complicated as it is by water and international barriers. Recent discoveries of unusually large gas deposits, such as the Dutch finds in the very heart of some of these consumer markets, moreover, compound the problem.

To pipeline North African or Middle East gas to Europe presents numerous technological and other problems which remain to be solved. The technical feasibility of transporting it by special tanker in liquid state (at −258°F) has been demonstrated. However, for a distance of about 1,000 miles, the cost may run as high as 40-50¢ per MMBTU, of which the cost of liquefaction constitutes the lion's share.[5] This liquefaction does not upgrade the gas but is merely necessary to reduce it to a transportable form and, as such, is somewhat comparable to the cost of packaging. The same MMBTU petrochemically upgraded would have produced about 55 pounds of ammonia or more than 90 pounds of urea. Transported in either of these forms over the same distance, the cost would have been about 10-15¢ in terms of MMBTU natural gas equivalent. Transformation into methanol, a liquid, would reduce the comparable shipping cost to less than 10¢ per MMBTU.

The relatively high cost of moving North African and Persian Gulf gas, as such, to their natural markets merely serves to emphasize the significance of a petro-

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[5] The liquefaction cost being a constant element, cost would not increase proportionally to the shipping distance.

chemically oriented solution for the producer nations in this part of the world, at least for the immediate future. Nevertheless, petrochemicals alone will not be able to solve the problem of "flare gas" entirely, although they would provide an important step in the right direction.

The Middle East currently produces close to 7.5 million barrels per day of crude oil and North Africa about 1.5 million barrels per day. Gas/oil ratios will, of course, vary from field to field and so will flare gas/oil ratios, as some gas will be consumed in field operations, sold for further processing or plant fuel, or will be reinjected into the crude oil reservoir. Allowing for these factors, the probable flare gas/oil ratio in both areas may average somewhere around 500 CF per barrel. On this basis, we arrive at a combined annual quantity of flare gas of about 1,600 thousand million cubic feet, and this quantity may be expected to increase as crude oil production develops. It would take a petrochemical industry nearly four times the size of that in the United States to provide useful outlets for this much gas.

Complicating the problem for the producer nations is the fact that petrochemical use of natural gas would, directly or indirectly, compete with the outlets for their crude oil. The rapidly expanding chemical industries in Europe, Japan and India are turning increasingly to light naphtha and other liquid feed-stocks. The Organization of European Economic Co-operation and Development (OEECD) estimates (5) showed that Europe alone used close to five millions tons of light naphtha and other liquid feed-stocks in 1963 for such chemical building blocks as ethylene, propylene, acetylene, butenes, butadiene, and, last but not least, synthetic ammonia. To operate the then existing plants at capacity (a situation which essentially prevails in 1964) would have raised the figure to about 7.5 million tons. At least one half of this is believed to be in the form of light naphtha. In addition, an estimated 1.5-2 million tons of naphtha will be converted in Europe to town gas in 1964.

Chemical and town gas demand in Europe for light naphtha alone is expected to exceed the 10-million-ton-a-year mark well before 1970, barring any significant inroads by Dutch gas. Assuming the average light naphtha content of crude at 20 per cent, the above figure would translate to a crude oil equivalent of 50 million tons a year, or 10 per cent of the combined output of the Middle East and North Africa at current rates.

The point of potential competition between natural gas and crude oil poses an intriguing problem, worthy of a more thorough analysis than is possible within the scope of this paper. If, instead, it seems to be somewhat glossed over here, it is largely due to the following considerations:

(*a*) The very magnitude of the quantities of natural gas that are being flared. Any reasonable solution which may contribute to minimizing such waste appears well worth a sacrifice on the part of the producer country, if not of the world as a whole.

(*b*) The magnitude of the world's almost unlimited need for fertilizers, suggesting that the use of natural gas for this purpose will supplement rather than supplant material produced from liquid hydrocarbons.

It is, perhaps, worthwhile to consider this latter point briefly, although it will be discussed in greater detail later on. One of the largest volume petrochemicals made from natural gas is ammonia, which is the basis for most nitrogenous fertilizers. A ton of ammonia, used as fertilizer, equals twelve acres of good farm land and can thus help resolve the critical problem of how to feed the one billion human beings still suffering from malnutrition. In almost all of the undernourished countries, there is sufficient land under cultivation which, with adequate fertilization, could yield enough to feed their population. Actually, even if only a small fraction of the flare gas of the Middle East and North Africa were converted to ammonia, it would provide more fertilizer than would be needed.

Dr Raymond Ewell, Vice-President for Research at the State University of New York, has estimated that, as a desirable minimum goal, Asia, Africa and Latin America would require 15 million tons of plant nutrients by 1970 and double that amount by 1980. This compares with a consumption of 3 million tons in 1960-61 and, probably, about 4 million tons in 1963-1964. (6)

Until fertilizer availability begins to approach figures of the magnitude suggested, concern about the displacement of crude oil by natural gas, at least in fertilizer manufacture, appears premature, if not out of place. From the point of view of the needy nations, therefore, the manufacture of ammonia would rank high, if not uppermost.

However, producer nations can hardly be expected to make such momentous decisions with respect to the utilization of their flare gas merely on emotional or ideological grounds. There are a great number of compounds that can be made from this gas, and the choice of those that are particularly suitable as a petrochemical foundation is more likely to be determined by such practical criteria as:

(*a*) The degree to which those raw materials that have no other foreseeable outlets can be used. Thus use of flare gas — and, notably, the methane and ethane it contains — is to be preferred to petrochemical projects based on LPG or liquid hydrocarbons. The latter are more easily transportable and have (or sooner or later will gain) ready access to world markets.

(*b*) The degree to which the project fits into the country's economy and is likely to generate new activity. Basic industries such as electric utilities, or cement and fertilizer plants, obviously rank high.

(*c*) The degree to which the output can profitably be sold in world markets. The significance of this last point can hardly be overemphasized, because, almost invariably, present levels of demand in producer nations are insufficient to justify a truly economic size petrochemical complex. If a petrochemical industry is to make any worthwhile contribution to the problem of flare gas, therefore, it must, of necessity, be based on the ability to sell most, if not all of the output in world markets, at least until such time as domestic demand shall have reached sizable proportions. This has a number of important implications, those that most readily come to mind being:

(i) The petrochemical complex must be able to compete in world markets. It cannot be created by protective duties. Tariff walls would only hamper the industry and retard the economic development of the producer country. Rather, what is needed is a liberal policy on the part of the producer country designed to minimize costs and investments and to maximize encouragement of pioneer capital.

(ii) The necessity of assurance of duty-free or at least non-discriminatory access to the logical markets for the output of the petrochemical complex through treaties, membership in trade blocs or otherwise. In this connexion, basic intermediates which can be further upgraded, such as synthetic ammonia or butadiene, are more likely to be looked upon with favour by the potential buyers — whether industrialized nations or developing countries striving to build up their own industries — than would more advanced products, such as solid fertilizers or synthetic rubber.

(iii) Assurance of access to large consumer markets on a duty-free or favoured-nation basis by treaty is, in and by itself, not enough. Also required are long-term commercial arrangements with organizations having captive use or established distribution channels in those markets. This, too, emphasizes the need for a careful selection of the petrochemicals that are to be produced. They should be in tune with the product range of the organizations in question.

Weighing all of the above considerations, it would appear that synthetic ammonia ranks very high on the list of possible starting points for a petrochemical industry in producer countries.

V. CHANGING INDUSTRY PATTERNS IN AMMONIA — DAWN OF A NEW ERA

Synthetic ammonia is a basic chemical, which derives primary importance from its ability to adapt the element nitrogen (which makes up about 82 per cent of its weight) cheaply and effectively to agricultural and industrial uses. The main application by far is in agriculture as one of the three basic plant nutrients, the other two being potash and phosphorus.

Ammonia is the raw material for a variety of solid and liquid fertilizers, such as ammonium sulfate, ammonium nitrate, urea, nitrogen solutions and many others. It also can be combined with phosphorus and/or potassium to form mixed fertilizers or such compounds as nitro-phosphates, ammonium phosphates and ammoniated superphosphates.

In recent years, the direct application of ammonia as such — i.e., without further conversion — to the land is gaining increasing popularity. Special equipment has been developed to inject anhydrous ammonia into the soil or to meter aqua ammonia into irrigation water. The use of ammonia on the farm in anhydrous form or as aqua ammonia was pioneered in the United States, where today nearly 30 per cent of all agricultural nitrogen is so applied, and this percentage is still rising.

The direct application of ammonia is still relatively unknown outside the United States but is beginning to gain attention in Denmark and other agricultural areas. It could be of great potential interest to developing nations. Agronomical studies will, however, have to establish the suitability of direct application methods to particular soils and climatic conditions.

Synthetic ammonia is made by combining hydrogen with nitrogen from the air. The hydrogen can be derived from a variety of sources, such as coal, lignite, coke, coke-oven gas, fuel oil, light naphtha, LPG, refinery gases and natural gas. It also can be made electrolytically or obtained as a by-product from other industries, such as chlorine-caustic plants, naphtha reforming etc. Availability and cost will primarily determine which of these many possible sources will be utilized in specific instances.

In countries such as the United States and Canada more than 80 per cent of the synthetic ammonia output and virtually all of the projected expansion are based on natural gas. In the Federal Republic of Germany, coke and coke-oven gas and in Norway and Switzerland electricity still form the backbone of the ammonia industry. However, there has been a pronounced trend in these last three countries and elsewhere in favour of more economical petroleum feed stocks, such as fuel oil and light naphtha, which are today widely available.

The costliness of storage and transportation of anhydrous ammonia has favoured its conversion in situ into solid or liquid derivatives, such as ammonium sulfate, nitrate, urea or nitrogen solutions. Recent technological breakthroughs in cryogenics and the availability of superior insulating materials have opened up entirely new horizons and have made revolutionary thinking possible in the industry. The storage in liquid form under atmospheric pressure of synthetic ammonia, and its transportation over long distances by barge or special tanker, are now possible at costs comparable to those of LPG. Actually, with proper design, LPG and synthetic ammonia facilities can be used interchangeably.

Modern industry thinking on handling and shipping ammonia, coupled with new concepts in the construction of ammonia plants of a size previously unheard of, could have a profound impact on, if not radically change the structure of, the world fertilizer industry. The small, fully integrated ammonia plant is rapidly being outdated.[4] The pattern which begins to emerge is one of central large-scale ammonia plants built in areas with low-cost natural gas. Fertilizer plants or direct applicators in various consuming areas can be supplied from these centres at sizable savings. A simplified comparison between the present structure of the industry and the shape of things to come is depicted in figure 1.

Two ammonia plants recently completed in Trinidad and Aruba are, in essence, prototypes of these new concepts in ammonia manufacture and distribution. Most

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[4] Urea is today about the only nitrogenous fertilizer that, for economic reasons, remains locationally bound to ammonia manufacture. This compound is made by combining ammonia with carbon dioxide. As large volumes of CO_2 are obtained as a by-product in synthetic ammonia plants, urea is a logical derivative to be produced at such locations.

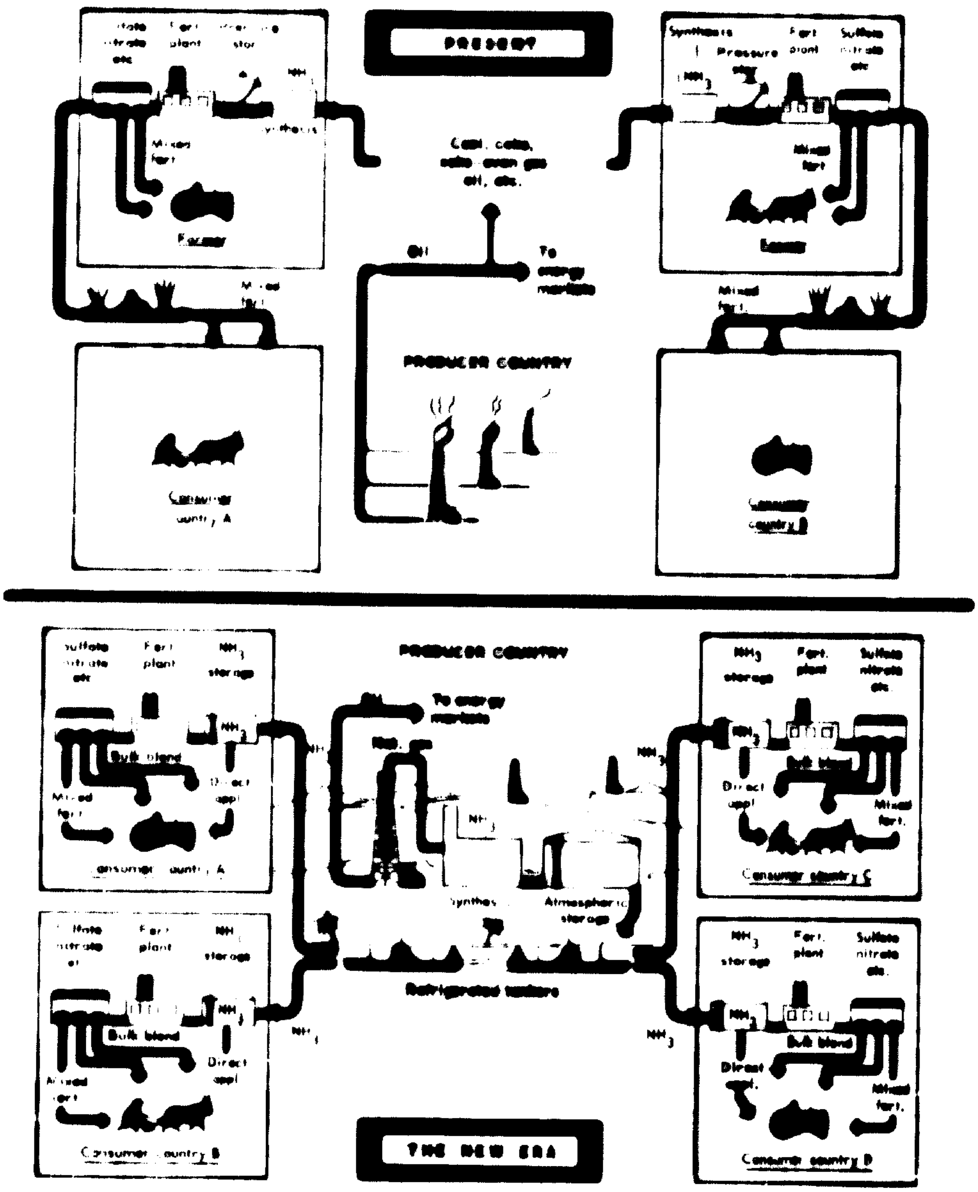

Figure 1. *Changing patterns in ammonia*

of their output is shipped in liquefied form on special tankers to the United States, Latin America and Western Europe, where it is converted into other forms of plant food or used for direct application.

The significance of the impending changes in ammonia supply and distribution patterns for producer countries and consumer nations alike is obvious. For the former, it could mean a significant step towards solving the problem of flare gas and the creation of a new economically sound basic industry; for the latter, a saving in the cost of an important fundamental raw material. Moreover, the ability to start with ammonia rather than to integrate all the way backwards to naphtha or fuel oil from imported crudes, greatly reduces the capital demand for fertilizer expansion in consumer nations. The capital thus freed would become available for other desirable projects.

The widespread availability of low-cost ammonia from a big "mother" plant may have even more far-reaching beneficial effects. It is likely to generate considerable new economic activity and to provide the basis for the creation of many new industries in developing countries. For instance, supply of ammonia in bulk will make feasible the construction of numerous downstream fertilizer plants in countries where fully integrated complexes could not be economically justified, due to limited demand or for other reasons. It can also serve as a means of modernizing agricultural methods through the introduction of direct application techniques, the cheapest method yet devised for feeding nitrogen to the crop where possible.

There can be no doubt that the world nitrogenous fertilizer industry is on the threshold of major changes and that a new era for ammonia is dawning.

VI. THE ECONOMICS OF A BASIC AMMONIA PLANT IN NORTH AFRICA

North Africa is strategically located with respect to some of the world's largest and fastest growing markets for fertilizers. Its potential sales territory would logically encompass two main areas:

(*a*) The countries bordering on the Mediterranean for whose supply North Africa is ideally situated, and

(*b*) The countries bordering on the Eastern Atlantic including most of Western Europe and West Africa, possibly extending as far as Cape Town.

An even broader long-range view would also take into account the markets of Latin America, which, through improving methods of transportation, are becoming economically reachable for North African ammonia.

Table 2 shows the 1961-1962 use of agricultural nitrogen in the above-named marketing areas, as well as such other salient data as population, arable land and national income.

Nitrogen consumption, four million tons in the fertilizer year 1961/62, has since increased steadily. The figure is now probably pushing the five-million-ton-per-year mark. This compares with an estimated 4 million metric tons for the United States in 1963/64 (7) and with preliminary estimates of a total world consumption of nitrogen of 17.65 million tons. (8) The latter figure includes both agricultural and industrial uses. On an over-all basis, the area covered by table 2 would represent about one-third of world nitrogen demand.

Most significant consumers are Western Europe, which accounts for close to 70 per cent of the region's total, and the Mediterranean area, which essentially makes up the balance. As yet, consumption in West African countries is low: 5,100 metric tons of nitrogen in 1961/62. While Africa's West Coast is entirely dependent upon imports for its fertilizer requirements and could eventually become a significant consumer, this area could not in the foreseeable future provide a sufficient base load for an ammonia plant in North Africa. The economic feasibility of such a plant will rather hinge primarily upon the ability to sell its output in the countries around the Mediterranean and in several Western European countries.

Our times are witnessing an unprecedented worldwide surge in fertilizer demand. Even at relatively modest rates of increase, fertilizer usage will certainly be doubled by 1970. It will probably rise even more steeply in several of the regions under consideration, such as the Mediterranean countries, where untapped potentials are impressive and the upswing in the economy is beginning to make itself felt.

All of this appears to augur well for the economic feasibility of an ammonia manufacturing venture in North Africa with its abundance of natural gas. There are, however, some important qualifications to be understood and particular problems to be resolved.

In the first place, Western Europe is not only the largest consumer but historically has also been the principal nitrogenous fertilizer supplier for the same area in which a North African based plant would have to look for its markets. Not only is a sizable expansion under way by established producers, but several new plants are also going up (see table 3) in what are traditionally fertilizer importing countries.

It would be unrealistic to expect any large-scale abandonment of expansion plans to accommodate a North African plant or a market growth that would so rapidly outdistance present and future production as to absorb its output. For a new producer to break into these markets "cold" would, at best, be a time-consuming and costly operation. The economic justification of a North African-based plant should rather rest upon its ability to blend into the existing and future regional fertilizer expansion programme. This involves a clear demonstration of the particular advantages such a venture could offer for the supply of basic intermediates, especially

TABLE 2. FERTILIZER NITROGEN USE AND OTHER SALIENT DATA FOR THE MEDITERRANEAN AND EASTERN ATLANTIC AREAS

	Pop.[a] *(1,000)*	*Nat'l inc.*[b] *(billion $)*	*Arable land (1,000 ha)*	*Consumption*[d] *N fertilizer (metr. ton N)*	*Imports*[d] *N fertilizer (metr. ton N)*	*N fert. cons. tons N per $ Mill. nat'l inc.*	*N fert. cons. tons N per 1,000 ha*
1. **Mediterranean area**	222,042	82.92	111,446	1,263,508	535,282	15.2	11.3
2. **Eastern Atlantic**							
(*a*) **W. Europe — Atlantic side** [e]	244,389	316.97	70,090	2,798,454	373,974	8.8	39.9
(*b*) **W. Africa**	97,683	5.37	78,550	5,089	5,091	0.9	0.067
TOTAL	564,114	405.26	260,086	4,067,051	914,347	10.0	15.6

SOURCE: Miscellaneous United Nations published data.

[a] 1963 or latest available.

[b] 1962 or latest available.

[c] 1959 or latest available.

[d] 1961-1962 or latest available.

[e] Includes all of France.

TABLE 3 [illegible]

([illegible])

Country	Operator	Plant location	Feedstock	Capacity	Status
		A. Mediterranean area			
Algeria	Soc. Alger. de l'Azote	Arzew	Nat. gas	[illegible]	Planned
Austria	Danube Petrochemie	Linz	Lt. naphtha	?	Planned
Bulgaria	Government	Stara Zagora	Fuel oil	100?	Plans call for doubling NH₃ capacity of plant
Greece	North Greece Ammonia Corp	Salonika	Ref. gas	90	Late [illegible]
Italy	ANIC	Gela	Ref. gas	100	?
Lebanon	?	Saida	Petroleum	?	Unknown
Morocco	Office Cherifien des Phosphates	Safi	Nat. gas	30	U/C
Spain	Fertilizantes Iberia	La Coruna	Ref. gas	100	Unknown
		Castellon	?	133	Unknown
		Huelva	?	30?	Unknown
	Amoniaco Espanol	Malaga	Lt. naphtha	100	U/C late [illegible]
	Empresa Nacional Calvo Sotelo	Puertollano	Coal?	25	Unknown
		Saragosa	Coal?	132	Planned
		La Coruna	?	11	U/C
Syria	Homs Refinery	Homs	Lt. naphtha or Ref. gas	22	Planned 1967
Tunisia	Ind. Chim. Maghrebines	La Skhirra	Lt. naphtha or Ref. gas	54	Approved
United Arab Republic	Egypt Iron and Steel Company	Helwan	Coke-oven	?	Planned
		B. Atlantic area			
Belgium	Ammoniaque Synthetique et Derives	Willebroek	Coke-oven, water gas, fuel oil	[illegible]*	July [illegible]
	Kuhlmann	Rieme-Selzaete	Naphtha	10*	Completed [illegible]
	S.A. Pour la Fabr. des Engrais Azotes	Houdeng-Goegnies	Coke-oven gas	39*	Mid-[illegible]?
Denmark	Dansk-Norsk Kvaelstoffabrik	Grenaa	Ref. gas	38	On stream [illegible]
France	PBC	Grande Couronne	Ref. gas	25*	Completed August [illegible]
	Pierrefitte	Soulom (H.P.)	Nat. gas	75*	U/C?
	ONIA	Toulouse	Nat. gas	110*	Completed
	Grande Paroisse	Waziers	?	40	Unknown
		Montoir Bret	?	90	Unknown
Germany	Scholven	Gelsenkirchen	Lt. naphtha	90 *	Completed early 1966
			Lt. Naphtha	90 *	Early 1966
	Victor	Castrop-Rauxel	Nat gas	55 *	Planned
Ireland	Nitrogen Eireann Teoranta	Arklow	Fuel oil	30	U/C
Netherlands	BASF-MEXOG-Albatros	Rotterdam	Ref. Gas?	270	Planned
	Dutch State Mines	Geleen	Lt. naphtha and Nat. gas	400	October 1966
			Lt. naphtha and Nat. gas	200	Completed December 1963
Norway	Norsk Hydro	Heroya	Fuel oil	110 ᵇ	May 1965
Portugal	Unio Fabril	Lavradio	Lt. naphtha	?	Expansion under study
Sweden	Svenska Saltpeter	Koping	Fuel oil	50	1964
Switzerland	Lonza	Lalden	Lt. naphtha or Ref. gas	54	?
United Kingdom	I.C.I.	Billingham	Naphtha	540	U/C early 1966
		Immingham	Naphtha	170	1966
		Severnside	Naphtha	180 *	Late 1964
		N.A.	Naphtha	270	Planned for 1966

SOURCE: Published data from various trade and other journals.

* Expansion.

U/C Under construction.

N.A. Not available.

ᵃ May be partial replacement of existing facilities.

ᵇ May be partial replacement of existing hydroelectric-based capacity.

ammonia. As will be recalled, the general aspects of the changing ammonia situation were dealt with in the preceding chapter.

While there are numerous ponderable and imponderable factors to be considered — particularly because of the relatively novel concept involved — in the final analysis, it will be the dollar and costs figure which will be the deciding factor. Let us briefly, therefore, review the question of how the relative economics of ammonia manufacture in Europe compared with that in North Africa.

Although in Italy, France and Holland, sizable quantities of ammonia are, or will be made from natural gas, Europe's current wave of ammonia expansion is preponderantly based on the use of liquid feed-stocks. The technology in this field has made great strides in recent years with the development of naphtha reforming processes and improvements in the partial oxidation of heavy fuel oil. These processes are likely to set the economic pattern of the industry, at least for the next several years.

The estimated cost of manufacturing ammonia from liquid feed-stocks for a typical producer in Western Europe is presented in table 4, while those for a North African plant, which would be natural gas-based, are given in table 5. The latter table also shows, for general comparative purposes, the cost of a similar plant for United States Gulf Coast conditions. In order to keep the data as nearly as is possible, on a comparable basis, grass roots plants were assumed in all cases. The other bases upon which the estimates rest are evident from the tables themselves and need not be gone into here.

There is, however, one point on which we should briefly dwell, namely, the relatively high investment required for a first ammonia plant in a North African location, as compared with a similar plant located on the United States Gulf Coast. The differences essentially stem from two courses.

(a) The higher cost of construction in a developing country, coupled with the likelihood that a plant of given size will be designed as a multiple rather than a single unit. This is especially true where the large unit size would be a relative novelty in the industry.

(b) The other, and far more significant difference in capital requirements is occasioned by the investment needed for off-sites and infra-structure — such as power supply, water systems and sewage disposal plants, roads and transportation, housing, hospitals and schools, port and harbour facilities — which a pioneering industry

TABLE 4. COST OF AMMONIA MANUFACTURE FROM LIQUID FEED-STOCKS

Capacity	140,000 metric tons/yr	
Process	Oil gasification	Naphtha reforming
Investment (BL + OBL)	$15 MM	$12 MM
Investment per ann. ton	$107	$85.70

Operating cost	*Units/ton*	*$/unit*	*$/ton*	*Units/ton*	*$/unit*	*$/ton*
1. Feed-stock	.8 ton	14.00	11.20	.52 ton	18.00	9.36
2. Fuel (gas)				15.5 MMBTU	0.30	4.65
3. Power	1,150 kWh	.8 ¢	9.20	880 kWh	.8 ¢	7.04
4. Cooling water	90 M gal.	2 ¢	1.80	90 M gal.	2 ¢	1.80
5. Boiler feed (net)	.5 M gal.	1.00	.50	.65 M gal.	1.00	.65
6. Labour and supervision			2.20			2.20
7. Chemicals and catalyst			1.00			1.82
8. Oper. and maint. mat'l	1 1/2 per cent of inv.		1.61	1 1/2 per cent of inv.		1.29
9. Overhead 50 per cent of (6)			1.10			1.10
10. Insurance, taxes, etc	1 1/2 per cent of inv.		1.61	1 1/2 per cent of inv.		1.29
11. Cost working capital	5 per cent of $1.4 MM		.50	5 per cent of $1.4 MM		.50
SUB-TOTAL (cash cost)			30.72			31.70
Depreciation 10 per cent			10.70			8.57
TOTAL, cash cost and depreciation			41.42			40.27

SOURCE: Chemical Projects Associates estimates.

Note: Above is for a grass roots plant, based on Western European conditions. Integration with existing facilities such as a refinery, chemical plant or a fertilizer complex could reduce the investment figure by $2-4 MM, depending on circumstances, as well as the cost of overhead. Figures have slide-rule accuracy only.

TABLE 5 COMPARATIVE COST OF AMMONIA MANUFACTURE IN N. AFRICA AND THE PERSIAN GULF *vs.* THE U.S. IN VARIOUS SIZED PLANTS (GRASS ROOTS BASIS)

(Metric tons ammonia per year)

	150,000	300,000		600,000		750,000	
	N.A. & P.G.	*U.S.*	*N.A. & P.G.*	*U.S.*	*N.A. & P.G.*	*U.S.*	*N.A. & P.G.*
Number of trains	One train	One train	Two trains	Two trains	Two trains	Two trains	Two trains
Investment $ MM							
Process units	8.6	12.2	17.0	24.0	28.8	28.5	33.8
Offsites, housing etc.	7.4	2.2	7.9	3.2	9.3	3.0	10.0
Storage	1.6	1.6	2.2	3.2	4.2	4.0	4.9
Dock or breakwater	2.8	—	2.8	—	2.8	—	2.8
TOTAL	20.4	16.0	29.9	30.4	45.1	35.5	51.5
Investment per ton							
Process units	57.40	40.70	56.70	40.00	48.00	38.00	45.00
All other	78.60	12.70	43.00	10.70	27.20	9.30	23.60
TOTAL	136.00	53.40	99.70	50.70	75.20	47.30	68.60
			MANUFACTURING COST *($ per metric ton ammonia)*				
1. Gas (feed and fuel) 40 MMBTU	2.00 [a]	7.00 [b]	2.00 [a]	7.00 [b]	2.00 [a]	7.00 [b]	2.00 [a]
2. Utilities	— [c]	1.55	— [c]	1.55	— [c]	1.55 [c]	—
3. Labour and supervision	4.00	1.00	3.50	0.70	2.50	0.55	2.25
4. Chemicals and catalyst	0.55	0.45	0.55	0.45	0.55	0.45	0.55
5. Operating supplies	0.15	0.10	0.15	0.10	0.15	0.10	0.15
6. Maintenance material [d]	2.03	0.80	1.49	0.76	1.13	0.71	1.03
7. Overhead 50 per cent of (3)	2.00	0.50	1.75	0.35	1.25	0.28	1.13
8. Insurance, taxes, etc. [e]	3.00	0.80	1.99	0.76	1.51	0.71	1.37
9. Contract services [f]	1.65	—	1.25	—	0.85	—	0.75
10. Cost-working capital	0.80	0.50	0.80	0.50	0.80	0.50	0.80
Sub-TOTAL (cash cost)	16.26	12.70	13.48	12.17	10.74	11.85	10.03
Depreciation 10 per cent	13.60	5.34	9.97	5.07	7.52	4.73	6.86
TOTAL, cash cost and depreciation	29.86	18.04	23.45	17.24	18.26	16.58	16.89

SOURCE: Chemical Projects Associates estimates.

Note: 150,000 t/yr and 300,000 t/yr based on actual cases, 600,000 and 750,000 t/yr extrapolated. Figures slide rule accuracy only. N.A. - North Africa. P.G. - Persian Gulf.

[a] 5¢ per MM BTU

[b] 20¢ per MM BTU. Requirement only 35 MM BTU as power is purchased, see (c).

[c] Included in other items.

[d] 1.5 per cent of total investment.

[e] 1.5 per cent for U.S. and 2 per cent for N. Africa and Persian Gulf.

[f] Including catering, local supplies, housing, communications etc.

in a developing country would have to provide. Such facilities and services are normally already available in industrialized environments, such as on the United States Gulf Coast and in many areas of Europe.

Let us now take a closer look at the comparative costs of ammonia manufacture presented in the tables. The European example refers to a unit capable of making 140,000 metric tons of ammonia per year in a single train, a capacity larger than that of most other plants in Europe. The difference between this and the 150,000-ton per year size chosen as the base case for North Africa is so slight that it can be ignored for all practical intents and purposes. Estimates for larger plant sizes, up to 750,000 tons per year, are also shown in table 5. The data for the 150,000 and 300,000-ton complexes are composites, based on numerous detailed studies for specific cases covering a wide variety of circumstances. They are sufficiently typical of North African conditions in general to serve as a useful basis for the present purpose, although some cost elements will, of course, vary from one location to another. The estimates for the larger-size plants were extrapolated from the figures for the 150,000 and 300,000-tons-per-year units, and, as such, have a somewhat lesser degree of accuracy.

Turning to table 4, which is representative of European cost, it is interesting to note how close the economics of the partial oxidation and naphtha reforming processes are to each other. For the conditions chosen and looking solely at the cash cost,[2] oil gasification has a slight edge ($1 per ton) on naphtha reforming. Adding in depreciation reverses the situation. The difference is so slight, however, as to be well within the margin of error of the estimates.

The choice of one process over the other is more likely to be determined by the specific circumstances of the case. The lesser investment called for by the naphtha reforming process would, however, *ceteris paribus*, result in a better rate of return at any given sales or transfer price of the ammonia. Naphtha reforming rather than fuel oil oxidation is, therefore, likely to provide the sounder gauge for determining the price levels which a North African plant would have to meet for sale of its ammonia to a European fertilizer manufacturer.

The cash cost of North African ammonia — $16.26 per metric ton for the 150,000-ton-per-year base case — is well below the estimated $31.70 per ton for which ammonia can be made in Europe from naphtha on a comparable scale. The margin is narrowed considerably if the cost of shipping ammonia to Western Europe and other related out-of-pocket expenses are included, but it still remains favourable for North Africa, unless offset by import duties, as the following calculation shows:

	$ per metric ton ammonia
Cash cost f.o.b. North Africa	16.26
Freight (average)	10.00
Extra cost of handling and liquid storage at destination	2.00
Sales expense or commission	1.50
TOTAL, cash cost landed in storage in Europe	29.76

The difference of about $2 per ton, while modest, is in the right direction, and is sufficiently interesting to pursue the economic comparison further.

The next step then is to consider how the cost will be affected if the various financial charges, such as depreciation and return on investment, are added in on both sides. These could radically change the picture. They actually do, as we shall see, unless a favourable tax environment and suitable financing methods can be provided.

Financial charges are greatly affected by:

(*a*) The income tax environment. Obviously, the higher the applicable tax rates, the greater the gross margin needed to provide a given net rate of return to the investor.

(*b*) The method of financing. Equity (or risk) capital expects a higher rate of return than the bondholder, and investments overseas more than local investments. In the United States, for instance, the average after-tax profit of the chemical industry in 1963 was between 13 and 14 per cent of the stockholder's equity. (9) By comparison, the average rate of return on prime grade (Moody's AAA rated) industrial bonds was 4.14 per cent. (10)

Financial charges loom particularly large as cost factors for a pioneer ammonia plant in North Africa, because of the many needed off-sites, ancillaries and infra-structure earlier mentioned. Programmes to build up the infra-structure in under-developed areas of Europe and low-interest loans offered are typical examples of what is being done elsewhere to attract new industries. In the United States, tax-free municipal bonds are being used widely for the financing of utilities, housing, site development and other services as a similar inducement. (11)

There are different ways in which rates of return can be calculated, but one that has been gaining most favour in recent years is the discounted cash flow (DCF) method. As is well known, of course, this system involves computing the cash flow in the form of after-tax profits plus depreciation expected from the operation over a number of years (the so-called useful life of the project) and discounting it at interest rates corresponding to the desired rate of return. The DCF method is far from ideal, in that it tends to flatter projects of a short-range nature and penalize those of a longer-range character. In the present instance where projects of a comparable type are involved, this method is nonetheless an accurate tool.

In the following, a simplification is used which does not affect the validity of the finding for the problem at hand

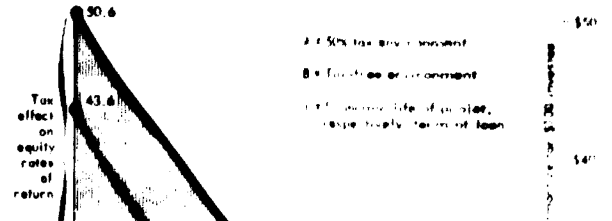

Figure II. *Cost effect of financing methods and tax rates*

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[2] The term "cash cost" is used in this paper to denote the total out-of-pocket expenses incurred in the manufacturing operation and includes raw material, fuel, utilities, cost of conversion, etc., but not depreciation, general administrative overhead, selling expenses or return of investment.

TABLE 6. COST OF FINANCING AND TAX RATES

PER CENT OF ORIGINAL INVESTMENT REQUIRED ANNUALLY TO COVER AMORTIZATION AND AFTER TAX YIELDS SHOWN, STARTING THREE YEARS AFTER INVESTMENT IS MADE

A *Environment with 50 % income tax*

B *Tax free environment*

Yield (after tax) Percentages	*Number of years economic life or term of loan amortization*							
	10 years		*15 years*		*20 years*		*30 years*	
	A	*B*	*A*	*B*	*A*	*B*	*A*	*B*
3.75	17.2	13.6	13.2	9.9	14.2	8.1	10.0	7.0
5.0	20.0	15.0	15.8	11.2	13.6	9.3	12.0	8.9
7.50	26.2	18.1	21.6	14.1	19.4	12.2	16.2	10.0
10.0	33.2	21.6	28.4	17.5	25.4	15.7	25.4	14.7
15.0	50.6	30.3	45.6	26.1	40.6	24.3	40.0	20.5

SOURCE: Chemical Projects Associates calculations based on annuity and interest tables.

Note: The percentages in the A columns are approximate only as they will be affected by the allocation as between amortization and income under applicable tax laws and other factors.

The simplification consists in the assumption that, in all cases, there will be a three-year time lapse between investment and start of cash flow but that, thereafter, the cash flow will immediately be at capacity level.

The cash flows needed in tax-free and 50 per cent income tax environments, with rates of return and years of useful project life (respectively, years over which a loan is amortized) as parameters, are shown in table 6. The data have been plotted for selected cases in figure II. The curves show the considerable impact that tax environment and method of financing have on the economics of an industrial venture.

Table 7 shows how these factors may affect the price levels needed to induce a European producer to consider buying, rather than making ammonia. Deducting $13.50 per metric ton to cover freight, extra cost of handling, etc., and ignoring import duties, these figures translate into prices f.o.b. North Africa ranging from $31.46 to $46.65 per metric ton ammonia. These, then, are the approximate prices below which North Africa must be able to go if the European producer is to be dissuaded from putting up his own ammonia facilities.

Figure III shows the effect of plant size and method of financing on the price at which ammonia could be sup-

TABLE 7. EFFECT OF FINANCING AND INCOME TAX ON COST OF AMMONIA IN WESTERN EUROPE

Basis: 140,000 metric tons/yr. (naphtha reforming), operation at 100 % capacity

Investment: Grass roots plant battery limits plus off-sites	$12000000
Per annual metric ton NH_3	$85.70
(Exclusive of working capital)	

Rates of return:

Equity: 10 %, DCF after tax 10-year economic life
Bonds: 5 %, p.a. after tax 20-year amortization
Profits and amortization starting after third year

Ex-plant cost per metric ton NH_3

Method financing	*Tax rate*	*Cost of financing*	*Cash-cost*	*Total*
1. 100 per cent equity	50 per cent	33.2 per cent of $85.70 = $28.45	$31.70	$60.15
2. 50 per cent equity	50 per cent	33.2 per cent of $42.85 = $14.23		
50 per cent bonds	50 per cent	13.6 per cent of $42.85 = $5.83		
		TOTAL = $20.06	$31.70	$51.76
3. 100 per cent equity	Tax free	21.6 per cent of $85.70 = $18.51	$31.70	$50.21
4. 50 per cent equity	Tax free	21.6 per cent of $42.85 = $9.26		
50 per cent bonds	Tax free	9.3 per cent of $42.85 = $4.00		
		TOTAL = $13.26	$31.70	$44.96

SOURCE: Chemical Projects Associates estimates.

Note: Figures have slide rule accuracy only.

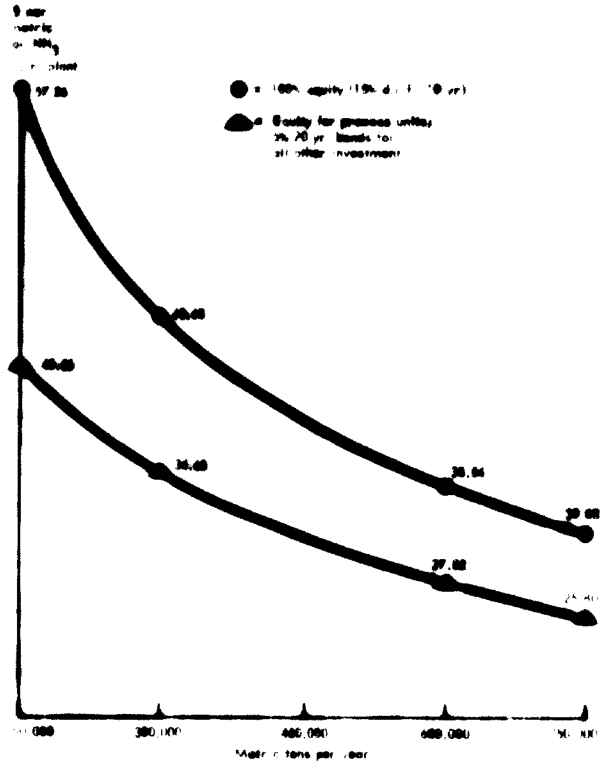

Figure III. *Effect of plant size and financing on cost of ammonia in N. Africa and Persian Gulf assuming tax-free environment*

plied from North Africa, assuming a tax-free environment. The latter assumption had to be made, because otherwise North African ammonia would have priced itself out of the market. The figures do not include general administrative overhead or sales expense. The latter are allowed for in the $13.50 per ton differential. The general overhead can be ignored here, because it is offset — in part, at least — by the corresponding omission of this charge in the case of the European producer.

Looking again at figure III, then, the $57.26 per ton for which ammonia could be supplied f.o.b. North Africa from a 150,000-ton-per-year plant, if financed entirely with equity capital, is well above the $31.46-$46.65 range mentioned above. A plant twice that size would bring the cost down to $43.68, which is barely within the desired range. It is doubtful whether this would provide a European producer with enough incentive to buy his ammonia except under a long-term contract.

If, on the other hand, equity financing were confined to the process units proper, and if the utilities and other infra-structure could be financed with five per cent twenty-year bonds, the base case (150,000 tons per year) with $40.66 per ton becomes economically *feasible*. In passing, it is interesting to note that this figure is well below the $43.68 for the larger-sized plant, indicating that, from a cost point of view, the availability of appropriate financing is more important even than plant size.

In conclusion, the economic feasibility of a 150,000-ton-per-year ammonia plant in North Africa looks promising, and that of a larger capacity even more so, provided that:

(*a*) Access to European and Mediterranean markets can be gained on a duty-free or non-discriminatory basis by virtue of treaties or membership in trade blocs;

(*b*) Proper tax and other incentives, including low-cost gas, are provided by producer nations;

(*c*) Financing of off-sites, ancillaries and other infrastructure through low-interest, long-term loans is made available.

VII. THE ECONOMICS OF A BASIC AMMONIA PLANT ON THE PERSIAN GULF

A number of studies and estimates have been made for the location of petrochemical complexes on the Persian Gulf. While there were obviously variations between particular locations, fundamentally the cost elements on the Persian Gulf were found to be similar, if not identical, to those discussed in the previous chapter as being typical for a North African based plant, assuming in both cases equal gas prices. For this reason, the same data presented in figures II and III, as well as in tables 5 and 6, can also serve as useful general bases for determining the economic feasibility of an ammonia plant on the Persian Gulf. There are, however, two respects in which the situation here could differ from that in North Africa.

(*a*) In the first place, in such Persian Gulf locations as Abadan and Ras Tanura, a petrochemical complex would find utilities, housing, roads, sewage, repair shops, port facilities and other services which could probably be shared with established refineries and other industries. This would reduce capital requirements essentially to those for the processing units proper and for such specialized off-sites as refrigerated storage, thereby minimizing one major area of difficulty for a pioneering industry. A fair rental for the use of the existing facilities would, of course, be chargeable to the petrochemical project. If such charges were calculated on a basis corresponding to the financing of these ancillaries through five per cent, twenty-year bonds, then the cost data shown in figure III would also be valid here. This is not to suggest that there might not be a saving in the sharing of off-sites and infrastructure with other industries, as opposed to building from scratch, however, our present concern is with over-all regional petrochemical potentials rather than site studies.

(*b*) A second difference is in the size and type of market which a Persian Gulf-based plant could most logically serve. West of Suez it would find itself at a competitive disadvantage vis-à-vis a North African-based plant. East of Singapore, competition from Japan would certainly make itself felt. The marketing radius for Persian Gulf ammonia would thus appear primarily to encompass the countries of the Middle East, East Africa and South-West Asia.

Figures on fertilizer consumption and other relevant data for these areas are presented in table 8. Although these markets have a total arable land area 20 per cent greater than that within the North African orbit (310 mil-

TABLE 8 POPULATION, NITROGEN USE AND OTHER SALIENT DATA FOR THE PERSIAN GULF AREA

		[illegible]	[illegible][a]	[illegible]	[illegible][d]	[illegible][d]	[illegible]	[illegible]
1 Persian Gulf		39,097	1.90	20,407	7,008	7,008	2.1	0.92
2 South West Asia								
(a) Afghanistan		13,800	n.a.	9,004	n.a.	n.a.	n.a.	n.a.
(b) Burma		20,600	1.10	8,004	3,600	3,000	3.3	0.40
(c) Ceylon		10,400	1.29	1,505	30,000	30,000	27.7	20.0
(d) India		449,301	38.29	159,400	350,000	175,100	0.7	1.0
(e) Malaya		7,000	1.32	2,100	25,200	20,300	10.1	11.0
(f) Pakistan		90,012	n.a.	30,000	60,600	37,000	n.a.	2.5
(g) Other		1,071	0.19	140	n.a.	n.a.	n.a.	n.a.
	TOTAL, above	600,907	50.11	250,970	480,004	270,000	14.3	2.0
3 East Africa (incl. S. Africa)		80,500	9.00	80,500	100,004	60,500	19.0	1.90
	GRAND TOTAL	719,500	60.30	350,000	541,576	304,070	14.0	1.75

SOURCE: Miscellaneous United Nations published data.
[a] 1964 or latest available.
[b] 1962 or latest available.
[c] 1960 or latest available.
[d] 1961-62 or latest available.

lion hectares versus 280 million) and a population larger by 20 per cent (719 million versus 504 million), comparable nitrogen fertilizer consumption and national incomes are much lower (542,000 tons N and $50 thousand million versus 4.1 million tons N and $405 thousand million in 1962). About three-quarters (400,000 tons N in 1962) of the fertilizer consumption is concentrated in South West Asia, with India being the most significant user of nitrogen.

Fertilizer consumption in India has been rising at a rapid rate. In 1964-65 it was close to 350,000 tons in terms of nitrogen equivalent. The country's Planning Commission has estimated that a more than sevenfold quantity of fertilizer nitrogen will be required by 1970-71 and has

TABLE 9 ESTIMATED COST OF PERSIAN GULF AMMONIA SUPPLY TO INDIA (ASSUMING TAX-FREE ENVIRONMENT)
(All figures in tons of 1,000 kilos = 1.1 short tons)

	Reference or basis	Plant size tons NH₃/yr.	
		100,000	300,000
1. Cash cost f.o.b. Persian Gulf	Table 5	$21.26	$13.48
2. Depreciation and return on investment			
(a) Process units (15 per cent DCF, 10 yrs)		12.40	17.20
(b) Off-sites and infra-structure (5 per cent, 20 yrs)		7.00	4.00
3. Sub-total	Figure C	$40.66	$34.68
4. General administrative overhead, selling expenses, process royalties, etc	12.5 per cent of (3)	5.10	4.34
5. Total possible selling price f.o.b. Persian Gulf		$45.76	$39.02
6. Average cost of tanker shipment	10,000 ton shipments	10.00	10.00
7. Total landed cost in India[a]		$55.76	$49.02
8. Extra cost of handling and storage at destination	Estimated	2.00	2.00
9. Total all-inclusive cost in storage in India[a]		$57.76	$51.02

SOURCE: Chemical Projects Associates estimates.
[a] Presumes there will be no import duty. Figures have slide-rule accuracy only.

TABLE 10. ESTIMATED COST OF AMMONIA MANUFACTURE IN INDIA

Capacity: 75,000 metric tons/yr NH_3
Process: Naphtha reforming
Investment: $10 MM battery limits and off-sites excluding purchased power, water etc. $133 per annual metric ton

Operating cost	$ per metric ton NH_3	Foreign exchange element	
		Per cent	$/ton
1. Feed-stock (.92 tons naphtha at $10)	9.20	100	9.20
2. Fuel (gas) (93.1 MM BTU at 5¢)	4.65	100	4.65
3. Power (880 kWh at 1.5 ¢)	13.20	60	7.92
4. Cooling water (100 M gals at 2¢/M gal.)	2.00		
5. Boiler feed (.60 M gals at 1.50)	0.90		
6. Labour and supervision	4.40	10	0.44
7. Chemicals and catalyst	2.05	90	1.81
8. Operating and maintenance materials 1 1/2 per cent of investment	1.90	60	1.14
9. Overhead 50 per cent of (6)	2.20	15	0.33
10. Insurance, taxes etc. 2 per cent of investment	2.66		
11. Cost of working capital	0.80		
TOTAL, cash cost	44.20		25.58
Depreciation 10 per cent per annum	13.30	60	7.98
Total, manufacturing cost (exclusive of general administration selling expense and Royalty)	57.50	$64.70	33.56
Add			
General administration overhead, selling expense and process royalties etc. *	7.20	20	1.44
Income tax	27.40		
Return on investment (15 per cent DCF, 10 yrs)	27.40	50	13.70
TOTAL, possible sales price f.o.b. plant	119.50		48.66

SOURCE: Chemical Projects Associates estimates.

* Taken at 12.5 per cent of manufacturing cost. Figures have slide-rule accuracy only.

set an output of two and one-quarter million tons nitrogen as the target for its Fourth Plan. (12)

India's Third Plan called for an output of one million tons of nitrogen by the end of 1966, but implementation is likely to fall short of this goal. Indicative of the urgency of the situation, the Government of India reportedly has embarked on a crash programme for fertilizer production. In order to achieve its objectives, it has decided that a fertilizer plant should be located at every oil refinery. (13)

Whether and how an ammonia plant on the Persian Gulf might help to fill the urgent fertilizer needs of India and complement its fertilizer programme to the mutual benefit of all concerned would appear to be a particularly timely question. An intra-regional arrangement with India offers one of the brightest prospects of coming to grips with the flare gas problem in the Middle East. It obviously has many facets, of which the more salient economic aspects will be considered here.

One must assume that large-scale imports of finished fertilizers, even at relatively low cost, would have little attraction for a country such as India, which is working to build up its own industry. The supply of an intermediate — synthetic ammonia — on the other hand, might be a far more attractive proposition, in that it could materially help to further the realization of India's fertilizer goals.

Section IV commented on general trends in the method of ammonia manufacture and supply. The practical questions that remain to be considered here are (*a*) what are the possible savings in cost and (*b*) what are the savings in foreign currency that the economy of India could realize from importing part of its future nitrogen requirements in the form of ammonia rather than as naphtha or crude oil?

The estimated cost at which ammonia could be supplied from the Persian Gulf is shown in table 9. These estimates refer to plants of 150,000 and 300,000 tons per year, respectively. They presume a 5¢/MMBTU gas cost, a tax-free environment, financing of the process units with equity capital and of the infra-structure with five per cent, twenty-year bonds. The estimated cost at which ammonia can be produced in India by the reforming of naphtha in a 75,000-metric-ton-per-year plant is presented in table 10. This capacity was selected principally because of the ready availability of reasonably accurate data. It

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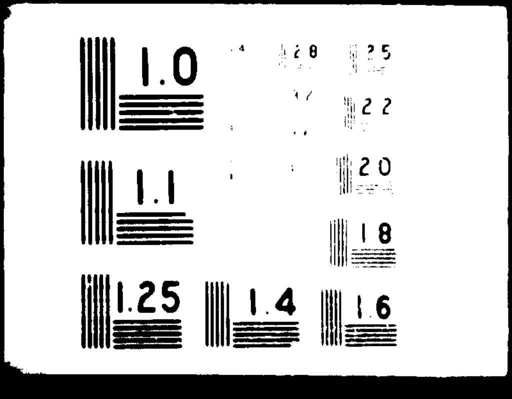

also happens to correspond closely to the size of several existing and projected plants in India, although some larger units are reportedly in the planning stage.

Table 9 suggests that ammonia might be supplied from a 150,000-ton-per-year plant at $45.76 per ton f.o.b. Persian Gulf. Freight, handling and storage at destination might add another $12, for a total landed price of $57.76. This is well below the $64.79 for which ammonia could be made from naphtha in India, even disregarding any return on investment. Allowing for a 15 per cent DCF rate of return and income tax, the possible selling price of Indian ammonia would be nearly $120 per ton.

Putting it another way, India could buy anhydrous ammonia from the Persian Gulf at below its own cost and without having to put up any investment. The capital saving could be diverted to the construction of additional fertilizer facilities in India. The over-all result for the country's economy would be more fertilizers at an earlier date than might otherwise be possible. Last, but not least, there could be a substantial benefit to the farmer in the form of greatly reduced fertilizer prices. The saving might be as much, perhaps, as $60 per ton ammonia equivalent, or $73 per ton nitrogen.

If the above comparisons are made for the larger, 300,000-ton-per-year plant, the case for Persian Gulf ammonia would be even much more favourable. The data for this alternative are readily apparent from table 9 and need no further elaboration.

While the above calculations are only order of magnitude, the results are so striking that there can be little room for doubt as to the savings that Persian Gulf ammonia could signify for the economy of India. The situation is somewhat more complicated, however, when considered from a foreign currency point of view, an angle which cannot be ignored in this instance. Table 10, therefore, also includes data on the possible magnitude of the foreign currency element in the cost of naphtha-derived ammonia. Obviously, in arriving at these figures, assumptions had to be made with respect to such factors as the value of naphtha in world markets, the degree to which imported or domestic fuel is used in the plant or in the generation of electricity, the amount of foreign participation, etc. The figures shown are thus, of necessity, subject to a number of qualifications. They will, however, serve to illustrate the potential advantages that are inherent in an arrangement involving Persian Gulf ammonia.

The foreign currency cost of ammonia made from naphtha in India is about $48-49 per metric ton. This figure compares with possible selling prices f.o.b. Persian Gulf of $45.76 and $39.02 per ton, according to plant capacity. To these figures must be added the cost of

TABLE 11. BALANCE OF PAYMENT EFFECTS OF AMMONIA ALTERNATIVES FOR INDIA

		Capital account	*Current account*
Case A. Manufacture of 150,000 t/yr. ammonia in India in two 75,000 t/yr. naphtha-based plants			
Cost of two 75,000 t/yr. plants (rounded)	$20 MM		
Of which : foreign currency element, say, 80 per cent .	$16 MM		
Less foreign investment, say, 50 per cent of $20 MM . .	$10 MM		
Net currency outflow		$6 MM	
Foreign currency element of output 150,000 t/yr. *at* $48.66 (see table 10)			$7.3 MM/yr.
Case B. Importation of ammonia coupled with investment of $6 MM for a 30 per cent interest in Persian Gulf complex			
Investment for participation in Persian Gulf ammonia plant		$6 MM	
Foreign currency cost 150,000 t/yr f.o.b. Persian Gulf (see table 9) 150,000 tons *at* $45.76			$6.86 MM/yr.
Other foreign currency cost . 60 per cent of $10/ton shipping cost and 20 per cent of $2/ton cost of extra handling and storage, or 150,000 tons *at* $6.40 . .			$0.96 MM/yr.
Total foreign currency cost			$7.82 MM/yr.
Less pro rata share in cash flow of Persian Gulf plant ($24.40/ton, see table 9) 30 per cent of 150,000 × $24.40			$1.08 MM/yr.
Net foreign current account case B			$6.74 MM/yr.
Net foreign current account case A			$7.30 MM/yr.
Annual currency saving of case B over case A			$560.000/yr.

SOURCE: Chemical Projects Associates estimates. Figures slide-rule accuracy only.

shipping the ammonia in liquid form by special tanker, estimated at $10 per ton on the average, and the extra cost of handling and storage at destination, about $2 per ton. The foreign currency element of the latter item is likely to be small, probably not more than 20 per cent or, say, $0.40 per ton. That of the shipping cost will, to a large extent, be determined by the extent to which Indian flag tankers are used. If we assume that the foreign currency element would average 60 per cent, the total cost of Persian Gulf ammonia in terms of exchange would be increased to $52.16 and $45.42 for the two examples covered in table 9. These figures straddle the indicated $48.66 foreign currency element of Indian-made ammonia.

Depending upon the particular case, therefore, there might be a saving or a slight increase in the annual foreign currency cost. In either event, however, there would be a considerable immediate reduction in India's capital outflow, as the balance of payment would be relieved of the necessity to import equipment. Alternatively, the net saving on the capital account could be invested to acquire a participation in a Persian Gulf ammonia plant.

Using the data for the 150,000-ton-per-year plant in order not to overstate the case, the balance of payment effect for India would be approximately as shown in table 11.

The foreign currency saving of $560,000 per year which Persian Gulf ammonia would mean, while modest perhaps, shows that there might indeed be a sound basis for an intra-regional arrangement between India and the producer nations of the Middle East. Details of such an arrangement would merit serious consideration and further exploration.

VIII. BROADENING THE PETROCHEMICAL HORIZONS

Once a first synthetic ammonia plant has been successfully established, a foundation will have been laid on which to build other industries and gradually enlarge and diversify the petrochemical base. It is a well-known fact that "industry begets industry". The most immediate effect of a core plant would be the local ancillary and related activities to which it would give rise. For instance, a need would be created for construction contractors, maintenance and repair shops, as well as small business to supply the food, clothing, educational and recreational needs of the many permanent workers employed. Access to low-cost gas and power could also generate numerous small industries, such as brick, tile and ceramics and, particularly, a cement plant, discussed later. Last but not least, availability of ammonia could serve to establish a network of distributors for its direct application in agricultural uses. The beneficial impact on the farming community would be even more pronounced in some of the later stages, when solid and other fertilizers are added to the production programme.

In the following, we will be mainly concerned with outlining the various petrochemical possibilities that are opened up once a first basic plant has become a successful working operation. Which of many alternatives is most indicated at any particular time or location will depend upon developments in domestic and export markets. It is not possible here to present a rigid blueprint for a North African or Persian Gulf complex, as each area will, of course, have to be studied specifically and in meticulous detail. However, we have outlined what might be the logical development for a stage-wise expansion of petrochemicals in a developing area.

The hypothetical programme is predicated on the belief that it is more important to use flare gas and, notably, methane and ethane rather than the more readily marketable LPGs and liquid hydrocarbons. An attempt has also been made to develop the programme in such a way that, to the extent possible, each subsequent stage is logically tied to and builds upon the technology of the previous stage, or is connected to it by virtue of common raw materials or by-product utilization.

The illustrative cases presented in figures IV and V do not purport to be a complete description of the multiplicity of possibilities that could logically follow the establishment of a core plant, nor are the stages suggested necessarily to be taken in the order given. Subject to these qualifications then, let us look at some of the steps that might be taken to broaden the petrochemical targets.

Having established the ammonia plant as a going concern, a logical next step would be downstream integration to the manufacture of various nitrogenous and other fertilizers. Urea, which is made by combining ammonia with CO_2, would, in many cases, rank high as a choice, both because of its versatility and because it can put to good use the CO_2 by-product of an ammonia plant. Urea is used as raw material for urea-formaldehyde resins, which find wide application as adhesives, coatings and moulding compounds. Urea's major significance, however, is as a fertilizer, where its increasing popularity lies in its high nitrogen content of 46 per cent.

The manufacture of other solid and liquid plant foods can also be considered. As the fertilizer markets are likely to outgrow the first ammonia plant in a relatively few years, it is visualized that a second 150,000-ton-per-year unit will have to be built in order to provide the raw materials for this second stage of the fertilizer programme.

Illustrated in figure IV is the manufacture of such compounds as urea, ammonium nitrate, ammonium sulfate, as well as phosphatic and mixed fertilizers. Ammonium sulfate, phosphatic and mixed fertilizers would provide a useful outlet for by-product sulphur from natural gas or oil refining. The quantities shown in the figure reflect economic size plants, but they can, of course be changed and modified as the market demand should justify.

The quantity of natural gas going into the second stage of the fertilizer programme under discussion is naturally greater than that required for the original plant alone, as gas is also needed for fuel in downstream facilities. The investment is likewise higher, both for the process units and for additional infra-structure. The handling of solids requires more elaborate harbour and shipping facilities than the minimum allowed for in the ammonia stage. However, once solids have been added to the complex, any subsequent expansion becomes easier. Where such

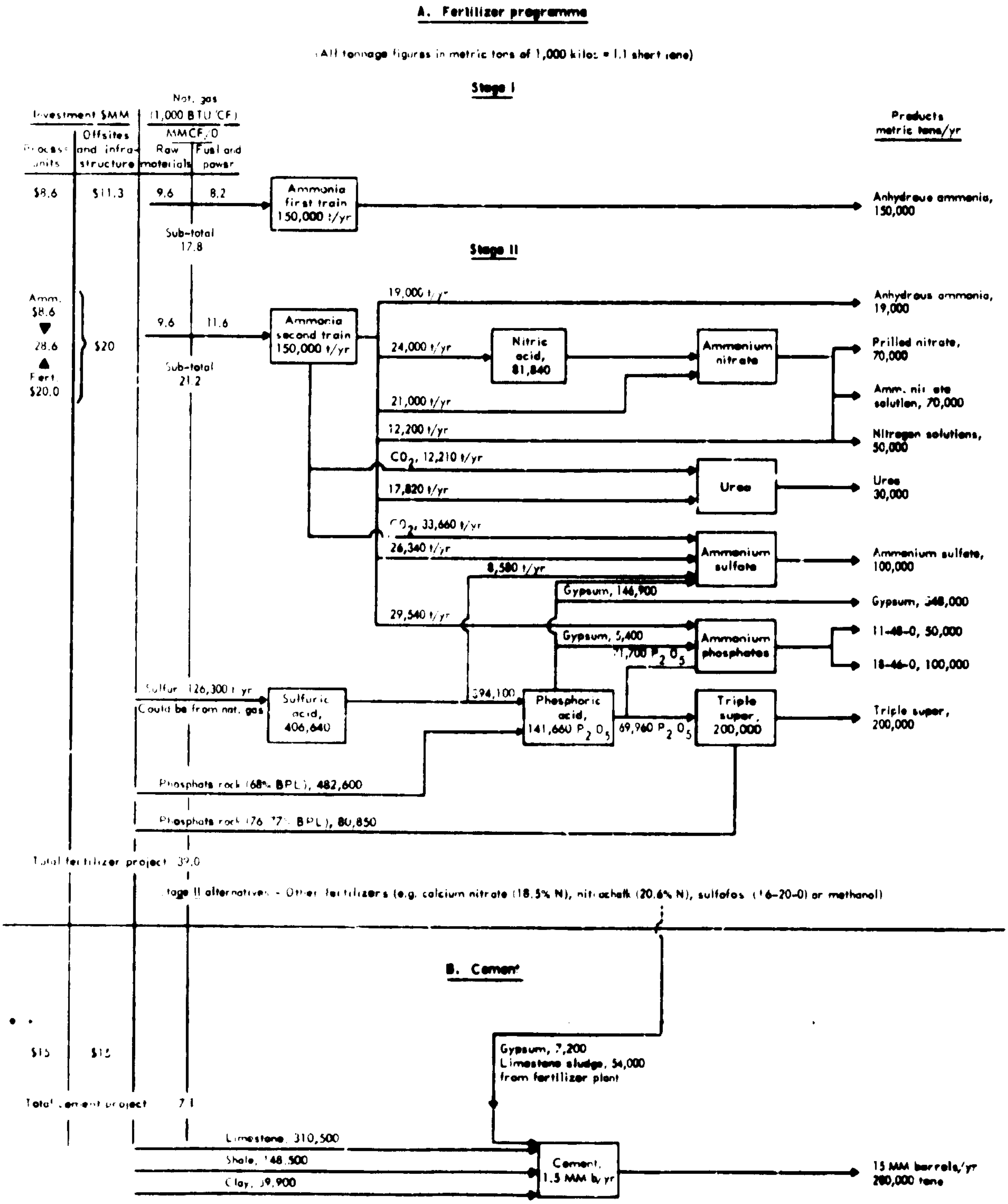

Figure IV. *Example of stage-wise petrochemical programme based on natural gas*

harbour facilities already exist, considerable savings can obviously be realized.

Another promising area of gas utilization is cement manufacture. Although, strictly speaking, cement is not a petrochemical, it is an important addition to the basic economy of a developing country. Not only is much cement needed for construction, but, in producing countries, large quantities are also used in the oil fields. In most locations, the raw materials — limestone, shale and clay — are available. Furthermore, a cement operation might tie in with the fertilizer programme, in that by-product gypsum from a phosphoric acid plant and limestone sludge could be utilized.

A third potential for broadening the petrochemical base is in the area of plastics monomers and electrochemicals. An electrochemical industry — and, particularly, the manufacture of chlorine and aluminium — is predicated on the availability of low-cost power, which could be made from natural gas. Chlorine and natural gas would provide a route to vinyl chloride monomer, either via acetylene or via ethylene, as shown in alternatives 1 and 2, respectively, of figure V.

Vinyl chloride monomer is an intermediate in the manufacture of polyvinyl chloride (PVC) plastics. Consumption

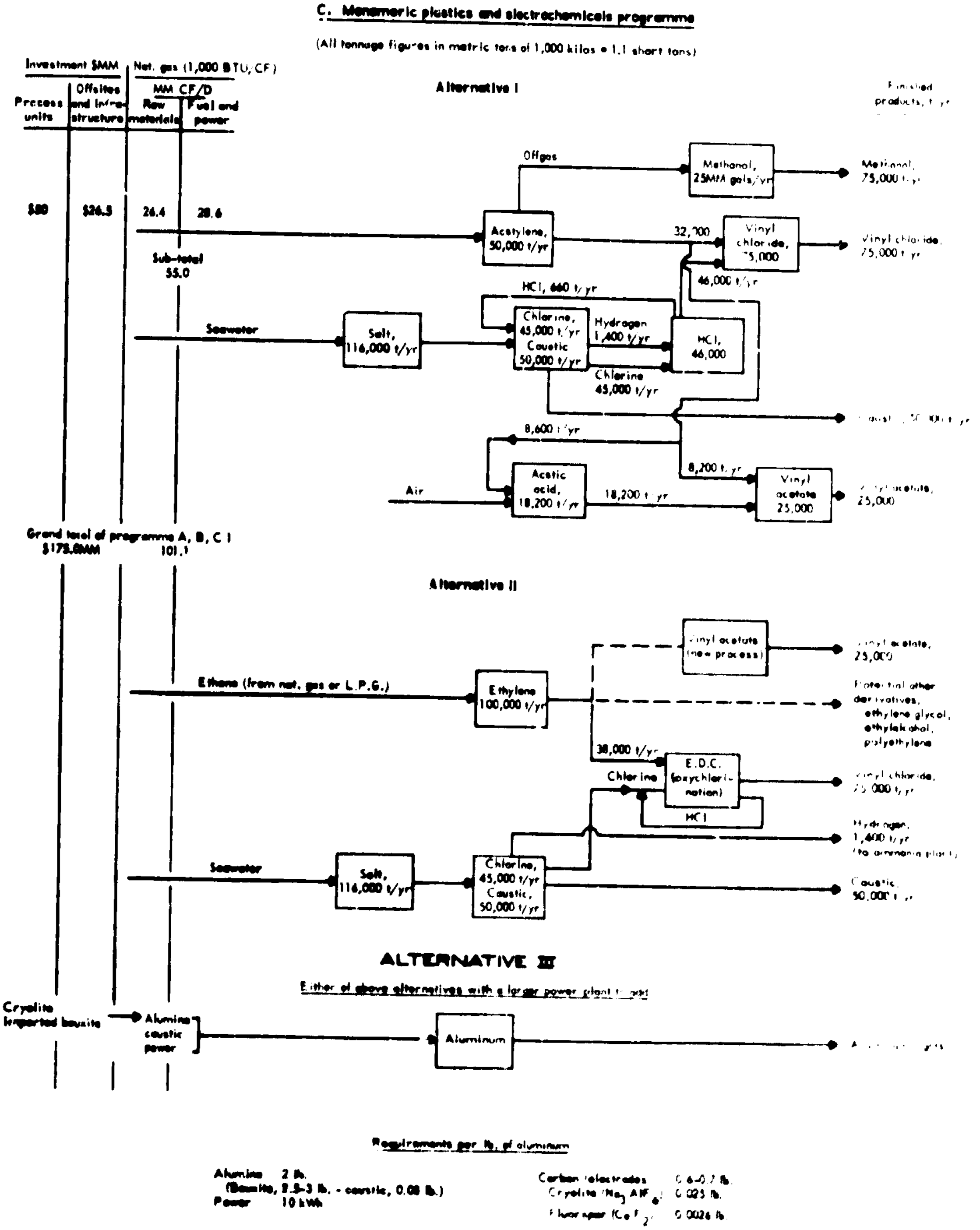

Figure V

of PVC is rapidly growing virtually everywhere. The industry in Europe is largely integrated all the way from the raw material to the polymer. If the complex is to be competitive, a large PVC plant is required. The monomer can be made economically only on a very large scale, but polymerization plants of a relatively small size — say 5,000-10,000 tons a year — can be operated successfully, provided they have access to low-cost monomer. For this reason, it is believed that a large vinyl chloride monomer plant in North Africa or on the Persian Gulf, which would supply several polymer plants in the surrounding countries, would have a sound economic justification. This has been borne out by preliminary market surveys.

If the acetylene route is taken to produce vinyl monomer, methanol would be a logical by-product. This commodity is traded worldwide in large volume. It is the precursor of formaldehyde, which, in its turn, leads to numerous resins. We already had occasion to mention the urea formaldehydes.

The modern trend in vinyl chloride manufacture, however, appears to favour the ethylene route, although much will depend upon the cost of natural gas. If the monomer is made via ethylene, methanol could still be made. In this case, it would be as an adjunct to the ammonia operation, because the synthesis gas made for ammonia would also provide a logical starting point for methanol.

The ethylene alternative would pave the way for the manufacture of various other chemicals, such as: polyethylene, ethylene oxide, ethylene glycol and ethyl alcohol. Markets for these products could be built up over a period of time.

Incidentally, the large quantities of caustic obtained as a co-product of chlorine, combined with the availability of low-cost electric power, would provide a good basis for an aluminium industry, as is shown in alternative 3 of figure V.

The few examples cited above by no means exhaust the petrochemical possibilities that could be envisaged for producer nations but may serve to indicate what can be accomplished in a relatively short time. From a longer-range view, the potentials are virtually limitless, as the case of the United States Gulf Coast has demonstrated. It was barely twenty-five years ago that the first plant to make chemicals from petroleum refining gases was constructed there. Yet, today, the area accounts for nearly two-thirds of the basic organic chemicals produced in the United States. Of course, developments on the United States Gulf Coast were greatly speeded up and simplified by a number of circumstances, not the least of which was the vastness of the home market. The United States experience emphasizes the critical part that access to consumer areas plays in the realization of a nation's petrochemical potentials. The pace at which such potentials become realities in North Africa and the Persian Gulf will be largely determined by the off-take arrangements that can be made with other nations.

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6. PROSPECTS OF DEVELOPMENT OF PETROCHEMICAL INDUSTRIES IN INDIA AND OTHER COUNTRIES OF ASIA AND THE FAR EAST

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I. INTRODUCTION

In the ECAFE region, petrochemical industries have developed intensively in Japan in the last few years. Since ethylene is the cheapest and, therefore, the most important building block of the organic chemical industry, its production serves as a yard-stick for comparing the magnitude of petrochemical production in different countries. At present, Japan occupies the fourth place in the world with a total capacity for ethylene production of about 505,000 tons per year, compared with that in the United States of 3.971 million tons.[1] It is expected, however, that on completion of projects under construction, Japan will take the second place with ethylene capacity of the order of 1.3 million tons a year.

Australia is the only other country in this region with an established ethylene capacity by the petrochemical route of about 71,000 tons. With regard to India, at present, ethylene derived from alcohol of the order of 15,000 tons is used in the production of polyethylene and styrene. However, by 1966 it is expected that India will have petrochemical ethylene available to the same extent as in Australia today, and there are plans to increase this capacity substantially in the next few years. In this region, Pakistan seems to be the only other country which has definite plans for the production of petrochemicals in the near future.

II. BACKGROUND FOR PRODUCTION OF PETROCHEMICALS, INCLUDING FERTILIZERS

The above situation arises from the fact that in this region, until recently, the demand for the principal petrochemical products, *viz.*, fertilizers as well as synthetic plastics, rubbers and fibres, has been small. Populations in this area have so far been engaged primarily in exploiting natural resources and in agriculture. The spread of alluvium by many rivers has maintained the fertility of soils without much use of fertilizers, and helped to ensure an adequate food supply in most countries and, in some instances, notably in Burma and Thailand, provided even a surplus for export. Natural rubber grown in countries like Malaysia, Indonesia, Thailand and Ceylon, was the main source of supply of the world's automobile industry before the Second World War and even now is an important source of supply. Cotton, silk and wool grown in the area in substantial amounts met the demand for fibres. Thus, while the needs of a simple agricultural life were met by natural products available in the area, the populations did not have incomes large enough to generate demands for sophisticated products like synthetic plastics. Therefore, until recently, in most countries in the area, the demand for organic chemicals was not large and the circumstances necessary for the establishment of petrochemical industries did not exist.

The situation is, however, changing rapidly in many countries with the adoption of national policies for rapid industrialization. Since the objective of the policies is to increase the earning capacity of the people so as to improve living standards, the areas chosen for rapid industrialization are such as would increase the availability of basic goods in the country. An urgent need is the necessity to increase the production of food to ensure a more satisfactory diet for the rising populations. This, in its turn, creates a demand for the application of fertilizers on a large scale.

III. FERTILIZERS IN INDIA — CONSUMPTION AND PRODUCTION

In India it has been recognized[2] that centuries of cropping and inadequate manuring have left the soils largely depleted in plant nutrients, and that, for stimulating bigger yields per acre currently and to build up soil fertility on a long-term basis, there is need for extensive application of fertilizers. This has resulted in a rapid increase in the consumption of nitrogenous, phosphatic and potassic fertilizers during the last five years, as shown in table 1 below.

TABLE 1

Year July-June	*Consumption in tons*			*Ratio*		
	N	P_2O_5*	K_2O	N	P_2O_5	K_2O
1959-1960	230,816	50,111	21,342	1	0.22	0.09
1960-1961	244,874	53,673	35,047	1	0.22	0.14
1961-1962	365,754	62,934	30,837	1	0.17	0.08
1962-1963	398,092	92,510	36,503	1	0.23	0.09
1963-1964	465,960	120,987	51,352	1	0.26	0.11

* Figures of P_2O_5 consumption are exclusive of rock phosphate directly applied to plantation crops. Such application in terms of P_2O_5 is estimated at about 10,000 tons per annum.

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[1] Cf. Supplement to *European Chemical News* of June 19, 1964.

Currently, fertilizer imports amount to 220,000 tons of nitrogen, with domestic production of about 250,000 tons of N/year. New factories under construction will increase the capacity for fertilizer production in the country to 500,000 tons of N in the fiscal year 1966-67 and about 1 million tons by 1968-1969. The Planning Commission have been considering for some time the target to be set for the production of nitrogenous fertilizers by the end of the Fourth Five-Year Plan, i.e., by 1970-1971. The programmes in hand show that a total capacity of 1.2 million tons of nitrogen will certainly be reached in that year. There is also under consideration a crash programme for increasing this capacity further to 2 million tons of nitrogen per year. In achieving this programme, it is proposed that units capable of producing 200,000 tons of ammonia per stream be established so as to benefit from the economics of large-scale operation.

IV. USE OF NAPHTHA FOR FERTILIZER PRODUCTION

Production of nitrogenous fertilizers depends upon the availability of a source of hydrogen. Until recently, the fertilizer industry in India used either electrolytic hydrogen, or hydrogen derived from carbonaceous materials like coke oven gas and coke. Partial oxidation or steam reforming of petroleum naphtha, natural gas and refinery gases, as well as gasification of coal and lignite, would be the more important sources in the future.

In conformity with the general trend the world over, in the next few years, an increasing proportion of synthetic ammonia will be made from petroleum naphtha. For example, at the current level of production of 250,000 tons N, naphtha is the raw material for about 5 per cent of it. When the production reaches 500,000 tons, the proportion derived from naphtha will be 20 per cent, whereas with a further increase in the figure to one million and two million tons of nitrogen per year, naphtha will be the raw material for 35 and 60 per cent, respectively. Thus, by 1970-1971, the requirement of naphtha for the production of fertilizer nitrogen will be of the order of 1.1 million tons per year. At the same time, because of the relatively low cost of coal at the pit-head, there will still be some scope for the production of nitrogenous fertilizers by gasification of coal.

V. AVAILABILITY OF NAPHTHA

Naphtha required for fertilizer production is expected to be readily available within the country. In order to meet the internal needs of kerosene, diesel oil and furnace oil, India has a plan to establish a petroleum-refining capacity, based on domestic as well as imported crudes, of the order of 15 million tons by 1965-1966, and 28 million tons by 1970-1971. Even though the refineries are designed to yield a small gasolene fraction, there will be a considerable surplus of it available as petroleum naphtha, because of a low requirement of motor gasolene for the small passenger-car population in the country. The estimate of surplus petroleum naphtha by 1970-1971 is of the order of 3.0 million tons per year, a figure that would provide all the raw material for the fertilizer as well as the petrochemical programmes under contemplation, and still leave a surplus for power production and export.

VI. SCOPE FOR IMPORT OF LIQUID AMMONIA

The position described above is important in the context of a suggestion often made that in this region large ammonia plants be established where there is an abundant supply of raw materials such as natural gas, and liquid ammonia be supplied to other countries for making nitrogenous fertilizers. At the ECAFE Conference on the Development of the Fertilizer Industry in Asia and the Far East, held in Bombay in November 1963, it was stated that even if a part of the hundreds of million standard cubic feet of natural gas that is flared every day in the Southern Iranian oilfields, is converted into ammonia in Iran in a 150,000-tons-per-year ammonia plant, then the same could be shipped and stored at a port in Western India at a cost of $U.S. 45 per ton. It is now known that with the adoption of the steam reforming process for naphtha in a plant with a capacity of 200,000 tons per year or more of ammonia, cost of domestic production can approach the delivered price of liquid ammonia stated above. Also, utilization of naphtha for fertilizer production would help considerably in solving the problem of disposal of surplus naphtha. In view of this situation, as well as the balance of payments problem that every developing country has to face, it seems doubtful whether import of liquid ammonia on a sustained basis will prove attractive to a country in this region.

VII. ORGANIC CHEMICAL INDUSTRIES IN INDIA — BEGINNING WITH ALCOHOL AS RAW MATERIAL

Organic chemical industries started in India with industrial alcohol as a raw material. Some alcohol was produced from molasses soon after the establishment of a substantial sugar industry in the country in the 1930s. Its production, however, received considerable impetus with a decision of the Government to use power alcohol as motor fuel in admixture with petrol, under the Power Alcohol Act of 1948. By 1955, production of alcohol had reached 10 million gallons a year and it was already being used as a raw material for the making of cellulose acetate, acetone and DDT, in units with capacities of the order of 1,000 tons a year. At that time, a feeling grew in the country that the increasing availability of molasses-based alcohol at low cost was a national asset that ought to be used for the production of diverse chemical products such as plastics, solvents and synthetic rubber, particularly because until that time alternative raw materials commonly employed for their production, *viz.*, petroleum crudes or natural gas, were not available in the country to the desired extent. Government, therefore, appointed the Power Alcohol Committee to examine the problem in all its aspects and to recommend measures for increasing the production of alcohol in the country as well as for its rational utilization for different purposes.

The Committee observed that it should be possible to raise the production of alcohol to about 45 million gallons by 1960-1961. It recommended also that a major proportion of the alcohol could be consumed as a raw material for the production of polyethylene, acetic acid and acetic anhydride, cellulose acetate, and butadiene required for the making of SBR rubber. With the exception of the SBR unit, the capacity for production of the other chemicals was rather small in relation to present-day standards. This was so partly because the demand for such chemicals was small at that time and also because the amount of alcohol available near any single location was rather limited. In making these recommendations, the Committee was aware that the use of alcohol as a raw material would be somewhat expensive in comparison to raw materials derived from petrochemical sources. It was, however, felt that since the latter were not available in the country, introduction of an organic chemical industry based on alcohol might serve as a first step to its later development as a petrochemical industry, by the introduction of newer techniques and the creation of a larger demand for the products. On the basis of the Alcohol Committee's Report, licences were issued for production of various organic chemicals and most of the units were established by 1962-1963, i.e., the first year of the Third Five-Year Plan. Current production of industrial alcohol is of the order of 33.2 million gallons a year and its use for admixture with motor fuel was discontinued in early 1963.

Simultaneously with the development of the alcohol industry, plans were made for the recovery of benzene, toluene and naphthalene from coke ovens that were being set up in the three new steel works in the public sector. Also, in the same period, two units licensed for PVC contemplated the use of acetylene obtained from calcium carbide produced in an integrated chemical complex.

VIII. THE PETROCHEMICAL COMMITTEE — PLANS FOR A PETROCHEMICAL INDUSTRY

Towards the end of the Second Five-Year Plan, the prospects of a wider raw material base for organic chemical industries appeared promising as a result of a petroleum-naphtha surplus that was expected to occur with the planned development of petroleum refining in the country. Natural gas appeared as a possible raw material in some areas. It was also anticipated that although the availability of benzene from coal carbonization would increase from about 5,000 tons at that time to 50,000 tons by 1965-1966, the demand for the same would be very much greater, i.e., of the order of 80,000 tons per year. The gap could be filled only by organizing the production by the petrochemical route. A reappraisal of the programmes and levels of development of organic chemical industries, thus, seemed necessary, and in October 1960, Government appointed the Petrochemical Committee to study the subject in all its aspects and to evolve a plan for organizing the production of synthetic rubbers, plastics, insecticides, detergents and organic solvents as petrochemicals during the Third and the Fourth Five-Year Plans. The Petrochemical Committee submitted its report to Government in 1962.

A. *Synthetic plastics*

The Petrochemical Committee estimated the likely requirements of many organic products by 1965-1966 as well as 1970-1971. The total requirement of polyethylene, PVC, polystyrene and polypropylene was estimated for the two years, at 90,000 and 280,000 tons respectively. A recent reassessment shows that it is likely that polypropylene might not be made in the country by 1970-1971, but that the total requirement of the three other plastics would rise to a figure of about 400,000 tons per year. This compares with the present production of about 25,000 tons. This expansion will be achieved by establishing new units that will have individual capacities of the order of 30,000 tons per year, as well as by expansion of existing units simultaneously with a change-over to petrochemical ethylene as a raw material rather than ethylene derived from alcohol, and acetylene obtained from calcium carbide. There would also be need for plasticizers corresponding with the production of PVC.

B. *Synthetic rubber*

The demand for rubber of all types was estimated at 140,000 tons by 1965-1966 and 280,000 tons by 1970-1971. After taking account of natural rubber grown in the country, these figures of consumption seemed to justify the establishment of one unit each for the production of butyl, cis-1-4-polybutadiene and cis-1-4-polyisoprene rubbers. Butyl rubber is already used in the country to a considerable extent for the manufacture of automobile tubes. Its use would become general for the production of all automobile as well as bicycle tyre tubes when butyl rubber is made in the country. The isobutylene and isoprene required for its production are expected to be available in one of the proposed petrochemical complexes.

The recommendation in favour of polybutadiene and polyisoprene was made because SBR can be used only to a limited extent in the production of truck tyres and the existing unit can supply all needs for the next few years. At one time, it was expected that cis-1-4-polybutadiene would be able to replace natural rubber to a considerable extent. Recent experience shows, however, that on rough and unpaved roads, serious chipping and chunking might occur. Polyisoprene has been introduced more recently. In India, there is some difficulty in finding an adequate amount of starting raw materials for the production of polyisoprene; its cost of production is also rather high. Under these circumstances, it is likely that production of polybutadiene may come up earlier than that of polyisoprene or other newer synthetic rubbers.

A recent assessment of the requirement of rubber shows that consumption is increasing at a somewhat slower rate than that estimated by the Petrochemical Committee. The revised figures for consumption of all rubbers are about 110,000 tons by 1965-1966 and 220,000 tons by 1970-1971. Under these circumstances, the immediate necessity is to proceed with the establishment of a plant for butyl rubber, to be followed by one more unit for cis-1-4-polybutadiene for operation towards the end of 1969.

C. *Synthetic fibres*

Regarding synthetic fibres, the Committee had felt that major developments in this sector will take place in the Fourth Five-Year Plan. Actually, production of nylon 6 filament yarn has already commenced and a unit for polyester staple fibre will be in operation early in 1965. At present, these units will have to import caprolactam and DMT, respectively. Plans are, however, under discussion for making both these intermediates on a large scale in order to increase rapidly the production of synthetic fibres. This has become necessary not only for the purpose of replacing imported natural fibres like cotton and wool, but also because of the necessity to provide mixed fabrics of the drip-dry type. In view of the warm climate in most parts of the country, proposals are also under consideration for organizing production of synthetic fibres with properties similar to those of cotton.

D. *Detergents*

Dodecyl benzene was another item recommended by the Committee for production because of an anticipated increase in the use of synthetic detergents. The market for detergents is expected to increase rapidly in India because even at the current rate of consumption of soap of 0.6 kilogramme *per capita* per year, it is no longer possible to find in the country sufficient vegetable oils for production of the conventional types of soap. With increase in industrial employment arising from the Five-Year Plans, the demand for soap is bound to rise further very shortly. Also, middle-class families will find it increasingly difficult to obtain domestic help, and housewives will have to do their own washing, as is already the case in developed countries. This is another factor that would increase the use of detergents rapidly. At present the detergents are based on hard alkylates, because their very limited consumption and main use by populations of cities situated on the sea, ensures that the problem of effluent disposal, that has become serious in Germany and the United States, will not be of significant magnitude in India at least for a decade. It might be stated, however, that although at present hard alkylate detergents are being introduced in the Indian market, the possibilities of making products based on ethylene oxide, fatty alcohols or soft alkylates are also under investigation.

E. *Other organic chemicals*

Among other products recommended by the Petrochemical Committee, methyl alcohol, phthalic anhydride, acetone and aromatic hydrocarbons are particularly important. One unit for the production of about 33,000 tons of methyl alcohol per year is under constructions. The units to be set up for phthalic anhydride will be able to use either naphthalene or orthoxylene as the raw material. Acetone will be made in the petrochemical complex that is being set up in Bombay. Benzene will also be made in the Bombay complex as well as in a BTX unit under consideration at the petroleum refinery in Gujarat.

F. *Petrochemical complexes*

In order to accomplish the programme set out in its Report, the Petrochemical Committee has recommended the establishment of four naphtha crackers in different parts of the country, each with a naphtha throughput of the order of 200,000 tons per year. The intricate problem of ensuring full utilization of all the ethylene and propylene produced in such a cracker has been solved for the first unit to be set up in Bombay by the National Organic Chemicals. This will have a throughput of approximately 225,000 tons of naphtha per year and will yield 60,000 tons of ethylene and 35,000 tons of propylene. The main products will be:

20,000 tons of linear polyethylene (to be made by the associated company PIL);
30,000 tons of vinyl chloride monomer, of which 20,000 tons will be converted into PVC;
7,200 tons of butadiene;
11,000 tons of acetone;
14,000 tons of benzene;
12,000 tons of ethylene oxide; and
8,000 tons of 2-ethyl hexanol, and 8,000 tons of butanol, by the oxo synthesis.

This complex is expected to commence production towards the end of 1966.

The pattern of production of another complex of similar size essentially in the public sector, near the Gujarat refinery, is under active consideration. Precise programmes for two more complexes, one in South India and the other in the Eastern part of India, will be considered as soon as arrangements are finalized for the establishment of petroleum refineries in these areas. The four petrochemical complexes will be exclusive of other integrated units, which may have smaller captive naphtha crackers for supplying their own needs of ethylene. When this programme is implemented, the total production of organic chemicals is likely to approach a million tons per year.

IX. CONCLUSION

The history of the growth of an organic chemical industry in India from small beginnings with traditional raw materials into a full-fledged petrochemical industry might serve as a useful guide to other developing countries. Sometimes there is a criticism that, instead of establishing four naphtha crackers with an ethylene capacity of the order of 60,000 tons a year, it would have been an advantage if a single cracker was established in India of a size comparable with present international standards, i.e., with a capacity for ethylene of the order of 200,000 tons per year. Such criticism overlooks the fact that, in the first place, the naphtha required for operating a cracker of such size would not be available from a single refinery. For reasons of satisfactory distribution at low cost, refineries with a crude throughput of the order of 2 to 3 million tons a year have had to be established at port towns separated from each other by distances of several hundred miles. Transport of naphtha from such scattered refineries to a single point, as well as further transport of the finished products to all destinations, would add considerably to its cost. The other difficulty is that if a single petrochemical complex of this magnitude was set up, it might be difficult to find ready markets for all the products, because prior to the establishment of the cracker, it would not have been possible to import such products in the requisite amounts on account of shortage of foreign exchange. Undoubtedly the cost of production of all products made in a cracker with a smaller ethylene capacity would be somewhat high, but this by itself need not serve as a deterrent to the successful accomplishment of the programme. Even in international markets, prices of many petrochemical products have been falling rapidly, and yet the older naphtha crackers with small capacity continue to remain in operation. It is, therefore, desirable that in planning petrochemical industries in the developing countries, a judicious choice between a size which is regarded as comparable with international standards, and a capacity that can be considered as adequate for meeting immediate needs in the country, may have to be made. From this point of view some countries might find it worthwhile to set up units where no attempt is made in the beginning to find an economic use for all building blocks provided by naphtha crackers, but merely recover ethylene for conversion into polyethylene or PVC, and use all residual gases for the production of nitrogenous fertilizers.

7. THE ECONOMICS OF INTERNATIONAL DISTRIBUTION OF ANHYDROUS AMMONIA

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I. INTRODUCTION

Anyone who visited the World's Fair in New York City probably noticed the display of demographic data by a prominent insurance company. In large number visible for a considerable distance, this display keeps a running count of the net change in the population of the United States which amounts to one additional person every twelve seconds. Now this, in itself, may not seem to be such a rapid rate of gain, but visitors attending the Fair for more than a few days have generally been surprised that the total very quickly swells to more than 50,000 new Americans every week.

The world's population is growing considerably faster, adding one new person every two seconds for a total gain of more than 300,000 persons every week. At this moment, there are somewhat more than three billion people living on the earth and every three and a half weeks, another million persons have joined the throng.

Today, more than 10 per cent of the earth's people are literally starving, most of them living in the Near and Far East, Africa and Latin America. Fully one-half the world's people are receiving either too little nourishment or the wrong kind to maintain their health adequately. By the year 2,000, more than 6 thousand million persons are expected to occupy the earth and our food shortage is likely to be infinitely worse than it already is.

In recent years, there have been some improvements in agricultural production. Last year, for example, the Food and Agriculture Organization of the United Nations reported that annual world agricultural production increased between 2 and 3 per cent over 1962 food output. In fact, food output gained faster than the world population did last year. But during the last five years, world food production on a *per capita* basis, has changed very little and what slight increase in food output has been gained, has occurred in regions where it is needed least — in the already well-fed nations of Western Europe, North America, Oceania and the so-called River Plate countries of South America — Uruguay, Paraguay and Argentina. But it is clearly recognized that the greatest future population growth will come in regions where undernourishment and famine are most prevalent now in the developing nations. Thus, it is vital that we consider, today, the role of the petrochemical industries in providing raw materials for use in producing urgently needed food in these developing nations.

Because of the pressure of rapid population growth, the agricultural production of the developing nations of the Near East, Far East, Africa and Latin America must increase rapidly in the coming decades, even to maintain today's meagre diet. And to provide just barely adequate food supplies for decent living for all people in these countries, the developing nations must increase their food output several times faster than they have been able to do in recent years. An increase of 4 per cent per year in food output is considered absolutely essential by most world food experts; yet in recent years, their food production gains have averaged just over two per cent per year.

Several methods of increasing food production are being pursued with success — better varieties of crops and livestock, improved water practice, reduced loss by pests and disease, better agricultural production and food processing equipment and techniques, as well as revolutionary proposals for increasing protein production by various unconventional means. But it is generally agreed that improvement in soil fertility through the use of chemical fertilizers offers the most tangible and immediate promise of a decent diet for all the world's peoples.

In the nutrition of food crops, three primary nutrients are of fundamental importance — nitrogen, phosphorous (expressed as P_2O_5) and potassium (expressed by K_2O).

The role of nitrogen is, far and away, the most significant for our consideration here, because this basic protein-building block is removed from soils in the greatest quantities by crops such as cereal grains, maize and soybeans. Nitrogen must also be replenished frequently to ensure crop growth because it is not stored in the soil as readily as many other nutrients. And, of course, nitrogen fertilizers require our attention here, because they can be produced from petrochemical raw materials and represent a significant portion of the world's potential consumption of petrochemical materials.

Because of its central importance, nitrogen has become the largest volume plant nutrient added to soils, making up 36 per cent of total fertilizer used. The demand for nitrogen is growing rapidly, because it has proven to be such an effective and efficient means for improving crop yields, although it is important to remember that crops require a variety of vital nutrients, and nitrogen alone cannot do the whole job. Generally, farmers who have used nitrogen fertilizers have gained far more in the increased value of their bumper crops than they have paid for the fertilizer they used to produce these bumper crops, and in the developing nations, where cultivation practices are not very intensive, farmers who apply fertilizers to their soils almost always get great improvement in crop yields.

II. THE WORLD NITROGEN SITUATION

The earliest nitrogen fertilizers were animal wastes such as manures and guano. Later, Chilean nitrates and ammonium sulphate became important nitrogen fertilizers.

Following the First World War, the manufacture of ammonia supplanted natural nitrogen sources, and today nitrogen fertilizers manufactured from synthetic ammonia supply most of the world's agricultural nitrogen requirements.

During the year July 1962 to June 1963, 15,434,000 metric tons of nitrogen materials were produced throughout the world, of which approximately 15 per cent represents ammonia used in industrial applications. Table 1, below, shows that the developing regions, Africa, Asia, and Central and South America, consumed more nitrogen than they produced. Conversely, the heavily industrialized regions of West Europe, and North America produced in excess of their domestic requirements.

Because of this imbalance in production and consumption, 3.3 million tons of nitrogen were exported from producing countries during the year 1962-1963. Essentially, all of these exports were of solid nitrogen fertilizers, with three classes of materials, ammonium sulphate, ammonium nitrates and urea, representing 76 per cent of the total trade. Other solid nitrogen fertilizers significantly involved in world trade are sodium nitrate, calcium nitrate, and complex fertilizers such as ammonium phosphates, which contain more than one of the primary nutrient materials.

Several things are noteworthy about world trade in nitrogen fertilizers. Despite the rapid increase of anhydrous ammonia production facilities in the developing countries, particularly in India, Pakistan and China (Taiwan), the volume of nitrogen imports by these nations has grown substantially in recent years.

Coupled with this strong and growing demand for nitrogen fertilizer in developing countries is the trend to higher concentrations of nitrogen fertilizer. Anhydrous ammonia (82 per cent N), urea (45 per cent N), ammonium nitrate (33.5 per cent N) and ammonium phosphates (11-21 per cent N) are rapidly becoming large tonnage products in world trade because it is significantly more economical per unit of nitrogen to distribute a ton of anhydrous ammonia containing 82 per cent nitrogen than say, a ton of ammonium sulphate at 20.5 per cent nitrogen.

World-wide methods and rates of fertilizer application are likewise changing so that it is not uncommon to hear of applications of nitrogen to the soil in the ranges up to and even exceeding 150 pounds per acre. These heavier application rates per acre have encouraged the use of more concentrated forms of nutrients, so that handling costs are minimized. Perhaps the most significant development in this area has been the rapid growth in the direct application of anhydrous ammonia to the soil in recent years. This method of applying nitrogen was developed in the United States in the early 1950s and has grown very rapidly from 217,000 tons of anhydrous ammonia in 1952-1953 to more than 1,185,000 tons in 1962-1963.

Generally speaking, it has been our experience that in areas where the use of direct application anhydrous ammonia is new, application rates start at relatively low levels of approximately 60-80 pounds of ammonia per acre for small grains and 80-100 pounds of ammonia per acre for application to maize. As farmers gain experience in the direct application of anhydrous ammonia, rates of application tend to increase to around 120-150 pounds per acre for small grains and as high as 200 pounds per acre for application to maize.

Underlying the growth of this practice of application of anhydrous ammonia directly to the soil is economy. It is simply more efficient per unit of nitrogen to transport and apply the more concentrated forms of nitrogen fertilizer.

III. A NEW CONCEPT OF WORLD DISTRIBUTION OF [illegible] ANHYDROUS AMMONIA

In recent years, a major technical and economic break-through has been accomplished in the development of a means of transporting liquid anhydrous ammonia at 28°F at, essentially, zero pressure. This technical achievement has made it economically feasible to transport shiploads of anhydrous ammonia over long distances at a relatively low unit cost per ton. Some of the technical details of two specially designed anhydrous ammonia cargo vessels owned by Oswego Chemical Carriers Corporation and chartered by W. R. Grace & Co. to transport this commodity to various parts of the world, will be discussed later.

The ability to transport anhydrous ammonia economically by tanker has been joined to an equally significant technical and economic break-through in the production

TABLE 1. WORLD NITROGEN PRODUCTION AND CONSUMPTION, 1962-63
(Figures in thousands of metric tons of nitrogen)

	Production	*Consumption*
West Europe	5,581	4,523
East Europe	2,424	2,358
Africa	250	461
North America	4,623	4,560
Central America	116	347
South America	222	213
Asia	2,191	3,064
Australasia	27	60
WORLD TOTAL	15,434	15,586

SOURCE: *Nitrogen* (British Sulphur Corporation, January 1964), p. 12.

of anhydrous ammonia in Trinidad by W. R. Grace & Co. In 1957, this firm erected a small plant at Point Lisas, Trinidad for the production of 35,000 tons per year of anhydrous ammonia which was converted to ammonium sulphate and urea. These products were marketed in the adjacent Caribbean area. At this plant site, natural gas, a key raw material in the manufacture of anhydrous ammonia, was available at a reasonable price, electric power was generated using natural gas as a primary fuel, a deep water harbour was adjacent to the plant site, and the labour and political climate were favourable. Thus, when it became economical to ship anhydrous ammonia world-wide in recent years, markets of considerable size were opened and all of these factors combined to favour a major expansion of the production of anhydrous ammonia in Trinidad and Tobago. In January 1964 the expanded plant with a production capacity of 230,000 tons per year of anhydrous ammonia was put into operation at Trinidad and Tobago.

The same company is now constructing still another large anhydrous ammonia production unit which will have a production capacity of 230,000 tons of anhydrous ammonia per year. The total plant output of 495,000 tons per year of anhydrous ammonia will make Grace's Trinidad plant one of the largest anhydrous ammonia production centres in the world.

The ammonia is sold throughout the world after being stored locally in terminals owned wholly or in part by W. R. Grace & Co. or wholly by others. This firm has recently formed a company for the distribution of ammonia for direct soil application in Denmark where direct application of ammonia has gained a foothold and is growing very rapidly. Currently, between 20,000 and 25,000 tons per year of anhydrous ammonia are applied directly to the soil in Denmark.

The use of ammonia for direct application is also growing in Sweden, Northern France, and has been introduced in other European countries. Terminals have been established in the Thames Estuary in the United Kingdom and at Tampa, Florida, where anhydrous ammonia is sold to other companies for conversion into a variety of nitrogen fertilizers or N-P-K mixed fertilizers. Similar ammonia terminals are under construction in Canada and Finland. These terminals are owned by others and are linked to nearby chemical plants which will convert the anhydrous ammonia to various kinds of nitrogen fertilizers and N-P-K mixed fertilizers.

IV. A FERTILIZER INDUSTRY BASED ON TRINIDAD ANHYDROUS AMMONIA

The establishment of low-cost bulk ammonia shipment opens a completely new approach for developing countries to become basic manufacturers of their fertilizer requirements and to establish an industrial complex that can employ their people usefully as well.

Many developing or newly emerging nations clearly realize the importance of sound agricultural development to their over-all development. Agriculture's most essential contribution to the economic development of a country is to provide the additional food required for a growing population, as well as its needs for fibres, building materials and other industrial raw materials of agricultural origin.

Developing countries are faced with the huge task of feeding their ever-growing populations and of finding gainful employment for greatly increased numbers of workers. I would like to suggest here a plan which it is felt will make a major contribution towards solving a portion of each of these problems.

The first consideration of a developing country in establishing a fertilizer industry should be to assess its own needs for these products. Careful consideration must be given to the attitude of the farmer and his knowledge of the use of fertilizers, his lack of modern farm machinery, and his limited awareness of, or reluctance to try, the improved crop varieties and agricultural chemicals that are now available to him. These factors deter the growth of fertilizer application and tend to lengthen the number of years required to get fertilizer consumption levels in economic balance with the proposed output of any fertilizer plant a developing nation might construct. In some areas, adjoining developing countries could conceivably combine their requirements or consideration could be given to the manufacture of fertilizers for export. However, both of these courses are not without considerable risk and difficulty.

There have been many small ammonia synthesis plants built in the world, which, because of the economics of ammonia production, have become high-cost producers demanding a substantial government subsidy in order to survive. The following factors are chiefly responsible for the high cost of ammonia produced in relatively small-scale units:

(*a*) The high capital cost of installation;

(*b*) Small initial market for plant output because of farmers' reluctance. This, in turn, minimizes efficient production which depends on full-volume, continuous operation;

(*c*) Lack of plentiful, low-cost hydrocarbon feed-stock necessary for ammonia production;

(*d*) Imported oil or hydrocarbon feed-stocks at a relative high cost;

(*e*) High cost of electric power or lack of power generating facilities which will add materially to the original capital investment and production cost;

(*f*) Lack of technically trained personnel to operate the plant.

W. R. Grace & Co. by its establishment of the vast Trinidad anhydrous ammonia production complex and its pioneering experience in refrigerated terminal storage and distribution by refrigerated tankers, offers to developing nations a means whereby a fertilizer industry can be established.

Such a new fertilizer industry could be based upon the concept of a refrigerated ammonia terminal and adjacent production facilities for converting the anhydrous ammonia to nitric acid, ammonium nitrate, calcium ammonium nitrate, nitrogen solutions, urea, ammonium sulphate and finished N-P-K compound fertilizers. The production scheme would be tailored to manufacture the fertilizer products required specifically for that nation's agricultural needs.

Total capital investment for a complex of this nature would be far less than that required to install ammonia synthesis facilities in the developing country. It would also avoid the necessity of constructing a rather costly small-volume ammonia plant to serve a market that is growing slowly.

We have recently evaluated the potential of a number of developing countries for utilizing this type of complex and feel that it can be economically feasible under a wide range of conditions.

W. R. Grace & Co. has established a fertilizer manufacturing facility based upon this concept at Wilmington, North Carolina. At this location, Trinidad anhydrous ammonia (see photograph I) is being discharged from the *William R. Grace* anhydrous ammonia tanker to a 20,000-ton refrigerated storage tank. The plant facilities consist of a nitric acid plant, ammonium nitrate unit, calcium ammonium nitrate facilities and a plant for manufacture of a number of different nitrogen solutions which are used both for manufacturing compound fertilizers and for direct application to the soil.

While this plant is sized and the types of product manufactured are intended particularly for the agricultural demands of the East Coast of the United States, this scheme could be employed in a developing nation on a somewhat smaller scale by tailoring the plant size and finished products to the agricultural needs of that nation.

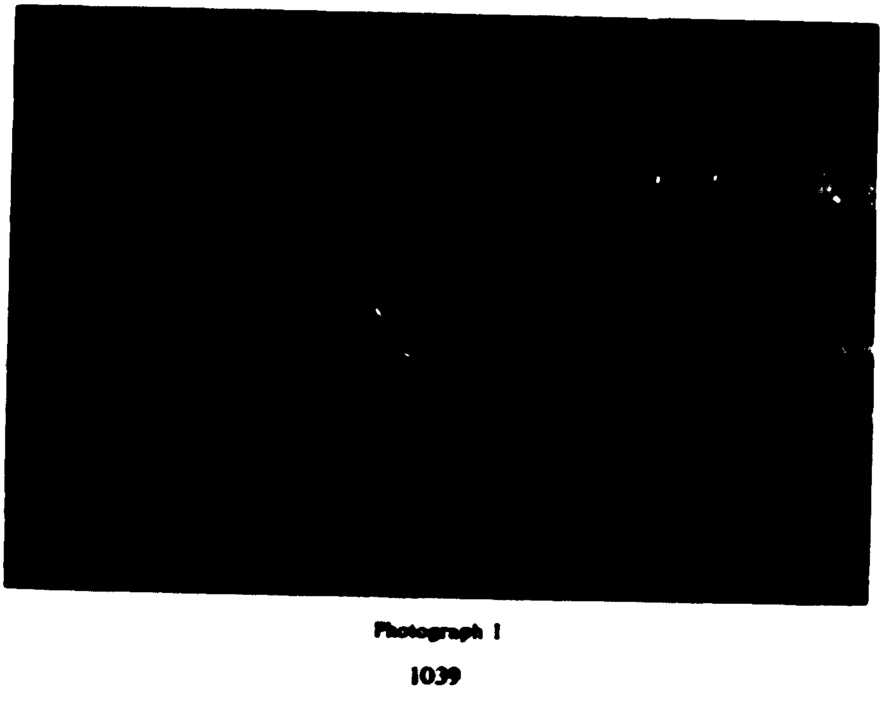
V. REFRIGERATED ANHYDROUS AMMONIA TANKERS

The world's first sea-going tanker designed expressly for the international shipment of anhydrous ammonia as a refrigerated cargo was launched on January 15, 1964 at the Verolme United Shipyards in Rotterdam, the Netherlands (see photograph II). The tanker was delivered to its owners, Oswego Chemical Carriers Corporation, on 19 June, 1964 and entered into service immediately transporting anhydrous ammonia as an agricultural fertilizer cargo from Point Lisas, Trinidad and Tobago to terminals on the Eastern seaboard of the United States. This tanker was designed to carry either a complete cargo of anhydrous ammonia at a temperature of -28°F, or a complete cargo of propane at a temperature of -44°F. Both cargoes would be transported at atmospheric pressure of essentially 0.5 to 2.5 pounds per square inch gauge. The characteristics of the vessel are as follows:

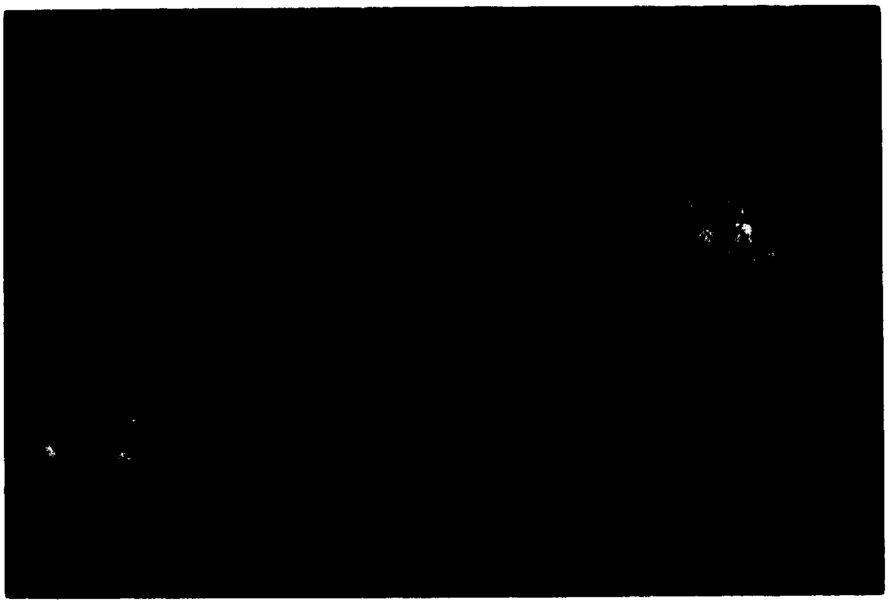
Over-all length	513
Moulded breadth	69.6
Moulded depth	41
Draught in sea water	24.8
Trial speed at full draught	17 knots
Deadweight, long tons	9,850
International gross-registered tons	10,001
International net registered tonnage	6,061

This tanker was built under special survey of the American Bureau of Shipping to their highest class, ✠ A1 (E) with a special notation that the cargo holds are suitable to carry liquefied petroleum gas cargoes at atmospheric pressure and temperatures as low as -50°F. The tanker meets the full requirements of the United States Coast Guard for carrying cargoes of anhydrous ammonia and the liquefied petroleum gases (LPGs) of propane, butane and butadiene.

The hull is of all-welded construction made of normal ship's steel. The ammonia cargo is carried in four insulated individual cargo holds which are made of a normalized carbon steel. This steel has been especially heat treated to improve its notch toughness, that is, its ability



Photograph I



Photograph II

to resist a brittle fracture at temperatures between -20°F to -50°F. Each hold is surrounded by a secondary barrier that is capable of containing the chilled cargo should a leak inadvertently occur in one of the primary cargo holds. A bone-dry inert gas is circulated through the void space that exists between the cargo hold and this secondary barrier. This void space is maintained at approximately 0.5 psig with inert gas to prevent the infiltration of moist sea air into the environment surrounding the chilled cargo tanks.

The four holds have a combined capacity of 9,300 short tons of anhydrous ammonia which has a specific gravity of 0.68 at an operating temperature of -28°F.

The cargo is loaded onto the tanker from shore storage tanks at a temperature of -27°F to -28°F. Heat gain into the cargo holds and into the loading lines is removed by a process known as the auto-refrigeration of the cargo. This means that the cargo vapours which are released from the free liquid surface are withdrawn into the first stage of a two-stage compressor and condensed at approximately 200 pounds pressure against a seawater coolant. The condensed liquid ammonia is flashed back to atmospheric pressure into the cargo tanks to maintain these holds at their steady-state temperature of -27°F to -28°F. Two identical York Marine Pak refrigeration units are installed in the midship deckhouse. Both units are operated during the loading operations in Trinidad. Only one unit is used on an intermittent basis when the vessel is in the seaway in either the fully loaded or ballast condition in order to maintain the low temperature level required.

Cargo is discharged by four deepwell Bingham pumps which are of sufficient capacity to empty the tanker in twelve hours. These four pumps can deliver as much as 5,600 U.S. gallons per minute of ammonia at a pressure of 100 psig into the receiving terminal's unloading line. The cargo tanks are equipped with liquid level indicator, temperature probes and pressure sensing equipment. Pressure and vacuum relief valves are installed as standard equipment.

Should a fracture occur in the cargo container, the presence of a leak into the inert gas stream would be immediately detected by a continuous sampling Beckman analyser which would immediately sound an alarm. Any abnormal increase or decrease in temperature of the void space is sensed by temperature probes equipped with alarm overrides. All instrumentation for control of the cargo pumps and for surveillance of the cargo system is located in a special control room adjacent to the aft deckhouse. Accommodation is provided in air-conditioned quarters for a crew of thirty-eight.

The vessel is propelled by a MAN Type K8Z70 120 D diesel engine which develops 9,600 metric brake horsepower at 135 revolutions per minute. During the vessel's trial runs, this equipment was capable of propelling the vessel at a speed of seventeen knots.

A sister vessel, the *Joseph P. Grace*, has recently been launched and will shortly enter regular runs on anhydrous ammonia service.

VI. REFRIGERATED STORAGE OF ANHYDROUS AMMONIA

Over the past eight years, W. R. Grace & Co. has had experience storing anhydrous ammonia under pressure as a liquid in standard spheres or hortonspheres and in the form of aqua ammonia in large carbon steel oil-storage-type tanks. These units have certain limitations, particularly if quantities to be stored are in excess of 6,000 short tons. The hortonspheres have a size limitation and at the present time, 3,000 short tons is the approximate maximum that can be stored in a single unit because of excessive physical size and resulting cost. It is obvious that aqua ammonia at 28 per cent ammonia content would require an exceedingly large number of storage tanks to contain 6,000 tons of anhydrous ammonia equivalent. In addition, aqua ammonia has the shortcoming of requiring suitable recovery facilities for the anhydrous ammonia for use in other processes or applications.

Aqua ammonia has an additional major disadvantage because it is a dilute solution and, subsequently, shipment of this material incurs a rather high cost penalty due to the large amount of water being transported.

Incidentally, we have also had considerable experience in using railroad pressure tank cars and we are now shipping anhydrous ammonia in single unit tank cars with a carrying capacity of 72 short tons. Trucks are now in service with a carrying capacity of between 12 and 20 short tons of anhydrous ammonia.

Approximately four years ago a technological and economic study was made, comparing the storage of ammonia in large tanks in the form of aqua ammonia, in pressure spheres and in refrigerated tanks. The study proved and clearly defined the breakpoint at which pressure storage spheres become uneconomical because of their limitation of size and subsequent large numbers of units required to store, say 20,000 tons of anhydrous ammonia. This amount of storage can be accomplished in one refrigerated storage tank at a considerably lower capital investment. During the last three years we have constructed or now have under construction five 20,000-ton refrigerated terminals, three 16,000-ton units, two 15,000-ton units and one 12,000-ton tank. Our operating experience with these units has been very good and has confirmed our original conclusions that for large tonnage storage, the refrigeration technique is the most economical one.

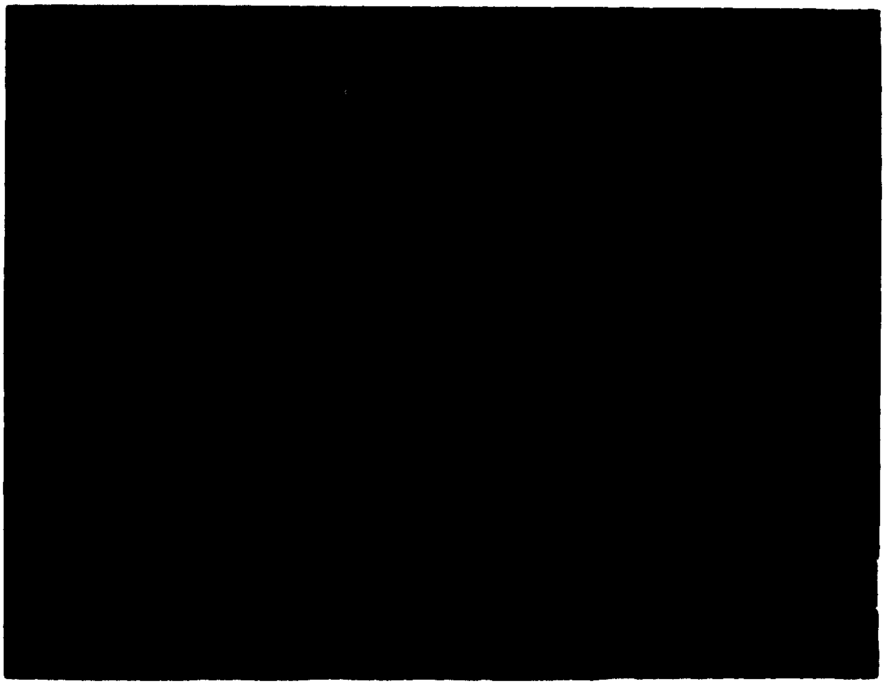
It is envisioned that a developing nation wishing to take advantage of this method of storage because of its small annual throughput of 12,500 to 30,000 tons per year might well consider the construction of a refrigerated terminal with a capacity of 10,000 or 14,000 short tons.

This 14,000-ton terminal, according to latest quotations, would require a capital investment of approximately $735,000. The 10,000-ton would require an investment of $600,000. A detail break-down is shown below:

TABLE 2 CAPITAL COSTS FOR A 14,000-TON AMMONIA TERMINAL

	$US	*Per cent of total*
Storage tank	253,600	34.5
Insulation	120,500	16.4
Compressors	95,600	13.0
Electrical	44,800	6.1
Foundations, bldg's. etc	220,500	30.0
TOTAL	735,000	100.0

In order to receive anhydrous ammonia by ship it is, of course, necessary that the terminal site be adjacent to suitable deep water harbour facilities. This is essential not only for access from the ship to the terminal, but also to keep the anhydrous ammonia ship unloading line to a



Photograph III

minimum length to minimize its cost, and to reduce the mechanical work placed upon the anhydrous ammonia in pumping it through the longer line. This line friction and mechanical work results in a rise in temperature and a flashing of the ammonia as it discharges into the terminal tank. These vapours must be recompressed and returned to the storage tank as liquid, increasing operating costs of the terminal refrigeration system.

The total land area required for a 14,000-16,000-ton terminal is approximately one acre. Our Tampa, Florida terminal (see photograph III) occupies an acre and a half, consisting of a 16,000-ton storage tank, refrigeration machinery, tank truck and railroad tank car loading and weighing facilities and a small office.

Soil conditions will dictate to what extent special requirements will be needed for foundations to support the storage tank and compressors. In the case of the Tampa terminal, the site was filled by dredging for the adjacent waterway. It was necessary to drive piling to support the intended load, the length being determined by actual soil-boring tests. There are some 400 pilings supporting this main storage structure and the pilings extend approximately 20" above the normal ground level. The piling was trimmed off and a 36" reinforced concrete slab was poured on top of the pilings resulting in a pedestal effect with a free air space of 20" between the bottom of the slab and the ground level.

This free air space is necessary to prevent freezing of the moisture in the soil thereby causing an iceberg to form which may heave and cause failure of the tank foundation.

In some locations we have found the soil-bearing conditions to be sufficiently high enough so that it was possible to pour the 36" concrete slab directly on the ground. In this case we have installed a suitable electric heating grid in this concrete foundation slab to prevent ground freezing.

The tank is constructed of a normalized carbon steel and is guaranteed Charpy tested at 15 foot pounds at 50°F with an allowable stress of 21,000 PSI. The top and bottom of the tank are constructed of an ASTM A-201B type carbon steel with an allowable stress of 18,000 PSI. The above stress values are based on 0.3 of ultimate strength or 0.6 of yield strength as per American standards. We believe this to be a rather conservative approach and this has been confirmed since we have not experienced difficulties in the many installations we now have in operation.

All horizontal welds are performed with automatic welding machines. All vertical shell welds are fully X-rayed except near the top where minimum plate thickness is used and spot X-raying is employed.

There are no established Code specifications for this type of tank. However, we have been following Code procedure as detailed under API-620 where applicable.

All nozzle connections are made from ASTM A-333 type carbon steel.

Insulation of the tank is Pittsburgh-Corning Foamglas 5" thick. The first course of insulation 2 1/2" thick is set up in hot asphalt with the edges dipped and set into place with the side next to the tank dry. The tank wall must be free of moisture. A 1/2" air gap is allowed between the first and second 2 1/2" course of Foamglas insulation which, again, is dipped in hot asphalt and set in place. This second course of insulation is held in place by stainless steel bands placed on 2 ft. centres and machine stretched. Necessary expansion joints are allowed for in each layer of installation and the expansion joints are sealed with a vapour barrier.

After banding, the surface of the second course is given a spray coat of an asphaltic mastic. When this mastic has dried, the entire surface is covered with 0.020" thick corrugated aluminum sheeting held in place with pop rivets and suitable banding for further weather protection of the insulation. The tank roof is insulated in the same manner. However, instead of corrugated aluminum, the surface is covered with glass cloth and finished with a mastic coating.

The Pittsburgh-Corning Foamglas used has a K factor of 0.37 BTU/hr.sq.ft.°F./in. and we use a heat leak factor for this type of insulation applied in the manner previously described of 10.2 BTU/hr.sq.ft.

The holding compressors and filling compressor are adjacent to the tank and the entire system is graphically panelled with all controls and instrumentation so that one man can easily operate the unit and, in fact, the Tampa, Florida operation is completely automatic and can be made to operate unattended. The operator is needed primarily to load tank trucks and railroad tank cars.

The operating costs of a refrigerated anhydrous ammonia storage terminal will vary with the annual throughput. A 14,000-ton capacity storage terminal has a fixed capital investment of $735,000 as mentioned previously. This, however, does not include the cost of the land nor any extensive harbour or dock facilities. Assuming this capital investment, depreciation on a fifteen-year basis, and allowing for operating labour and usual overhead charges, terminal charges per short ton have been calculated at various annual throughput rates and are shown in table 3.

Figure I compares the corresponding terminal charge and annual throughput for refrigerated terminals of two sizes, 10,000 tons and 14,000 tons.

VII. ANHYDROUS AMMONIA PLANT INVESTMENT AND PRODUCTION COST DATA

To further evaluate the proposed scheme of basing a fertilizer industry upon Trinidad-produced ammonia, two charts, figures II and III, are presented.

TABLE 3. ESTIMATED TERMINAL CHARGES — 14,000-TON TANK

Annual throughput short tons	*Terminal charges, $ per short ton*
12,500	9.17
15,500	7.59
20,000	6.08
30,000	4.82

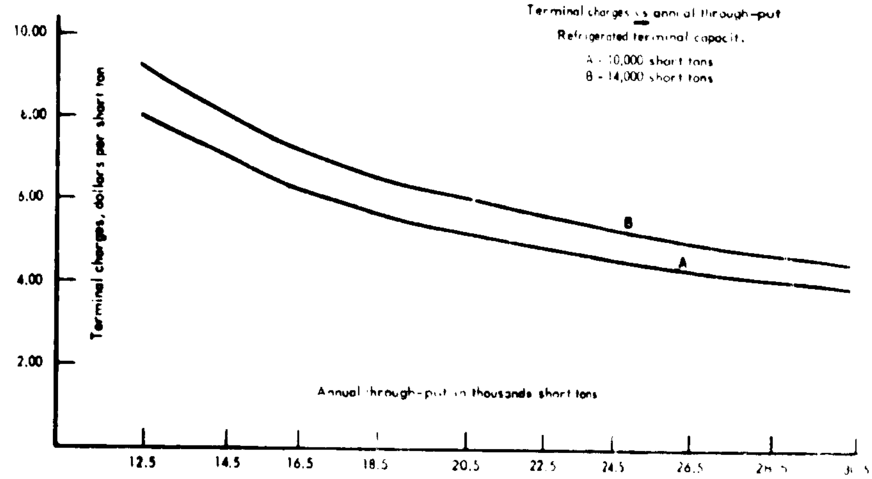


Figure I

The first chart indicates the relation between plant investment and plant capacity for various raw materials and processes.

A plant producing 100 short tons per day of anhydrous ammonia or approximately 33,000 short tons per year employing the steam reforming of naphtha as a hydrocarbon feed-stock incurs a cost of approximately $3.2 million for a battery limits plant according to figure II. To this plant investment must be added the cost of these so-called "off-site" facilities:

Land;
Buildings — office and laboratory;
Shops maintenance and stores;
Steam generation;
Water wells and treatment;
Electric power distribution;
Fire protection;
Sewers, roads, railroads;
Solid products warehouses;
Liquid products storage tanks.

We would suggest by our experience that these items add an additional 30 per cent-50 per cent to the battery limits plant investment cost indicated in figure II. In other words, in a plant to produce 100 short tons a day

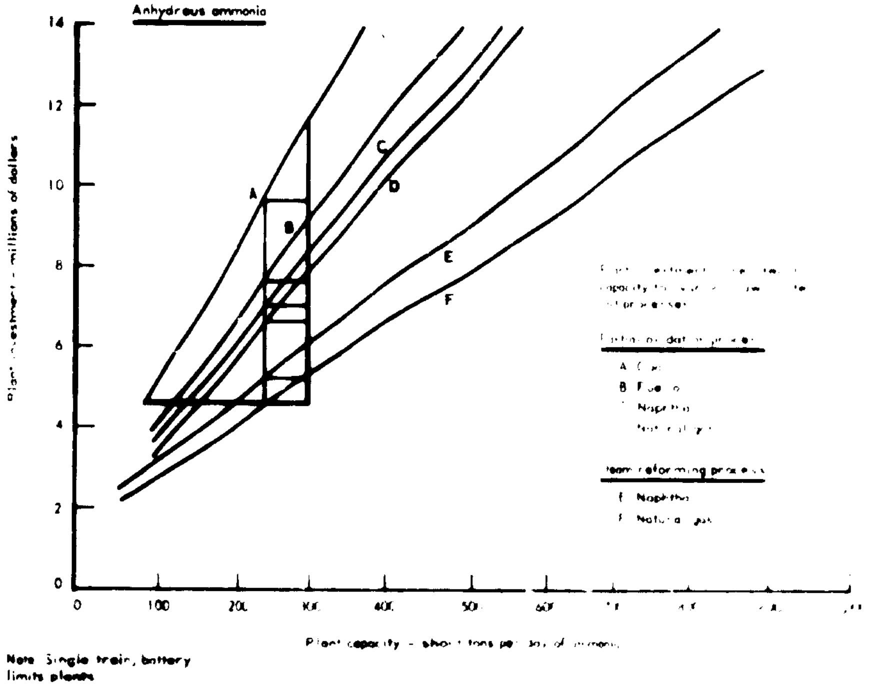


Chart courtesy the Sulphur Institute

Figure II

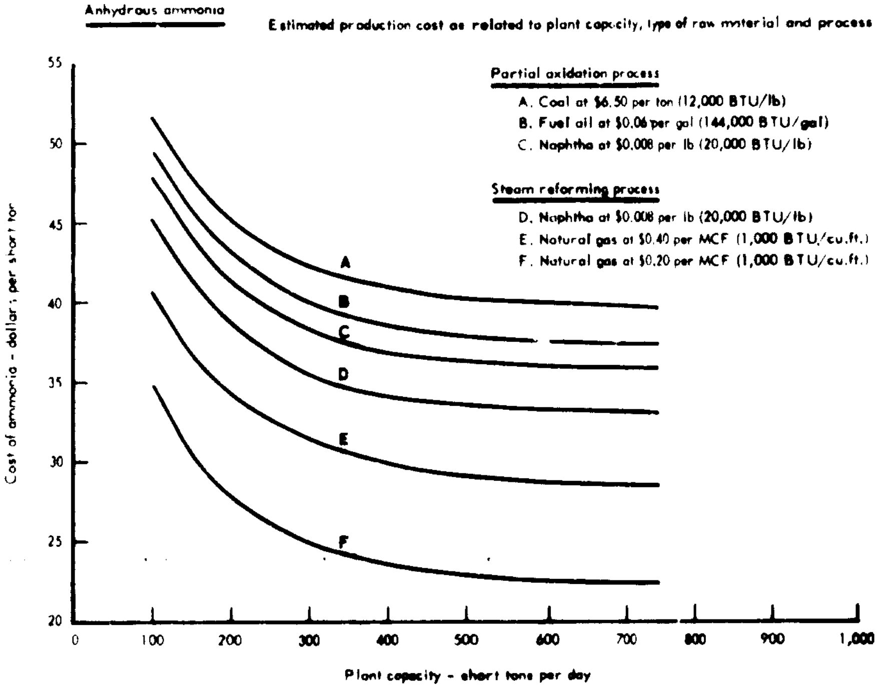


Chart courtesy the Sulphur Institute

Figure III

by naphtha steam reforming, the total cost is estimated to be between $4.2 million and $4.8 million.

The cost of producing anhydrous ammonia relative to plant capacity, type of hydrocarbon feed-stock material and process is shown in figure III. As indicated, a plant producing 100 short tons per day of anhydrous ammonia *via* steam reforming of naphtha has a production cost of $42.50 per short ton, not including depreciation and interest on capital employed.

Trinidad and Tobago with its production capacity of nearly 500,000 short tons per year and other favourable cost factors, can be regarded as one of the world's lowest-cost producers of anhydrous ammonia. This low-cost production, combined with the unique, proven method of transportation by refrigerated tanker and refrigerated storage terminals, offers a developing country anhydrous ammonia under a much more economical arrangement than if it would make the investment to build its own plant. A developing country can, at the same time, make a valuable contribution to its industrialization by putting some capital to work in converting anhydrous ammonia to suitable forms of nitrogen fertilizers.

8. OCEAN TRANSPORTATION OF ETHYLENE AND OTHER BASIC INTERMEDIATES FOR PETROCHEMICALS

René Boudet, Director General, Gazocean, and Melvin H. Gertz, President, Purvin & Gertz, Inc., United States of America

I. INTRODUCTION

Petrochemical products are such an important part of a modern industrial economy that developing countries must consider such operations as a possible component of their development programme. The petrochemical industries require relatively large capital investments with correspondingly high fixed charges, so the initial small-scale production to meet local market demand in many developing countries may be difficult to justify. For this reason, every possible alternate form of operation should be studied to determine the most economic initial installation. This paper will discuss certain new techniques now commercially available for ocean transportation of ethylene and other petrochemical intermediates in refrigerated tankers which should contribute to the feasibility of such projects in developing countries.

With the commercialization of ocean transportation, ethylene-consuming industries can now be located at points quite distant from the source of production of ethylene rather than being bound to "across the fence" pipeline deliveries or overland pipeline and truck shipments, as has been the case in the development of petrochemical complexes in the past. This separation of ethylene-producing and consuming facilities provides very interesting possibilities for co-operation between countries to achieve a more economic over-all pattern of production. Those developing countries favoured with an abundance of petroleum resources could produce ethylene from large-scale cracking operations based on various hydrocarbon feed-stocks. Such plants could supply not only the local internal requirements but also ship ethylene to various other points of consumption, particularly to countries where the limited market requirements preclude the installation of ethylene-producing facilities.

II. TANKER-DESIGN CONSIDERATIONS

For the economic transportation of ethylene by tanker, it is necessary to handle it as a liquid at essentially atmospheric pressure and at a temperature of minus 104°C. (–155°F.). The cryogenic techniques for this service have been developed in conjunction with the liquid methane or liquid natural gas projects which require operating temperatures as low as minus 162°C. (–259°F.). There are many difficult design features in building such low temperature tanks inside the hull of a ship. For this low temperature exposure, special metals are required, usually alloy steels with 9 per cent or more nickel content or certain aluminum alloys. The tanks must be designed to take the static and dynamic loads as well as the thermal stresses due to heating and cooling. They must be well insulated with a stable and reliable material. Even with the proper insulation, there is a certain amount of heat transfer to the liquid contents resulting in the evolution of vapours from the tanks in transit. In the case of methane transport, this vapour boil-off can either be vented to the atmosphere or used as fuel for the ship. With more valuable commodities such as ethylene, reliquefaction facilities would be provided.

The ships that are being constructed to transport liquid methane from Algeria to France and England have employed the so-called self-supporting tank design with tanks mounted vertically in the hull of the ship. The self-supporting tanks are designed to bear their own weight as well as that of the contents.

During the past several years, an integrated tank design for liquid methane tankers has been developed.[1] The integrated design utilizes the hull of the ship as the outer shell of the tanks. The integrated tanks are constructed of thin wall, flexible metal sheets with no integral strength of their own. The thin tank walls are designed to accommodate the extreme temperature changes, but at the same time, they are bonded to the insulating envelope in such a way that the hydrostatic and hydrodynamic pressures of the contained liquid are transmitted to the structure of the vessel. The integrated design utilizes the volume of the hull more effectively than the self-supporting tanks, so it results in a lower over-all investment for a given tank capacity. The first commercial application of the integrated technique is a tanker called the *Pythagore* constructed during this year in France. The ship is owned and operated by the French shipping company Gazocean and was designed by its engineering subsidiary Technigaz.

To understand the design problems for a low temperature tanker as well as the particular features of the integrated tank design, it might be well to describe the

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[1] See "Pythagore", *Shipbuilding and Shipping Record* (London, February 13, 1964), pp. 214-216.

Pythagore in greater detail. The principal characteristics of the ship are as follows:

Over-all length — 56.50 metres (185 ft. 4 in.)
Breadth — 8.50 metres (27 ft. 11 in.)
Depth to main deck — 4.60 metres (15 ft. 1 in.)
Loaded draught — 3.56 metres (11 ft. 8 in.)
Volume of cargo tanks — 600 cubic metres (21,200 cubic feet)
Speed — 11 knots.

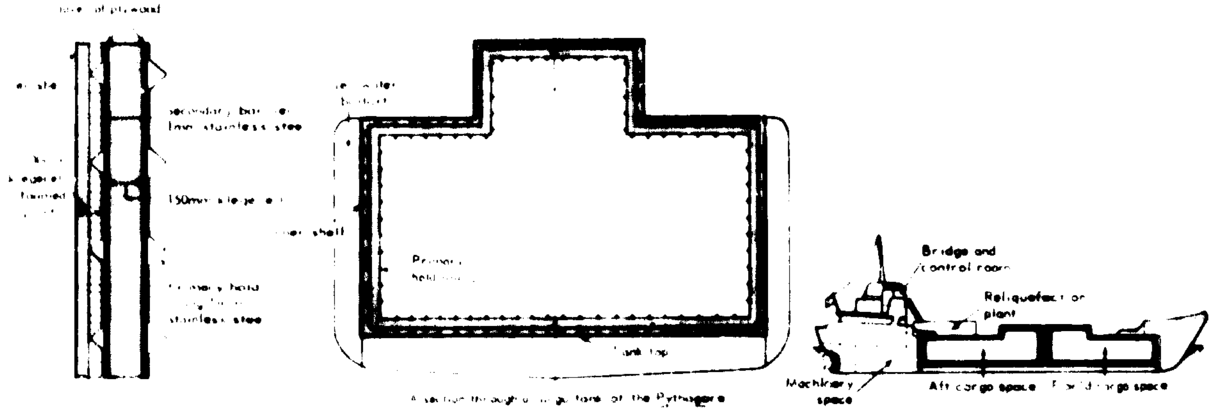
In figure 1, a cross-section through a cargo tank of the *Pythagore* is shown along with a diagrammatic barrier detail and the inboard profile of the vessel. The innerliner of the tank, which is exposed to liquid methane temperatures, must accommodate the extreme thermal stresses and at the same time be tied to the ship's structure. This is accomplished with a one-millimetre thick stainless-steel liner formed with a carefully designed pattern of double corrugations. Maritime regulations require installation of a secondary barrier capable of containing the cold liquid and protecting the hull of the ship in the event of a failure of the innerliner. The secondary barrier for the *Pythagore* is of the same type of corrugated stainless steel plate as the innerliner, but the corrugations are reversed. The innerliner and secondary barrier have layers of plywood behind them as structural backing, and they are separated by 150 millimetres of Klegecell, a rigid expanded polyvinyl chloride insulation. There is another 100 millimetres of Klegecell between the secondary barrier and the inner hull of the ship. The most critical features of the integrated construction are the design of the corrugations for the innerliner and secondary barrier along with the techniques for welding and bonding the metal plates and insulating layers together.

The *Pythagore* is a relatively small tanker with a cargo capacity of 600 cubic metres. The ship has actually transported liquid methane cargoes, but it is not large enough to be fully commercial in this service. However, it is equipped for transport of liquid ethylene, having reliquefaction equipment aboard for this more valuable commodity so the tank vapours can be recovered in transit. As an ethylene carrier, it is the first tanker capable of this service, and it can transport commercial quantities of ethylene over a considerable distance. For example, in continuous service, it could deliver almost 10,000 metric tons of ethylene per year at a distance of 1,000 nautical miles.

III. ECONOMICS OF ETHYLENE TRANSPORTATION

It is visualized that these ethylene transportation techniques could be used to advantage for the movement of ethylene from points of large-scale production having favourable raw material supplies to various ethylene consuming points in developing countries where the initial demand might be relatively limited. To illustrate the economics of such transportation, the cost of transporting ethylene has been estimated for various size ships of this type based on the cost experience with the *Pythagore*.

A special-purpose tanker like the *Pythagore* can be quite flexible in its ultimate use, but it is generally constructed for a particular movement and committed to that service on a full-time annual basis. For the present estimates, ship capacities are based on 330 operating days per year to provide for scheduled downtime as well as other interruptions. Under these operating conditions, the size of the ship increases as the annual quantity delivered is increased for a given destination. Similarly, the ship size increases as a fixed annual quantity of ethylene is moved a greater distance. For example, a ship with 630 cubic metres cargo capacity is required to move 10,000 tons of ethylene per year a distance of 1,000 nautical miles, and the size of the ship must be increased to 2,700 cubic metres to move 50,000 tons per year over the same distance. The design speed of the ship increases with size because of engineering and economic considerations, and this is the reason that ship size does not increase directly with annual quantity delivered to a given destination. If 50,000 tons of ethylene per year had to be moved over a distance of 5,000 miles, the ship size would be increased to 8,700 cubic metres. Here again, the ship size does not increase in direct proportion to distance because of the greater speed



A section through a cargo tank of the Pythagore with a diagrammatic barrier representation

An inboard profile of the vessel

Figure 1 *Design features of the* Pythagore with increasing size as well as the more favourable time utilization of the ships over longer distances.

For each particular ship size, an investment cost estimate was developed in terms of current construction costs in European or Japanese shipyards. All of the direct costs of operation including crew costs, maintenance, fuel etc., were developed for each ship size under typical European flag operation, and an annual capital allowance of 14 per cent of the investment was added to cover amortization, interest and return on investment. With the type of long-term financing generally available for such ships, these total transportation costs, being the sum of direct costs plus the annual capital charges, should represent a realistic rate for such a vessel. Dividing the annual cost by the quantity of ethylene delivered each year, a unit transportation cost was developed. These unit costs are summarized in figure II below in cents per pound of ethylene *versus* the annual quantity and distance. From these curves, it is seen that it would cost 1.58 ¢ per pound to transport 10,000 tons of ethylene annually over a distance of 1,000 miles, but the cost drops to 0.69 ¢ per pound if the quantity were increased to 50,000 tons annually over the same distance. To deliver the same 50,000 tons over a distance of 5,000 miles, the cost is increased to only 1.33 ¢ per pound. Thus, the transportation cost is not quite double that for the 1,000-mile distance when the ethylene is transported five times as far, or 5,000 miles. This sharp reduction in the transportation cost per unit of distance (cents per pound per mile) occurs primarily because of the rapidly increasing ship size with distance for a fixed annual delivery requirement. Also, as noted previously, the ship utilization in terms of time at sea *versus* annual service time increases with distance.

In addition to the transportation costs, expenses are incurred in unloading and storing the liquid ethylene at the receiving point. The cargo must be unloaded through insulated alloy lines and stored in low-temperature tanks at minus 104°C. (155°F.). Provision must be made for recovery of ethylene vapours generated during the unloading and storage operations. The cost of the unloading lines can be quite variable depending on the existing harbour and dock facilities for handling the tankers as well as the distance from the docks to the ethylene terminal. Storage tank capacities can also vary considerably, but they must be sized primarily to receive tanker load shipments and to maintain an adequate inventory at all times for plant operations. In general, the investment in storage will increase with the quantity of ethylene handled and with distance from the ethylene producing point because of the increasing tanker size involved.

Assuming the existence of satisfactory dock facilities, investment estimates have been made for a variety of operations involving variable quantities and distances. Annual operating costs for the unloading and storage facilities have been computed including 14 per cent capital charges for amortization, interest and return on investment, as in the case of the ships. These total costs have been divided by the annual ethylene quantity handled to determine a unit cost in cents per pound. With the storage facilities in reasonable proximity to the loading docks, the unloading and terminaling costs should fall in a range of 0.2 ¢ to 0.6 ¢ per pound of ethylene. Accordingly, for tentative estimating purposes, it is recommended that an average cost of 0.4 ¢ per pound be added to the transportation costs shown in figure II to cover the costs of unloading and storing the ethylene at the receiving point.

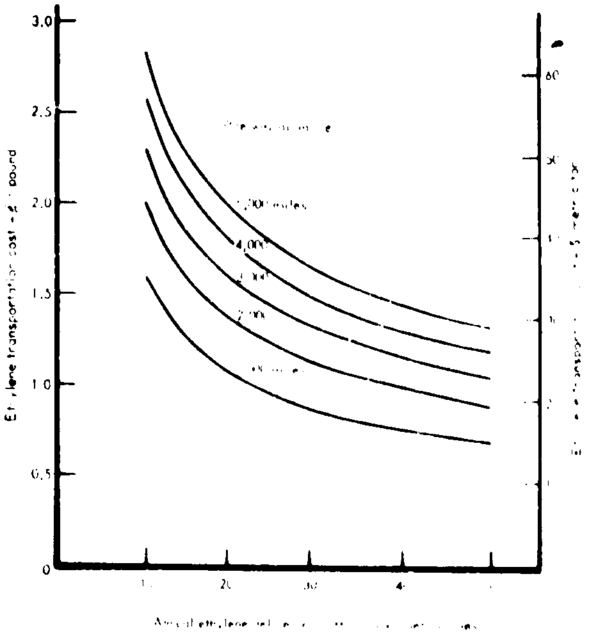


Figure II. *Ethylene transportation costs*

IV. POSSIBLE PATTERNS OF ETHYLENE TRANSPORTATION

With the abundant hydrocarbon reserves in North Africa, Algeria and Libya could become centres for ethylene production with shipments moving to all countries on the Mediterranean Sea. Although the shipments might be directed primarily to the developing countries with relatively small initial requirements, it is also possible that large volume shipments could move to the more industrialized countries on a competitive basis. With reasonable volume shipments, the entire Mediterranean area could be within reach of such production units at a total transportation and handling cost in the range of 1.0 ¢ to 2.0 ¢ per pound. Assuming that ethylene could be loaded into tankers in Algeria or Libya at a cost of 3.0 ¢ to 4.0 ¢ per pound, which should not be unreasonable for modern large-scale production facilities with low-cost raw materials, it could be delivered to all of the consuming areas in the Mediterranean at 4.0 ¢ to 6.0 ¢ per pound. This should be an attractive input cost for the production of ethylene derivatives.

Ethylene producing centres of this type could logically be established at several other strategic points of raw material supply. The Middle East could certainly become a focal point for such activity with installations in Iran, Iraq, Kuwait, Saudi Arabia. The most logical marketing area for production from this region would be movements by tanker to the Near East and Far East. Low-cost ethylene delivered from the Middle East should be competitive with local production in East Africa, India, Malaysia and beyond.

Similarly, Venezuela could become a low-cost ethylene producing centre in the Western Hemisphere with ethylene shipments moving throughout the Caribbean Area and to other points in South America, the West Coast of Africa and possibly to the United States and Canada.

Although co-operation between developing countries on this type of project should be particularly advantageous, ethylene shipments could also originate from existing or new plants in the industrialized countries. For example, ethylene could be moved to certain market areas from the Gulf Coast of the United States, and export shipments might also originate from some of the low-cost producing centres in the industrialized countries of Europe.

Ethylene off-take by tanker might also be attractive as a means for accommodating surplus ethylene from producing complexes where local ethylene demand limits the production of other chemicals required. For example, naphtha cracking units might be installed at certain locations where the principal products needed are propylene and butadiene, but the local market for ethylene may be insufficient to support desired production rates. Under such conditions, export shipments of the surplus ethylene could help to make the entire project feasible.

To show more clearly the use of figure II, the hypothetical case of a movement of ethylene from Abadan, Iran, to Bombay, India, might be considered as an example. Assume that 20,000 metric tons annually would be moved over this distance, which is 1,550 nautical miles one way. Following the vertical line in figure II for the quantity of 20,000 tons, it is necessary to interpolate between the 1,000 and 2,000-mile curves to obtain a transportation cost of 1.25 ¢ per pound. With the suggested allowance of 0.4 ¢ per pound for unloading and storage at the receiving point, the total transportation, handling and storage cost for ethylene delivered to Bombay would be 1.65 ¢ per pound.

V. TRANSPORTATION OF OTHER COMMODITIES

Although the discussion to this point has been confined to ethylene, this type of ship can also readily handle various other light hydrocarbons and chemical intermediates under refrigerated conditions. The tanker could transport liquid methane, ethane, propane or butane as primary raw materials, or petrochemical intermediates such as butadiene, propylene or vinyl chloride. As noted previously, liquid methane would set the most rigorous design conditions for the tanker metallurgy and insulation with a temperature of minus 162°C. (−259°F.), but the specific gravity of the liquid is only 0.424. To provide cargo flexibility, the supporting structure and the tanker unloading pumps would probably be designed to accommodate liquids with specific gravities as high as 0.7. As a result, the capacity of the tanker would be limited by the volume of its tanks up to a specific gravity of 0.7 and then by tonnage or weight at higher specific gravities.

The total annual operating costs for the various size tankers would be virtually unaffected by the particular commodity handled. Therefore, in view of the design conditions noted above, the unit transportation cost (cents per pound or dollars per ton) would vary inversely with the tonnage that could be accommodated in the tanks. Commodities with higher specific gravities than liquid ethylene would have correspondingly lower unit transportation costs than those shown for ethylene in figure II until a specific gravity of 0.7 was reached, beyond which there would be no further reduction. Pertinent physical constants for several commodities are tabulated below along with a transportation cost adjustment factor to convert the unit transportation costs for ethylene shown in figure II to an estimated cost for each particular commodity.

Commodity	*Normal boiling point*		*Specific gravity at normal boiling point*	*Transportation cost adjustment factor (relative to ethylene)*
	°C	*°F*		
Methane	− 162	− 259	0.424	1.342
Ethane	− 89	− 128	0.547	1.040
Ethylene	− 104	− 155	0.569	1.000
Propane	− 42	− 44	0.581	0.979
Butane	− 5	25	0.600	0.948
Propylene	− 47	− 53	0.610	0.933
Butadiene	− 4	24	0.652	0.873
Ammonia	− 33	− 28	0.681	0.836
Formaldehyde	− 21	− 6	0.815	0.813
Vinyl chloride	− 14	7	0.974	0.813

The ethylene transportation cost for a given annual tonnage and distance in figure II multiplied by the transportation cost adjustment factor listed above should provide a satisfactory preliminary estimate for each commodity. However, these transportation costs might be lower it if were possible to utilize larger-size tankers making deliveries to multiple destinations and thereby handling a greater total annual quantity. Methane for fuel purposes would generally require the use of larger tankers to obtain an economic transportation cost. The commodities other than methane, ethane and ethylene could be transported in more conventional general purpose LPG tankers under conditions where there might be some further savings in transportation cost.

VI. CONCLUSIONS

These new ocean transportation techniques should present many interesting possibilities for petrochemical operations. Various prospective movements for ethylene have been discussed. Ethane could be transported as a raw material for ethylene production at a destination where the by-products from cracking heavier hydrocarbons could not be utilized. With these specialized low-temperature tankers more generally available, ammonia, butadiene, propylene and vinyl chloride should move in increasing quantity. Since chlorine is an expensive commodity to transport, consideration might also be given to the possible movement of ethylene to areas where surplus or very low-cost chlorine is available for the production of various chlorinated hydrocarbons, including vinyl chloride.

There are many other interesting examples that could be presented, but the few cases mentioned should demonstrate the wide range of possibilities. The primary purpose of this paper has been to explain these new transport techniques and to provide transportation cost estimates as guidance for preliminary economic studies. These techniques should inject many new parameters into the consideration and planning of petrochemical projects and provide a basis for increasing international co-operation in the establishment of such projects in developing countries.

9. THE PETROCHEMICAL INDUSTRIES : EXAMPLE OF AN INTEGRATED PETROCHEMICAL COMPLEX

Prepared for the United Nations Centre for Industrial Development by l'Institut français du pétrole

The purpose of this feasibility study is to present a preliminary processing scheme for the production of basic products such as: olefins (ethylene and propylene) and aromatics (benzene, p-xylene and o-xylene) integrated in a 2,000,000-ton-a-year refinery based on light crude oil which supplies the naphtha feed-stock for petrochemical units and which provides outlets for petrochemical units by-products by blending them with the other refinery products (LPG and motor gasolene).

The attachments give process descriptions of the various units contained in the over-all plan as well as over-all material balances, capital costs, and elements of operating cost such as: utilities requirements, catalyst and chemicals consumption, labour requirements.

The operating costs are also included and the profitability of the plant is calculated on the basis of products sales at international prices.

A. BASIS OF PROJECT: MARKET ASSUMPTIONS

Taking into account the market demand for maximum middle-distillates production and gasolene production to be kept to a minimum, the major quantity of S.R naphtha could not be valorized as a motor gasolene.

On the other hand, olefins and aromatic intermediates are requested for plastics, synthetic fibres and detergents. Consequently, it seems that the best solution for valorizing this excess naphtha and for supplying to the end-products demand is the utilization of this raw material as feed-stocks for:

(*a*) A steam-cracking plant to produce:

(i) 80,000 T/year ethylene used in polyethylene, PVC and styrene manufactures,

(ii) 51,000 T/year propylene used in DDB and acrylonitrile manufactures,

(*b*) An aromatic plant composed of the following units:

(i) Catalytic reforming,

(ii) Aromatics extraction from catalytic reformate and S.C. gasolene,

(iii) Toluene hydrodealkylation,

(iv) Aromatic fractionation,

to produce:

(i) 80,000 T/year benzene used in plastics, detergents and synthetic fibres,

(ii) 20,000 T/year o-xylene used in plasticizers;

(iii) 10,000 T/year p-xylene used in polyester fibres.

The main advantages, resulting in the integration of the petrochemical units in the refinery plant, are the following:

(*a*) Better utilization of catalytic reforming unit which can operate at an economic size,

(*b*) Economic of scale for the general facilities, and consequently lower fixed charges;

(*c*) Lower manpower requirements;

(*d*) Better utilization and valorization of excess refinery products.

B. PROCESS SCHEME AND MATERIAL BALANCE

A block-flow diagram is presented in figure 1. Material balance for the over-all complex is given in table 1.

Detailed calculations for the different units are given in tables 5 to 15.

C. GENERAL DESCRIPTION

The over-all complex including the refinery and the petrochemical plant is composed of the following units: atmospheric distillation and gasolene stabilization, catalytic reforming; aromatics extraction; aromatics fractionation; hydrodealkylation, naphtha steam-cracking; hydrogenation of steam-cracking gasolene; and gas plant.

(*a*) The crude is charged to the atmospheric distillation where the following petroleum cuts are fractionated:

C_4 LPG
C_5 63°C pentanes
63 145°C light naphtha
145 165°C heavy naphtha
165 230°C | middle-distillates
230 375°C |
375° C + fuel oil

(*b*) Light naphtha is charged to the catalytic reforming (BTX operation) to yield: a reformate rich in aromatics, a stabilization overhead which is charged to the gas plant, a separation H_2-rich gas which is charged to the hydrodealkylation unit.

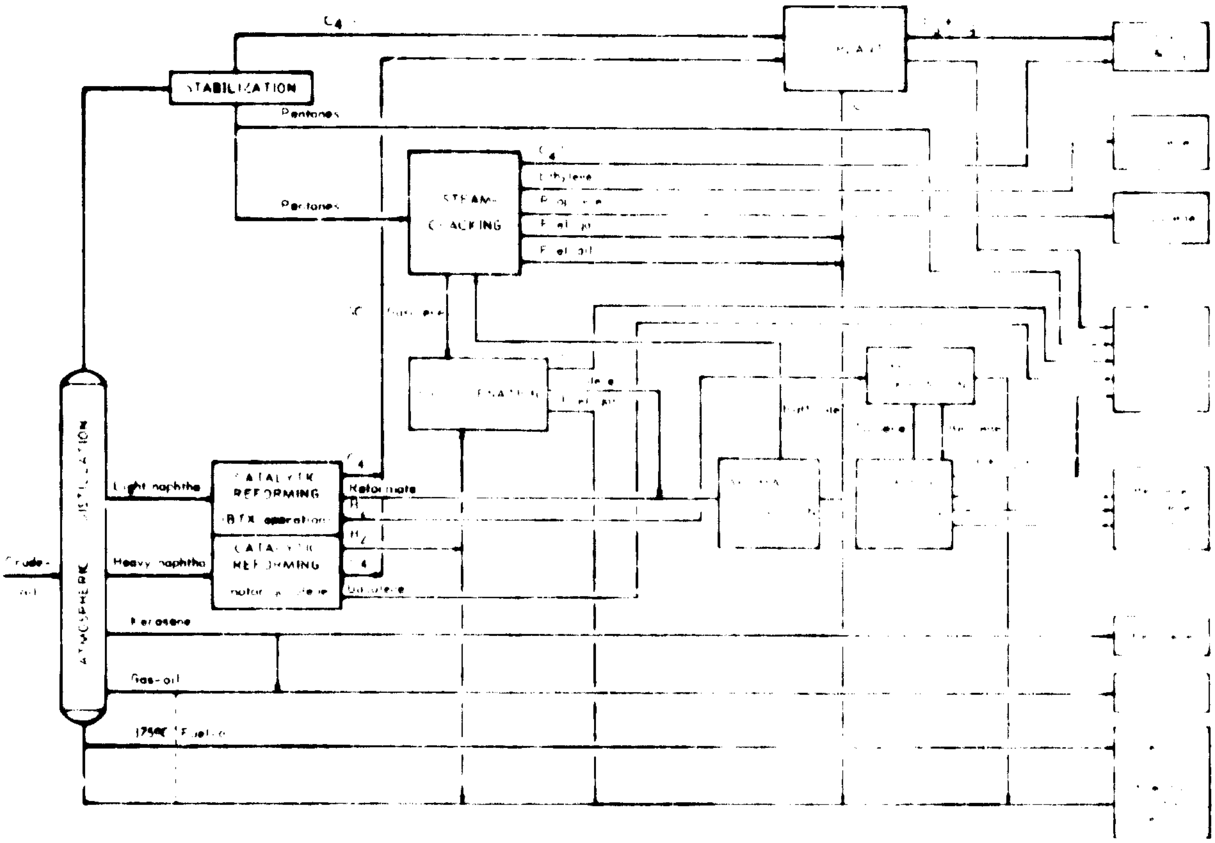


Figure 1 *Block flow diagram*

(*c*) Heavy naphtha is charged to the catalytic reforming (motor gasolene operation) to yield a high octane reformate, a stabilization overhead which is charged to the gas plant, a separation gas which is charged to S.C. gasolene hydrogenation plant.

(*d*) BTX operation reformate and hydrogenated steam-cracking gasolene are charged to the aromatics extraction to yield: a raffinate which is partly used as steam-cracking feed-stock, an aromatics mixture which is sent to aromatics fractionation.

(*e*) BTX, from aromatics extraction and hydrodealkylation products are fractionated in aromatics separation to yield: benzene, o-xylene, p-xylene, and toluene which are used as feed-stocks for the hydrodealkylation unit, the remaining C_8 aromatics and C_9 aromatics are sent to the gasolene pool.

(*f*) Raffinate and SR pentanes are used as feed-stocks for the steam-cracking unit which yields the following products: fuel gas; ethylene; propylene; butylenes-butadiene; gasolene, sent to the aromatics fractionation after hydrogenation, and fuel-oil.

(*g*) SR-C_4 from the atmospheric distillation, stabilization overhead from reforming (BTX and motor gasolene operations) are charged to the gas plant where the following products are fractionated: fuel gas, propane LPG, butane LPG; pentanes which are utilized into the gasolene pool.

D ECONOMICS OF THE OVER ALL COMPLEX

1 *Scope of the economic study*

Because of the complete integration of the petrochemical units into the refinery and the utilization of the petrochemical by products in gasolene pool and as fuel in the utilities generation, it is not possible to carry out separately the economics of petrochemicals manufacture and refinery production. Accordingly, economic study has been carried out for the over all complex.

2 *Basic data*

Detailed basic calculations required by the economic study are given in tables 2 (total refinery and petrochemical products sales), 3 (capital cost for the over all complex) and 4 (operating cost of the over all complex).

3 *Hypothesis*

(*a*) Crude oil price, refinery and petrochemical products prices

Crude oil CIF $/ton 16

Refinery products

LPG	$/ton	30
Motor gasolene NOR 96	$/ton	35
Motor gasolene NOR 85	$/ton	30
Kerosene	$/ton	28

Gas-oil	\$/ton	24
Fuel-oil	\$/ton	15

Petrochemical products

	\$/ton
Ethylene	110
Propylene	90
Benzene	70
o-Xylene	66
p-Xylene	290

(*b*) Location

The complex is assumed to be erected in Europe.

(*c*) Economic conditions

Payment of the plant: cash

Depreciation at 12.5 per cent of total investment

Financial charges (av.) at 3.5 per cent of total investment

Taxes on the benefits at 50 per cent.

(*d*) Profitability study

Profitability study of the over-all complex is carried out in table 4 *bis*. Taking into account the hypothesis and the economic conditions given here above, it results in a return on investment, after taxes, of 22.4 per cent or a 4.5 years pay-out.

TABLE 1. MATERIAL BALANCE FOR THE OVER-ALL COMPLEX

	From	*Tons/year*	
Fuel used as feed-stock in utilities generation and fired heaters			
Fuel gas	Gas plant	9,620	
Fuel gas	Hydrogenation	6,040	
Fuel gas	Steam-cracking	45,000	
Fuel gas	Hydrodealkylation	35,806	
Fuel gas	Reforming	5,740	
Fuel oil	Steam-cracking	9,000	
Fuel oil	Topping	101,000	
			292,200
Liquefied pressure gas			
C_3	Gas plant	22,100	
C_4	Gas plant and steam-cracking	96,000	
			118,100
Premium motor gasolene Regular motor gasolene	Reforming, aromatics extraction and fractionation, steam-cracking topping	70,000 129,700	
			199,700
Kerosene	Topping		100,000
Gas-oil	Topping		762,000
Fuel-oil	Topping		279,000
Olefins			
Ethylene	Steam-cracking	80,000	
Propylene	Steam-cracking	51,000	
			131,000
Aromatics			
Benzene	Aromatics extraction and fractionation	50,000	
o-Xylene	Aromatics extraction and fractionation	50,000	
p-Xylene	Aromatics extraction and fractionation	10,000	
			110,000
Loss	Steam-cracking		8,000
	TOTAL		2,000,000

TABLE 2. REFINERY AND PETROCHEMICAL PRODUCTS SALES

	Selling price $US/ton	*Tons/year*	*10³ $US/year*
Refinery products			
C_3 and C_4 LPG	30	118,100	3,543
Premium motor gasolene	35	70,000	2,450
Regular motor gasolene	30	129,700	3,891
Kerosine	28	100,000	2,800
Gas-Oil	24	762,000	18,288
Fuel-oil	15	279,000	4,185
TOTAL, refinery products			35,157
Petrochemical products			
Ethylene	110	80,000	8,800
Propylene	50	51,000	2,550
Benzene	70	80,000	5,600
o-Xylene	66	20,000	1,320
p-Xylene	250	10,000	2,500
TOTAL, petrochemical products			20,770
TOTAL SALES			55,927

TABLE 3. CAPITAL COST FOR THE OVER-ALL COMPLEX

	10³ $US	
Process units	26,800	
Off-sites	15,500	
TOTAL		42,300
Initial charge of catalysts and chemicals	546	
Paid-up royalties	2,000	
		2,546
Spare parts		2,000
Start-up expenses		2,000
Interest during construction		3,000
TOTAL CAPITAL COST		51,846

TABLE 4. MANUFACTURING COST

	Unit	*Unit cost $US*	*Annual quantity*	*Annual cost 10³ $US/year*	
Variable costs					
Raw material (crude)	Ton	16	2,000,000	32,000	
Catalysts and chemicals				466	
Labour	Men-Year	5,000	383	1,915	
TOTAL, variable costs					34,381
Fixed costs					
Depreciation at 12.5 per cent				6,500	
Interest at 3.5 per cent				1,800	
Maintenance					
Process units at 4 per cent				1,070	
Off-sites at 2.5 per cent				390	
General plant overhead at 2.0 per cent				1,037	
Taxes and insurance at 1 per cent				518	
TOTAL, fixed costs					11,315
MANUFACTURING COST					45,696

TABLE 4 *bis*. PROFITABILITY STUDY

	10³ $US/year
1. *Credit*	
Products sales	55,927
2. *Debit*	
Variable costs	34,381
Fixed costs	11,315
Manufacturing cost	45,696
3. *Profitability*	
Benefits before taxes	10,231
Benefits after taxes at 50 per cent	5,115
Benefits after taxes and depreciation	11,615
Return on capital	22.4 per cent
Pay-out time on total investment	4.5 years

TABLE 5. ATMOSPHERIC DISTILLATION — GASOLENE STABILIZATION

Estimated material balance

	Per cent weight on crude-oil	*Tons/year*	*Specific gravity*	*M³/year*
Feed	100	2,000,000	0.800	2,500,000
Products				
1. C_2	0.05	1,000	0.400	2,500
C_3	0.90	18,000	0.515	35,000
C_4	2.75	55,000	0.580	95,000
2. C_5-63°C	5.00	100,000	0.640	156,000
3. 63°-145°C	20.20	404,000	0.738	547,000
4. 145°-165°C	5.00	100,000	0.760	131,000
5. 165°-230°C	15.40	308,000	0.796	387,000
6. 230°-375°C	27.70	554,000	0.850	649,000
7. > 375°C	23.00	460,000	0.925	497,500
	100.00	2,000,000	0.800	2,500,000

TABLE 6. CATALYTIC REFORMING (MOTOR GASOLENE OPERATION)

Estimated material balance

Feed

145-165°C Cut 100,000 tons/year

Products

	Separator gas (tons/year)	*Stabilizator head (tons/year)*	*Reformate (tons/year)*
H_2	1,020	80	
C_1	2,960	140	
C_2	4,500	500	
C_3	2,000	5,000	
C_4	1,000	7,000	
C_5 +			75,800
	11,480	12,720	75,800

Properties of the reformate —

NOR clear: 94

Specific gravity at 15°C: 0.773

TABLE 7. STEAM-CRACKING

Estimated material balance

	Tons/year
Feed	
C_5-63°C cut	47,800
Raffinate from aromatics extraction	222,200
TOTAL	270,000
Products	
Tail gas	45,000
Ethylene	80,000
Propylene-propane	51,000
Butylene-butadiene	20,000
Gasolene	57,000
Fuel-oil	9,000
Loss	8,000
	270,000

TABLE 8. CATALYTIC REFORMING (AROMATICS OPERATION)
Estimated material balance

Feed

63°-145°C Cut . . . . 404,000 tons/year

Products

	Separator gas	*Stabilizator head*	*Reformate*
H_2	4,800	50	
C_1	1,000	200	
C_2	5,000	650	
C_3	8,500	4,800	
C_4	5,000	16,800	
C_5	1,000	20,800	
C_6 paraffins			63,100
C_7 paraffins			61,500
C_8 paraffins			52,200
C_9 paraffins			12,500
Methyl cyclopentane			6,800
Cyclohexane			1,200
C_7 naphthene			4,000
C_8 naphthene			2,000
C_9 + naphthene			400
Benzene			23,000
Toluene			44,000
Xylene + ethylbenzene			55,400
C_9 + aromatics			9,300
	25,300	43,300	335,400

TABLE 9. STEAM-CRACKING GAZOLENE FRACTIONATION AND HYDROGENATION
Estimated material balance

	Tons/year
Feed	
Steam-cracking gasolene	57,000
Gas from reforming	5,740
	62,740
Products	
Fuel gas	6,040
C_5	10,800
Gasolene to extraction unit	45,900
	62,740
Composition of the hydrogenated s.c.-gasolene	
C_6 non aromatics	3,680
Benzene	18,810
Toluene	11,920
Xylenes	7,360
C_7-C_8 non aromatics	4,130
	45,900

TABLE 10. AROMATICS EXTRACTION
Estimated material balance

		Tons/year
Feed		
1. C_6 + reformate		335,400
2. Hydrogenated steam-cracking gasolene		45,900
	TOTAL	381,300
Products		
1. *Aromatics*		
Benzene		40,600
Toluene		52,000
Xylene + ethylbenzene		57,000
C_9 + aromatics		9,500
		159,100
2. *Raffinate*		222,200
	TOTAL	381,300

TABLE 11. AROMATICS FRACTIONATION
Estimated material balance

		Tons/year
Feed		
Aromatics extraction products		159,100
Hydrodealkylation products		41,000
	TOTAL	200,100
Products		
Benzene		80,000
Toluene		51,500
o-Xylene		20,000
p-Xylene		10,000
Ethylbenzene + m-Xylene		27,000
C_9 + Aromatics		11,600
		200,100

TABLE 12. HYDRODEALKYLATION
Estimated material balance

		Tons/year
Feed		
Toluene from aromatics fractionation		51,500
Gas from reforming		25,300
	TOTAL	76,800
Products		
Off-gas		35,800
Heavy aromatics		500
Benzene		40,500
	TOTAL	76,800

Table 13. Gas plant
Estimated material balance

Feed	
C_4 straight run	74,000
Gas from reforming (motor gasolene operation)	12,720
Gas from reforming (BTX operation)	43,300
	130,020

Products (tons/year)

	Fuel gas	*Propane LPG*	*Butane LPG*	*Gasolene*
H_2	130			
C_1	340			
C_2	2,150			
C_3	7,000	20,800		
C_4		1,300	76,000	1,500
C_5				20,800
	9,620	22,100	76,000	22,300

Table 14. Estimated gasolene blending

	Tons/year	*Specific gravity (15° C)*	*M³ year*	*NOR clear* [a]
C_9 + aromatics	11,600	0.890	13,000	107
Ethylbenzene + m-Xylene	27,000	0.870	31,000	115
Reformate	75,800	0.773	98,000	94
C_5 from gas plant	22,300	0.628	33,500	82
C_5 from steam-cracking gasolene fractionation	10,800	0.628	17,200	82
C_5-63°C straight-run	52,200	0.640	81,500	78
	199,700	0.735	274,200	90 [b]

[a] An addition of 0.4 per thousand. TEL would permit to increase NOR to 96

[b] Gasolene pool at NOR clear 90 can provide : 70,000 tons/year premium gasolene at NOR clear 96, 129,700 tons year regular gasolene at NOR clear 85

Table 15. Refinery production

	Tons year	*Sp. gr*	*M³ year*
1. C_3 LPG	22,100		
2. C_4 LPG			
C_4 from gas plant	76,000		
C_4 from steam cracking	20,000		
	96,000		
3. Kerosene			
SR 165-230°C	100,000	0.796	125,000
4. Gas-oil			
SR 165-230°C	208,000	0.796	261,000
SR 230-375°C	554,000	0.850	649,000
	762,000		910,000
5. Fuel-oil			
375°C +	279,000	0.925	302,000

Table 15. Refinery production *(continued)*

Petrochemical production	*Tons year*
1. Olefins	
Ethylene	80,000
Propylene	51,000
2. Aromatics	
Benzene	80,000
o-Xylene	20,000
p-Xylene	10,000

Table 16. Estimated process units and off-sites cost

	$US	
Process units		
Atmospheric distillation, gasoline stabilisation	3,500,000	
Catalytic reforming	3,400,000	
Aromatics extraction and fractionation	6,500,000	
Hydrodealkylation	1,700,000	
Steam-cracking	10,000,000	
Steam-cracking gasolene fractionation and hydrogenation	600,000	
Gas plant	1,100,000	
		26,800,000
Off-sites [a], including : general plant services, general buildings, utilities production and distribution, receiving, shipping and storage		15,500,000
TOTAL		42,300,000

[a] Land not included.

Table 17. Estimated initial charges and yearly consumption of catalysts and chemicals

	Initial charge ($US)	*Expenses ($US/year)*
1. *Catalysts*		
Catalytic reforming	400,000	250,000
Gasolene hydrogenation	6,000	4,000
Hydrodealkylation	20,000	20,000
	426,000	274,000
2. *Chemicals*		
Aromatics extraction	120,000	50,000
Hydrodealkylation		2,000
Steam cracking		90,000
Refinery units and off-sites		50,000
	120,000	192,000
TOTAL, catalysts and chemicals	546,000	466,000

Estimated paid-up royalties

	$US
Catalytic reforming	700,000
Aromatic extraction	700,000
Hydrodealkylation	500,000
Gasolene hydrogenation	100,000
TOTAL	2,000,000

TABLE 18. ESTIMATED UTILITIES CONSUMPTION

	Electricity (kWh/hr)	*Cooling water (M³/hr)*	*Steam LP (tons/hr)*		*Steam HP (tons/hr)*		*Fuel (10^6kcal/hr)*
			Cons	*Prod*	*Cons*	*Prod*	
Atmospheric distillation	1,000	240	7.6				56
Gasolene stabilisation	325	120					
Reforming, gasolene and aromatics operations	600	680		15.4	15.4		52
Aromatics extraction and fractionation	3,100	3,300	41.0		6.6		82
Steam cracking	10,500	2,100				25.0	56
Steam-cracking gasolene fractionation and hydrogenation	82	76			3.2		
Hydrodealkylation	525	33	3.3		3.5		3
Gas plant	64	750	16.8		11.8		
	16,196	7,299	68.7	15.4	40.5	25.0	249
Off-sites	3,000 [a]	51	5.3	58.6	138.6	154.1 [b]	120
TOTAL	19,196	7,350	74.0	74.0	179.1	179.1	369 [d]

[a] Electricity for air cooling and water refrigeration included.

[b] Electricity production included.

[c] Steam generation included.

[d] Fuel consumed in the units and the steam generation plant, is provided by

	Tons/year
Fuel gas from gas plant	9,620
Fuel gas from hydrogenation	6,040
Fuel gas from steam-cracking	45,000
Fuel gas from hydrodealkylation	35,800
Fuel gas from reforming (motor gasolene operation)	5,740
Fuel oil from steam-cracking	9,000
Fuel oil S.R. 375° C +	181,000
	292,200

TABLE 19. ESTIMATED LABOUR REQUIREMENTS

	Men/shift [a]				*Men/day*				*Total*
	Foremen	*Chiefs Operator*	*Operators*	*Helpers*	*Engineers*	*Foremen*	*Workers*	*Helpers*	
Process units	3	5	15	17	6	3	5	6	180
Utilities		2	3	3	1	1	2	2	38
Storage, handling			1	1	1	2	3	8	22
General services			3	4	1	2	9	12	52
Laboratories		2	4	4	1		5	2	48
Offices					6		20	2	28
Infirmary							1		1
Watch				3		1		1	14
									383

[a] Basis : 4 shifts/day.

10. CHARACTERISTICS AND PROSPECTS OF THE PETROCHEMICAL INDUSTRY — WITH EMPHASIS ON THE YOKKAICHI COMPLEX

Tadao Yano, Mitsubishi Petrochemical Company, Ltd., Japan

Yokkaichi is located almost at the centre of Japan in the neighbourhood of Nagoya City and has a population of about 200,000. It is a city which has long since developed into a light-industries and commercial centre with the production of textiles and ceramics.

Herewith follows briefly the gradual development of this city, from a small town into a big centre of up-to-date petrochemical industry as it is known now. It is a history of the development of a small town of Japan, a story of Japanese heavy and chemical industrialization, especially of the progress of petrochemical industry and, at the same time, of the course which the Mitsubishi Petrochemical Company has followed until the present.

Of course, it is not intended to suggest that each step was the best whenever it was put into practice in the past, yet there are things in the company's experience which are suggestive and helpful to those countries now planning to develop their own petrochemical industry.

Yokkaichi City fronts one of the most important industrial highways in Japan, connecting two highly industrialized areas of Kanto, including Tokyo and Kansai which includes Osaka, Kobe and Kyoto. The old town which began to develop hundreds of years ago as an important point of traffic was designated by the Government as a treaty port in 1899. Since then it has pursued the path to prosperity as a trading port and as a brisk light-industries centre for textiles, on the one hand, and is an undisturbed provincial town, on the other.

The reason behind this peaceful town's connexion with petroleum was the old Japanese Navy's establishment here of its fuel depot and of its production mainly of heavy oil to be supplied to its battleships and of aviation gasolene to its aircraft.

During the Second World War, the Navy fuel depot in Yokkaichi continued operation despite the great damage and suffering caused by heavy air-raids of the Allied Forces. However, it was necessary later on, at the time of Japan's defeat in August 1945, to transfer to some peace-time industry.

In the midst of the food shortage at the end of the war, the most urgent requirement of the nation was the production of fertilizer, especially of ammonium sulphate. In October 1945, the competent authorities hastily decided to use this old fuel-depot site for the production of ammonium sulphate. Accordingly, in January 1946, the Japan Fertilizer Company started the construction of an ammonium sulphate plant at the site, overcoming various difficulties including shortage of materials.

In May 1946, however, the old Navy fuel depot was designated as one of the reparation objects by the Supreme Commander of the Allied Occupation Forces and the construction of the ammonium sulphate plant was suspended. However, after strenuous negotiations with the authorities concerned, manufacturing of ammonium sulphate, using hydrogen from the electrolysis process was permitted and a 20,000-ton-per-annum ammonium sulphate plant was completed in September 1946.

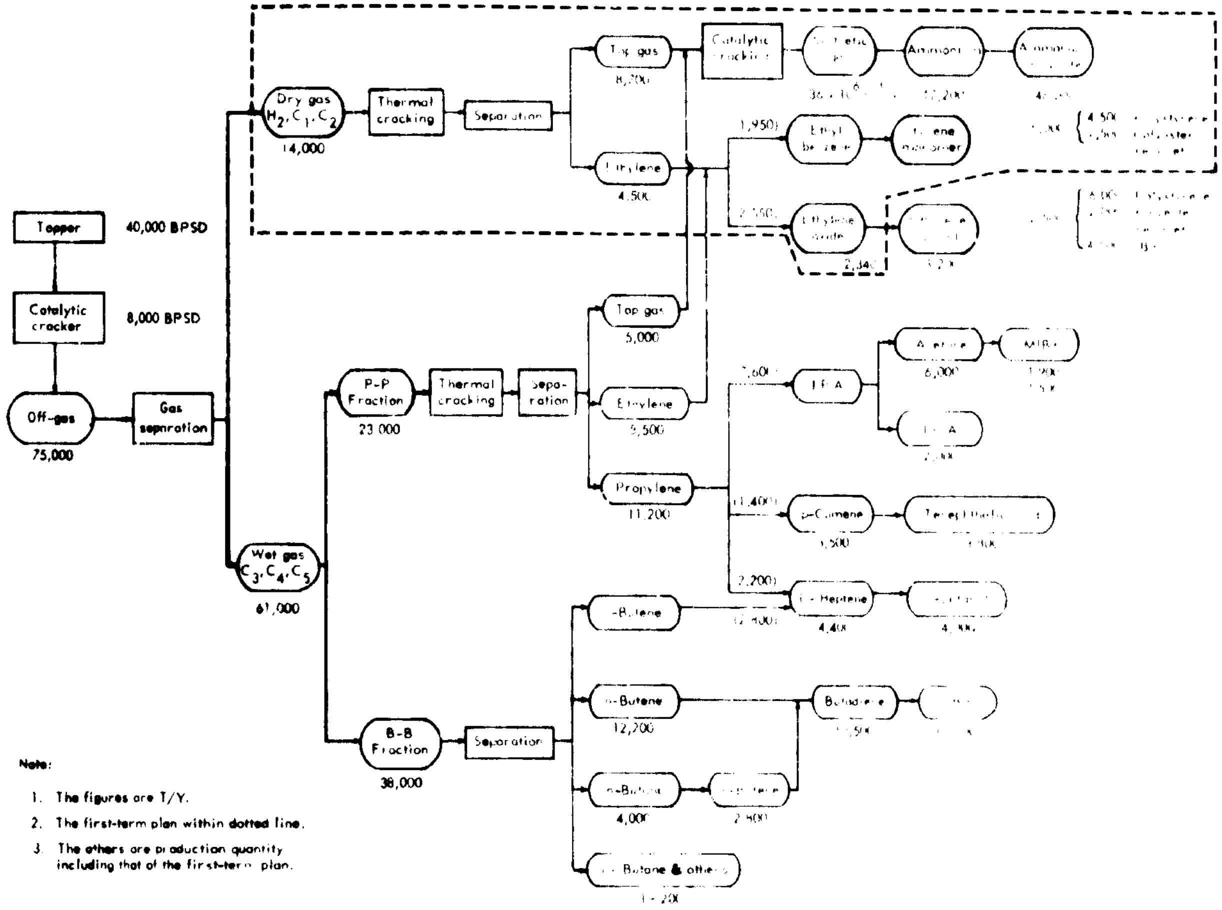
About two years later, in November 1948, this plant became independent of the Japan Fertilizer Company under the name of Tokai Ammonium Sulphate Company; the present Tokai Gas Chemical Company becoming a spearhead for the later development of this area as a petrochemical centre.

Yet, the spacious site of the old Navy fuel depot could not be filled with only the construction of an ammonium sulphate plant, although some additions were made the greater part of the site and old facilities were left in ruin.

With the enforcement of the Peace Treaty in April 1952, designation of the facilities as a reparation object was rescinded and oil refining and petrochemical projects were planned by tri-parties of the Tokai Ammonium Sulphate, the Shell group and the Mitsubishi group. Thus, in July 1952, the parties applied to the Government for the sale of the old Navy fuel depot site to them.

In August 1955, the Government decided to sell the said site to Showa Oil Company Limited on condition that "Showa Oil Company Limited shall consider close co-operation with the Mitsubishi group and the Shell group when any petrochemical project shall be planned for commercial production at the site by the latter two groups in the future."

After some experimentation, with the Mitsubishi group as the central figure of the planning work, the basic policy was decided among the three parties to the effect that the oil refining project should be carried out by a new company to be established by two major constituents of the Showa Oil Company Limited and the Shell group with financial participation of a certain amount of capital investment by the Mitsubishi group at the site of the old Navy fuel depot, while the petrochemical project should be carried out by another new company to be established



Note:

1. The figures are T/Y.
2. The first-term plan within dotted line.
3. The others are production quantity including that of the first-term plan.

Figure 1. *Petrochemical plan at Yokkaichi area (planned in Dec. 1955)*

by the Mitsubishi group with the participation of the Shell group at the north ward site adjacent to the fuel depot.

As a result of this decision, the Mitsubishi Petrochemical Company Limited was established in April 1956 with a scanty capital of about $US 550,000.

Table I shows the list of the shareholders of the Mitsubishi Petrochemical Company Limited since the company's inauguration, by which you will understand how our Mitsubishi group, with the full co-operation of the Shell group, has confidently gone into the petrochemical industry, firmly combining the strength of each individual company.

What kinds of products were thought best to be produced in those years? Our initial petrochemical plan was to use off-gas from the refinery, so that we first constructed a small-scale petrochemical plant with a comparatively small amount of money, with the intention of increasing capacity gradually in accordance with the increase of demand.

The plant schedule which was thought of at that time is shown in figure I. It meant that the scheduled products were only two:

Styrene monomer	Six thousand (6,000) tons *per annum*, and
Ethylene oxide	Two thousand three hundred and forty (2,340) tons *per annum*

Comparing these small figures with the present one I cannot help being impressed.

While we were proceeding investigation on the above-mentioned schedule, however, we found that it was impossible to run economically a petrochemical plant

TABLE I. SHAREHOLDERS OF THE MITSUBISHI PETROCHEMICAL COMPANY LIMITED

Mitsubishi Chemical Co., Ltd.	From April, 1956
Mitsubishi Rayon Co. Ltd.	From April, 1956
Asahi Glass Co., Ltd. (Mitsubishi group)	From April, 1956
Mitsubishi Bank Co., Ltd.	From April, 1956
Mitsubishi Shoji Kaisha Ltd.	From April, 1956
Mitsubishi Metal Mining Co., Ltd.	From April, 1956
Tokio Marine & Fire Insurance Co., Ltd.	From March, 1957
Mitsubishi Mining Co., Ltd.	From March, 1957
Meiji Mutual Life Insurance Co., Ltd.	From March, 1957
Shell Sekiyu Kabushiki Kaisha Ltd.	From October, 1957
Showa Oil Co., Ltd.	From October, 1957

which was designed to use the refinery's off-gas because the scale of refining in those years was still small in Japan.

Accordingly we switched our raw material over from off-gas to naphtha, in order to produce olefins by cracking naphtha. We worked over our plant schedule again and made the plan as shown in figure II.

The ethylene capacity of twenty-two thousand (22,000) tons *per annum* as cited in our first project was too small and can never be an economical unit for any commercial operation under the present circumstances. But in those days, no petrochemical product was made in Japan. All petrochemicals had to be imported which resulted in very high prices and profitable sales. Accordingly, a small-scale plant like this could raise a certain amount of profit.

It was in November 1957 when the final layout of the first project was fixed and we started the construction of plants.

The construction of plants went along very smoothly and was completed in March 1959. Related plants followed which immediately went into practical operation.

Ethylene	Twenty-two thousand (22.000) tons *per annum*
Polyethylene	Ten thousand tons (10,000) *per annum*
Styrene	Eighteen thousand (18,000) tons *per annum*

Successively in April 1960, plants for the following were put into poeration successfully.

Ethylene oxide	Five thousand (5,000) tons *per annum* and
Ethylene glycol	Three thousand (3,000) tons *per annum*

About one year later, in May 1961, the following aromatics plants were added:

Benzene	Thirteen thousand tons (13,000) *per annum*
Toluene	Fourteen thousand (14,000) tons *per annum*
Xylene	Eleven thousand (11,000) tons *per annum*

Each of these plants has been expanded and reinforced year after year, being strongly supported by ever-increasing demand caused by the rapid growth of the national economy of Japan, with the addition of new products such as polypropylene, alkylbenzene and epoxy resins etc. A petroleum resin plant was also constructed based on a self-developed technology.

Recently, we started construction of n-pentane, n-hexane, n-heptane and acrylic esters plants. Latest capacities by items of our plants are shown in table 2.

Our affiliates and subsidiary companies constructed their plants in the Yokkaichi area; among these were: the Japan Synthetic Rubber Company producing SBR and polybutadiene; the Mitsubishi Monsanto Chemical producing polystyrene, AS resin, ABS resin and polyvinylchloride; and the Mitsubishi Chemical Industries producing isooctanol, etc. The Yuka Badische Company Limited, a joint venture of Mitsubishi Petrochemical and Badische Anilin & Soda Fabrik AG in West Germany, produces expandable polystyrene and the Yokkaichi Chemical Company, another joint venture of Mitsubishi Petrochemical, Daiichi Kogyo Seiyaku Company Limited and Lion Fat and Oil Company, successfully produces non-ionic detergent and nonyl phenol etc., respectively. C_3 fraction is also being supplied to the Asahi Glass Company Limited, which also belongs to Mitsubishi Group, to be used as raw material for the company's production of propylene oxide.

Figure III shows the composition of the Yokkaichi complex in a comprehensive illustration of what I have said above.

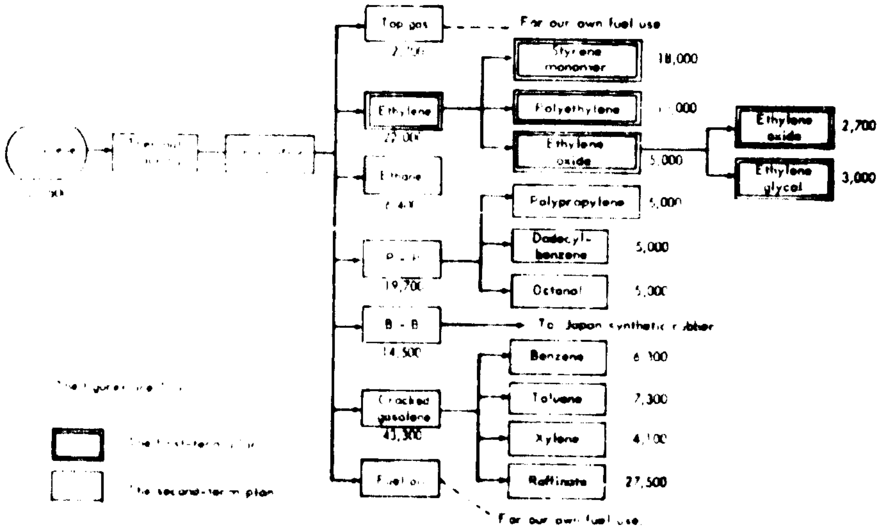
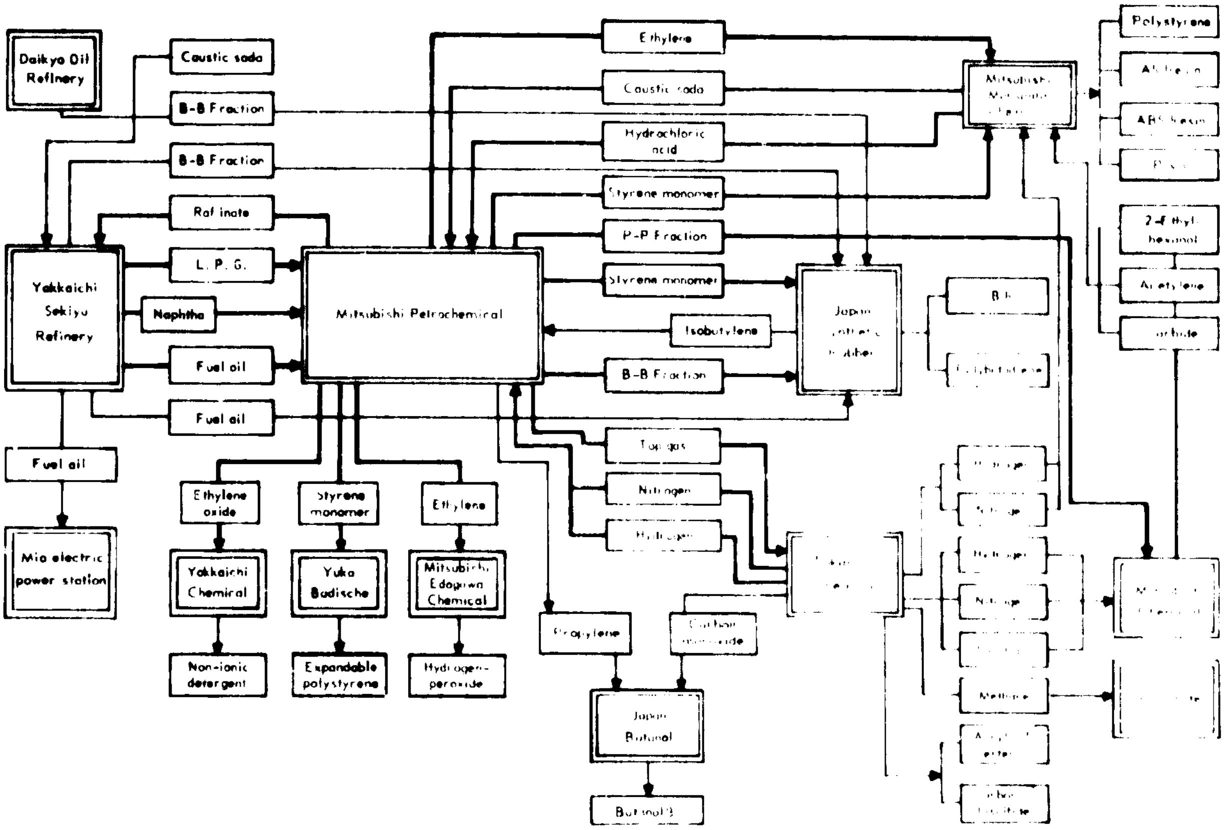


Figure II Petrochemical plan at Yokkaichi area (II) (drawn up in 1957)



• Under construction.

Figure III. *Yokkaichi Petrochemical Complex*

During these years, capital amount, number of employees and sales amount of Mitsubishi Petrochemical have advanced greatly as shown on figure IV and the value of shipment of chemical products out of Yokkaichi City advanced from 53 million US dollars in 1955 to 240 million US dollars in 1963, thus raising the position of Yokkaichi City to one of the most industrialized districts in Japan.

Drawn from my own experience, the points to be kept in mind especially when any one intends to go into the petrochemical business are as follows:

(*a*) The petrochemical industry is a process industry; therefore, from the beginning the scale of the plant should be considerably large so that the industry can cope successfully with severe international competition.

(*b*) With the construction of such a large-scale plant, it is necessary to achieve as high a rate of operation as as possible.

(*c*) To achieve a satisfactory operation of the plant as mentioned above, it is necessary to conduct a thorough market research in advance and to get the market fully developed with imported products prior to actual domestic production. When consumers would have been fully familiarized with imported products, they can easily replace them with domestically manufactured products whenever these appear in the market.

(*d*) It is necessary to introduce excellent techniques. When I say "excellent", this word implies such techniques as to produce products of high quality and cheap price without any noticeable technical trouble. In this connexion, it is also necessary, in selecting techniques, to prefer highly-tested techniques to not fully-tested techniques, however novel they may be.

TABLE 2. CAPACITIES AT YOKKAICHI PETROCHEMICAL COMPLEX

Name of plant	*Existing (t/y)*	*Under construction (t/y)*	*Total capacity (t/y)*
Ethylene (naphtha cracking)	82,000	100,000	182,000
Polyethylene (high pressure)	50,000	30,000	80,000
Styrene monomer	60,000	30,000 •	90,000
Ethylene oxide	17,000	24,000 •	41,000
Ethylene glycol	12,000	10,000 •	22,000
Benzene	25,000	31,000	56,000
Toluene	24,000	23,000	47,000
Xylenes	14,000	12,000	26,000
n-Pentane		1,200	1,200
n-Hexane		5,800	5,800
n-Heptane		4,100	4,100
Polypropylene	10,000	20,000	30,000
Alkylbenzene	20,000	12,000 •	32,000
Epoxy resin	4,000	3,500	7,500
Petroleum resin	2,000		2,000

TABLE 2 *(continued)*

Name of plant	*Existing (t/y)*	*Under construction (t/y)*	*Total cap. (t/y)*
Products hereunder being produced by our subsidiary company, and related company at Yokkaichi area			
Expandable polystyrene (Yuka-Badische Co.)	4,800	1,200	6,000
Butanol (Japan Butanol Co)	—	15,000 (Additional 15,000 t/y in 1966)	15,000 (30,000)
Non ionic detergents (Yokkaichi Chem Co.)	7,000	—	7,000
Nonyl phenol (Yokkaichi Chem. Co.)	1,800	—	1,800
Carbonbisulfate (Tokai Gas Chemical Co.)		30,000 [a]	30,000
Acrylic esters (Tokai Gas Chemical Co.)		6,500	6,500
2-Ethyl hexanol (Mitsubishi Chemical Co.) [a]	24,000	2,400	26,400
SBR (Japan Synthetic Rubber Co.) [b]	80,000	4,000	84,000
Polybutadiene (Japan Synthetic Rubber Co.) [b]	—	20,000	20,000
PVC (Mitsubishi Monsanto Chemical Co) [b]	27,700	12,000	39,700
Polystyrene (Mitsubishi Monsanto Chemical Co.) [b]	21,600	12,000	33,600
ABS (Mitsubishi Monsanto Chemical Co.) [b]		3,300	3,300
AS Resin (Mitsubishi Monsanto Chemical Co.) [b]	3,600	3,600	7,200

[a] Scheduled to construct

[b] Related company

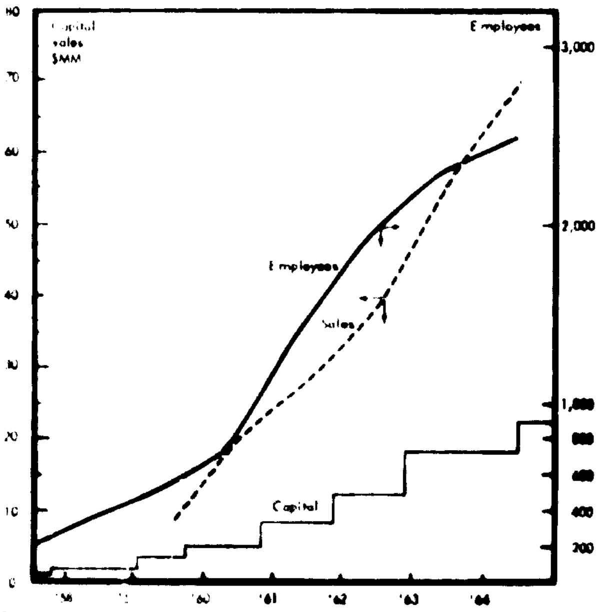


Figure IV. *The transition of capital, sales, employees of the Mitsubishi Petrochemical Co.*

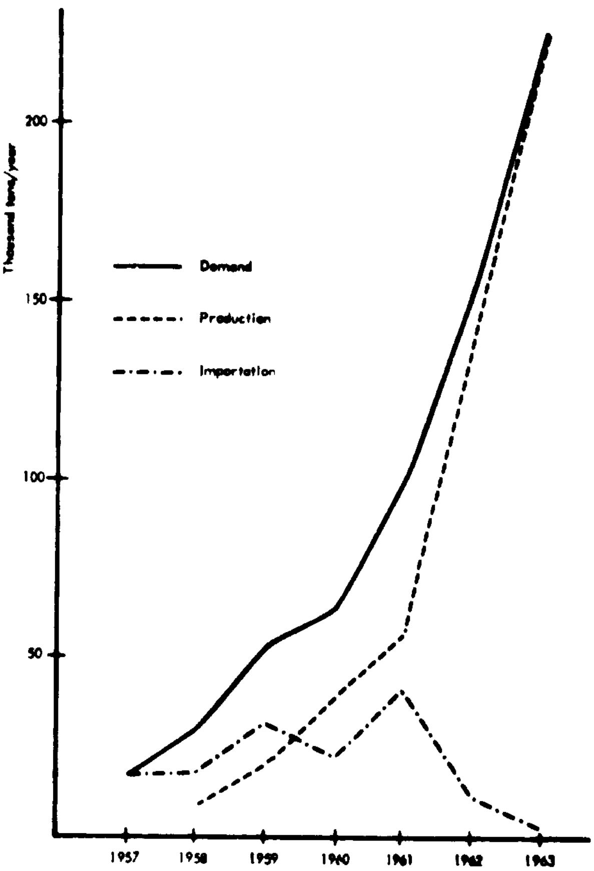


Figure V. *Demand, production and importation of polyethylene in Japan*

How were these points applied in our case? Looking at our history, I wish to explain briefly some reasons responsible for the success of our petrochemical undertaking in Yokkaichi area (see table 3).

At the top of the table, there is mentioned "Why?". The reasons for our starting the petrochemical business were not only for the pursuit of profit but also to prevent importation of petrochemicals with the intention of contributing our part to the improvement of the national economy. Then, in a more general sense, we wanted to do our part towards the promotion of the heavy and chemical industries of Japan. In other words, there was in Japanese economy an inevitability about the development of the petrochemical industry and a foundation upon which this business could grow. This was the first reason why our petrochemical business was undertaken and succeeded.

TABLE 3. CHECK LIST FOR PLANNING OF PETROCHEMICAL INDUSTRY

1. Why?
2. When?
3. What?
4. Where?
5. Who?
6. How?

In the second place, there is mentioned "When ?"

It was very fortunate for us that the time of the initiation of our business was coincident with the period of very rapid growth of over-all national economy and the demand for petrochemical products increased very briskly every year. This was the second reason for our success.

As a sample of our rapid business expansion, see figure V, where you will easily get an idea of the growth of demand for polyethylene.

The third question is "What?".

This meant not only that our selection of products was of superior adaptability to the requirements of the nation but also that we adopted the world's best technology for every item of our production after over-all study and investigation of world techniques.

The fourth is "Where?".

Yokkaichi is located in one of the most suitable districts in Japan for petrochemical industry, being an important point of traffic facing a good harbour and fronting railways and highways; it has a good quality labour force and utilities such as electricity and industrial water, etc. and is very close to big consumption areas.

In the fifth place comes "Who?".

Besides favourable assistance from the Japanese Government, we mobilized the excellent staff and personnel of the Mitsubishi group, a group of our sister companies, and at the same time, we enjoyed close co-operation with our good co-ordinators such as the Shell group and Badische Anilin & Soda Fabrik AG etc., and that was the fifth reason for our success.

The final one is How?".

Individual procedures did not matter much however cleverly planned, and in our case inter-reliance and inter-co-operation have played most important roles. Based on the spirit of "live and let live", these values have been firmly established not only among government authorities of the prefecture and the city, shareholders, management and staff and workers but also among co-operating companies, affiliates, subsidiary companies and engineering companies etc. This was the most important factor for our success.

In case any developing country wishes to develop its own petrochemical industry, it is sincerely hoped that the authorities as well as the businessmen of such a country will pay special attention to the 5 " W's" of Why, When, What, Where and Who and the "H" of How to achieve success explained above. At the same time, the Mitsubishi Petrochemical Company would like to extend its help at any time, as far as it is possible, to any country which wishes to start its petrochemical industry. We feel we have something to share from the knowledge and experience which we have accumulated in developing our present petrochemical complex, which started from almost zero.

11. STRUCTURE OF PETROCHEMICAL DEVELOPMENT IN MEXICO — REYNOSA AND PAJARITOS DEVELOPMENTS

Petróleos Mexicanos, Mexico

I. INTRODUCTION

A. *Legal aspects*

The Mexican Constitution places the direct domain of hydrocarbons on the Nation. This domain extends to the manufacture, storage, transportation, distribution and sales of such petrochemical derivatives used as basic industrial raw materials.

Therefore, the responsibility regarding the manufacture of products elaborated as a result of the first physical or chemical transformation falls on Petróleos Mexicanos (Pemex) or other government institutions.

Each of the corporations participating in the petrochemical development is constituted under the laws and rules of Mexico, as administered by the Foreign Ministry, as far as the permit to be established is concerned, and by the Federal Government through the National Petrochemical Commission, for the permit to operate, should this industry be a petrochemical one, and the Ministry of Industry and Commerce, in case the industry should be only chemical and or service rendering.

Notwithstanding the above, the Mexican Government encourages the participation of private investors in those activities outside the scope of the petrochemical law. As a result, the equity of the petrochemical corporations varies considerably as far as the composition of the investment is concerned. There are corporations in which Petroleos Mexicanos owns a hundred per cent of the equity (Instalaciones Immobiliarias para Industrias, S.A.); there are others in which Pemex owns 51 per cent of the equity (Tetraetilo de Mexico, S.A.), and still there are others in which Pemex owns only 30 per cent of the equity (PoliRey, S.A.). Each of the corporations maintains its corporate independence and is administered entirely in accordance with its own by-laws. Therefore, each corporation enters into contracts for the purchase of raw materials and the sale of its products, it contracts for the rental of the land, utilities and administration services.

B. *Joint services*

The petrochemical developments in Mexico are being carried under two different types of operations.

(1) *Joint services development*

This type of development is a highly concentrated and integrated one, such as the Pajaritos Development. In this case a large plot of land was acquired by Instalaciones Immobiliarias para Industrias, S.A. (a hundred per cent subsidiary of Petróleos Mexicanos). This corporation rents the different plots of land required by each of the operating companies. Also, Instalaciones Immobiliarias para Industrias, S.A. will provide to the operating corporations utilities such as steam, cooling water, electricity and sewers. Housing for employees and general administration services will also be supplied by this same corporation.

(2) *Conventional development*

Another type of development is the one taking place at Reynosa. In this project, Petróleos Mexicanos will supply the basic raw materials by pipeline within a given area (17 kilometres). Each of the operating corporations will be located adjacent to the pipelines, each one being responsible for its own land, utilities and services.

II. INVESTMENT SECTORS

The Petrochemical development in Mexico is taking place by institutions within three sectors.

(1) *Government sector*

Within the government sector operate corporations which were established to elaborate the petrochemical products, such as ammonia plants, which the Mexican Constitution states must be produced by Petróleos Mexicanos or other government institutions.

(2) *Mixed sector*

Within this sector operate corporations which were established to elaborate petrochemical products which by nature or circumstances it was considered desirable to have joint investments of the Government and the private sector, such is the case with tetraethyl lead.

(3) *Private sector*

Within the private sector operate corporations which were established to manufacture petrochemical products which are outside of the jurisdiction of the petrochemical law and thus can be elaborated by private investors, such as ethyleneglycols and ethanolamines.

III. ECONOMIC FACTORS

The petrochemical corporations have the benefit of all the tax considerations granted by the Government of Mexico to new and necessary industries. Besides, the National Petrochemical Commission, when granting the permits to construct and operate plants within the petrochemical development programme, has approved sales prices for the products of 15 per cent higher than international prices.

Generally, the plant capacities of these corporations have been established in order to supply the Mexican market at the plant point of equilibrium between income and expenses, and these corporations promote exports in order to obtain a higher income.

For this reason, the petrochemical companies have generally a sound basis for operations and growth since these corporations recuperate from the Mexican market their operating income, and from the export market a portion of their profits.

The majority of these corporations are promoting actively exports to Latin America, mainly to the countries members of the ALALC (Latin America Free Trade Area). The probabilities of success vary considerably from company to company, according to the type of products they manufacture and to the effort they put in developing exports.

IV CONTRIBUTION TO THE GROSS NATIONAL PRODUCT

The Pajaritos and Reynosa Developments will make a substantial contribution to the gross national product. The gross national product estimated for 1965 at current prices is 178 million pesos. Therefore, these two petrochemical developments will contribute approximately 0.35 per cent of the gross national product. These figures show that the petrochemical industry has an important role in the economy of Mexico, if we consider that the contribution of the petrochemical industry is 3.2 per cent of the gross national product.

V MANPOWER

The Pajaritos and Reynosa Developments will employ approximately 2,268 men. On the estimate that there are six members per family, it means that 13,608 persons will obtain benefits from these developments, without taking into account the additional persons that would be required to provide services, such as shops, transportation etc., to the persons directly connected with the developments.

The economically active population of Mexico in 1965, as estimated, will be of 15,000,000 inhabitants; therefore it can be said that the Pajaritos and Reynosa Developments will increase the economically active population of Mexico by 0.25 per cent.

VI IMPACT OF THE PETROCHEMICAL DEVELOPMENT

The development of the petrochemical industry in Mexico has brought about the following:

1. An increasing degree of confidence between private investors and the Government.
2. Integration and flexibility of operations and services, which has resulted in efficient operations and adequate product prices.
3. Self-liquidated investments and [illegible] capital assets within the country.
4. Reduction and elimination of imports with possibilities of increasing exports.
5. Rational exploitation of national resources.
6. A higher rate of industrial development in different areas of Mexico, which previously had not obtained the benefits of industrial development.
7. The establishment of new sources of work and industry within the petrochemical plants and connected business activities.
8. Increased technical and administrative competition between the different corporations [illegible] in an over-all higher efficiency.

VII PLANT LOCATIONS

This article describes the development at two of these petrochemical centres, namely Pajaritos Coatzacoalcos in the state of Veracruz and Reynosa in the state of Tamaulipas.

The Pajaritos development is based on ethylene [illegible] and also on the need of the petrochemical industry to manufacture tetraethyl lead in Mexico. Tetraethyl lead is a basic component of motor fuel and at present the largest item being imported by the petrochemical [illegible] in Mexico.

A. *Pajaritos*

The Pajaritos development is [illegible] integration: Tetraethyl lead fluid [illegible] (a) tetraethyl lead (b) [illegible] dichloride [illegible] dibromide (d) kerosene [illegible].

In order to make tetraethyl lead, ethyl chloride, ethylene dichloride and ethylene dibromide [illegible] thus should be produced locally.

Having local production [illegible] conversion of a part of [illegible] was advisable. This operation [illegible] by-product hydrochloric acid which [illegible] manufacture of ethyl chloride.

The manufacture of [illegible] a fraction of the total [illegible] salt as raw material. This last manufacture [illegible] caustic soda as by-product. [illegible] are not sufficient to utilize the sodium chloride that would be required to be handled as a consequence of the need to produce bromine locally from brine and sea water; thus the elaboration of sodium carbonate was established to utilize all the sodium chloride [illegible] available at Pajaritos.

By having ethylene as principal raw material at Pajaritos, the acetaldehyde plant was established [illegible] the manufacture of acetic anhydride, ethyl acetate, butyl acetate, n-butanol, methyl ketone, methyl ethyl ketone, vinyl acetate and cellulose acetate.

B. *Reynosa*

The petrochemical development at Reynosa is based on ethylene. Ethylene is produced by the pyrolysis of ethane near the gasolene plant of Petróleos Mexicanos at Reynosa.

Liquid ethylene is pumped by pipeline to an area near Reynosa, where the following plants will be built:

(*a*) Ethylene oxide plant.

(*b*) Ethyleneglycole and ethanolamines plants.

(*c*) Polyethylene plant.

VIII. PAJARITOS INDUSTRIAL DEVELOPMENT

A. *Basic description*

The industrial development of Pajaritos is formed by a group of plants producing a variety of products and operated by several different companies.

The natural gas from the oil and gas fields in the area (La Venta, Ogarrio, Sánchez Magallanes, Tonalá, El Plan and Santa Ana) is gathered and sent by pipeline to the gasolene plant of La Venta, where the liquid products are recuperated. Ethane (99.5 per cent purity) is sent by pipeline (seventy kilometres) to the ethylene plant in Pajaritos. In this installation a pyrolysis of the ethane takes place giving ethylene as main product. This installation has a nominal capacity of 36,500 tons per year. This plant falls within the basic petrochemistry and thus is being built and will be operated only by Petróleos Mexicanos.

The plants at Pajaritos are described below.

1. *Chlorine and caustic soda plant.* Brine is produced from Pajaritos and Tuzandpetl by means of wells. The brine is pumped to a chlorine and caustic soda plant. This plant, which uses the Oronzio de Nora Process, has a nominal capacity of 36,000 tons per year of chlorine and 65,000 tons per year of 50 per cent rayon grade caustic soda.
2. *Metallic sodium plant.* Plans are being drawn up for the construction of a metallic sodium plant. This plant will use the Du Pont Process and will have a nominal capacity of 7,000 tons per year of metallic sodium.
3. *Ethyl chloride plant.* In this plant ethylene is reacted with hydrochloric acid to give as product ethylchloride. This plant, which will use the Shell Process, has a nominal capacity of 13,500 tons per year of ethyl-chloride. The hydrochloric acid used in this plant is a by-product of the vinyl-chloride plant.
4. *Ethylene dichloride plant.* In this plant ethylene reacts with chlorine in a gaseous phase and by means of a catalyst. This plant uses the Shell Process and has a nominal capacity of 38,500 tons per year. The chlorine used comes from the chlorine-alkali plant.
5. *Ethylene dibromide plant.* In this plant ethylene reacts with bromine. The nominal capacity of this plant is 4,500 tons per year of ethylene dibromide. Plans are being drawn up to produce bromine locally at Pajaritos by recuperating bromine from sea water and brine.
6. *Acetaldehyde plant.* In this plant direct oxidation with air of ethylene takes place in order to obtain acetic aldehyde (acetaldehyde). This plant used the Hoescht Process and has a nominal capacity of 24,000 tons per year of acetaldehyde.

The ethyl chloride plant, ethylene dichloride plant, ethylene-dibromide plant and the acetaldehyde plant will be operated by private corporations to be described later on in this article. The ethylene plant will be operated by Petróleos Mexicanos.

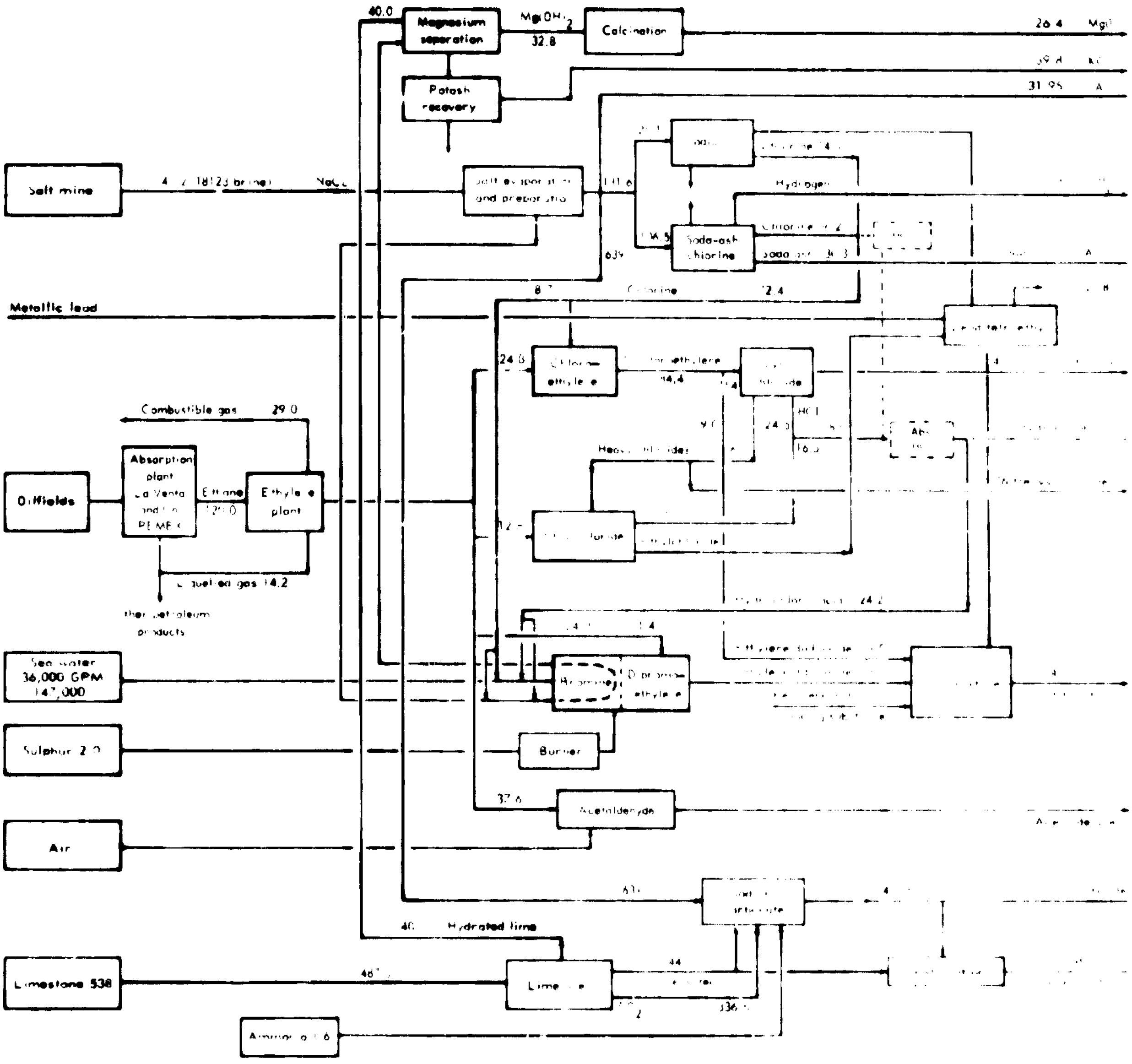
The products from the above-mentioned plants are used as feed-stocks to the following plants:

1. *Vinyl-chloride plant.* Part of the ethylene dichloride will be used as feed-stock to the vinyl-chloride monomer plant. In this plant ethylene dichloride undergoes a catalytic dehydrochlorination to give vinyl-chloride monomer as product and hydrochloric acid as by-product. This plant, which will use the Shell Process, has a nominal capacity of 18,500 tons per year of vinyl-chloride monomer.
2. *Tetraethyl lead and ethyl fluid plants.* The feed-stocks to these plants are the following: 13 tons per year of ethyl chloride; 4,500 tons per year of ethylene dichloride; 4,200 tons per year of ethylene dibromide; 2,000 tons per year of kerosene; 9,800 tons per year of lead; and 4,700 tons per year of metallic sodium. These plants use the Du Pont Process and produce 24,000 tons per year of ethyl fluid. These plants will be operated by a corporation to be described later on in this article.
3. *Soda ash and caustic soda plants (by caustification).* In order to produce the required amount of bromine, it will be necessary to produce sodium chloride in excess of the requirements of the plants mentioned above; thus, the soda ash plant is being built. These plants use the Diamond Alkali and Oronzio de Nora Process and have capacities of 180,000 tons per year of soda ash and 30,000 tons per year of caustic soda in flakes.
4. *Salt production.* A plant is being constructed for the production of industrial grade salt (sodium chloride). The said plant, which will use a Multiple Effect Evaporators Process, will have a nominal capacity of 31.96 million pounds per year of sodium chloride, for sale to industry in general. This amount of salt for sale to industry in general is in excess of the salt produced for the requirements of the Pajaritos Development, this requirement being 770.6 million pounds a year.

The feed-stocks to these plants are also salt (sodium chloride), brine, anhydrous ammonia and limestone from the region.

B. *Flow diagrams of the Pajaritos Development*

The general flow diagram of the Pajaritos Development is shown in figure I.



Data in million pounds per year

Pajaritos Industrial Complex

Figure 1

C. *Investors in the Pajaritos Development*

Several companies participate in the operation of this industrial development.

1. *Sales y Alcalis, S.A.* This company will operate the brine production and purification plants, the chlorine-alkaline-plant, and the soda ash and caustic soda by caustification plant. The investors in this company are the following:

	Per cent
Petróleos Mexicanos	28
Nacional Financiera	10
Diamond Alkali and Oronzio de Nora	26
Mexican private investors	36

2. *Acetaldehido de Mexico, S.A.* This company will operate the acetaldehyde plant. The investors in this company are the following:

	Per cent
Petroleos Mexicanos	51
Quimica General, S.A. y Hoescht	49

3. *Tetraetilo de Mexico, S.A.* This company will produce tetraethyl lead and ethyl fluid. The investors in this company will be the following:

	Per cent
Petróleos Mexicanos	51
E.I. Du Pont de Nemours	49

4. *Derivados Clorados, S.A.* This company will produce ethyl chloride, ethylene dichloride and vinyl

chloride. The investors in this company are the following:

	Per cent
Petroleos Mexicanos	60
Shell	40

5. *Instalaciones Inmobiliarias para Industrias, S.A.* This company owns the land on which the Pajaritos Development is being built (2,435 hectares). This land is situated South of the Pajaritos Lagoon and the Teapa Stream, to the East of the Coatzacoalcos River, to the North of the Capalote Estuary and West of the Veronica lot, in the municipality of Coatzacoalcos. This company will also provide to all the operating companies in the development utilities and general services, such as steam, electricity, fresh water and sewers. This company will also provide housing for the employees of the different companies, transportation services, railway transportation services, and general administration services. This company is owned entirely by Petróleos Mexicanos due to the requirements of Mexican legislation which restricts the ownership of land by foreign companies or individuals near the seashores and borders. Under these circumstances, the land is owned by Instalaciones Inmobiliarias para Industrias, S.A. and portions of land are rented by this company to the individual operating companies.

6. *Petróleos Mexicanos.* This institution is owned by the Mexican Government and will operate the ethylene plant. Petróleos Mexicanos will also supply the fuel gas (natural gas) and the ethane for the ethylene production.

7. *Comisión Federal de Electricidad.* This institution of the Mexican Government will operate the power plant which will supply all the needs of the Development.

D. *Port facilities*

In the Pajaritos Lagoon, a deep-water port is being constructed. Dredging has commenced on a canal communicating the Gulf of Mexico with the Lagoon. The port facilities are being constructed by the Mexican Ministry of the Navy and Instalaciones Inmobiliarias para Industrias, S.A.

When the Pajaritos port is completed, it will allow the operating companies on the Pajaritos Development convenient access to export markets. The lagoon is protected from the Gulf of Mexico, and the canal being dredged will permit the entry of large tonnage ships.

E. *Estimated investments in the Pajaritos Petrochemical Development*

	US dollars
Total estimated investments in the Pajaritos Petrochemical Development	1,080,042,500.00
1. *Petroleos Mexicanos*	
(*a*) Ethylene plant	104,137,500.00
(*b*) Utilities and services (ethane line etc.)	42,000,000.00
	146,137,500.00
2. *Derivados Clorados, S.A.*	
(*a*) Ethylene dichloride plant	28,500,000.00
(*b*) Vinyl chloride plant	23,000,000.00
(*c*) Ethyl chloride plant	26,000,000.00
	77,500,000.00
3. *Sales y Alcalis, S.A.*	
(*a*) Salt purification and connected plants	69,875,000.00
(*b*) Caustic soda and chlorine plant	81,250,000.00
(*c*) Sodium carbonate plant	259,280,000.00
	410,405,000.00
4. *Tetraetilo de México, S.A.*	
(*a*) Tetraethyl lead and fluid ethyl plant	112,500,000.00
5. *Acetaldehídos de México, S.A.*	
(*a*) Acetaldehyde plant	61,500,000.00
6. *Companies to be formed*	
(*a*) Ethylene dibromide plant	4,500,000.00
(*b*) Bromine plant	41,250,000.00
(*c*) Metallic sodium plant	62,500,000.00
(*d*) Chlorine liquefaction plant	7,500,000.00
(*e*) Hydrochloric acid plant	6,250,000.00
	122,000,000.00
7. *Instalaciones Inmobiliarias para Industrias S.A.*	
(*a*) Salt wells, boilers, sewers, land, housing, etc	150,000,000.00

F. *Production value of the Pajaritos Development*

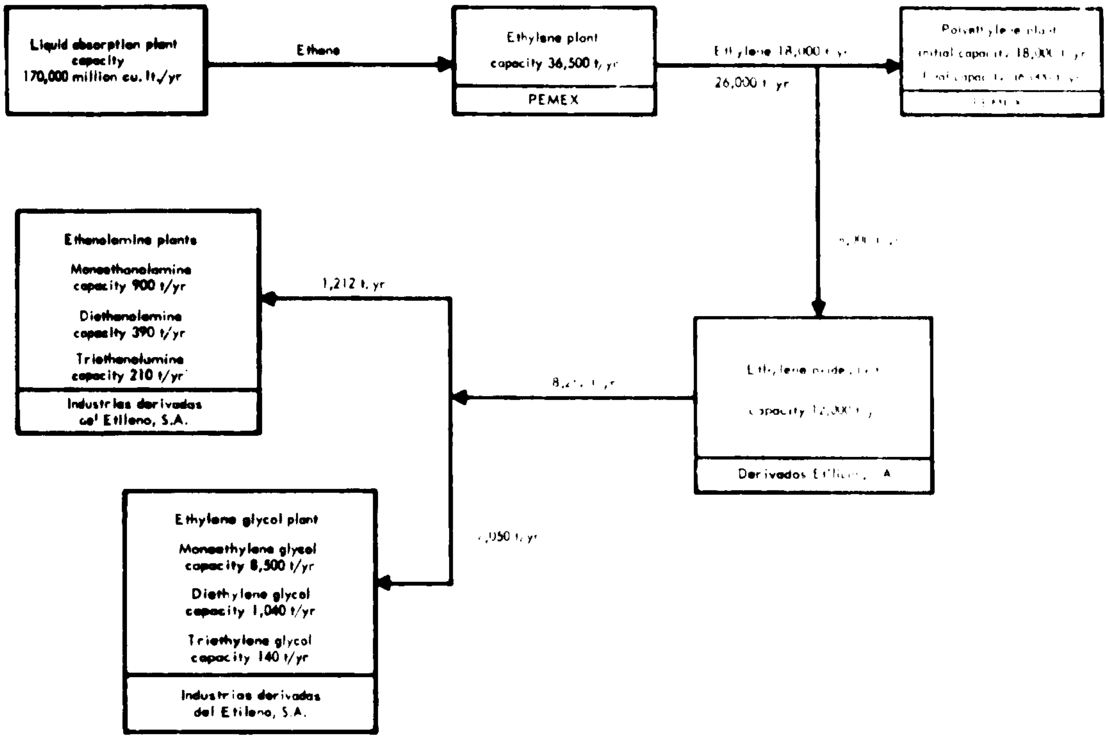
Production data taken from the general flow diagram shown in figure II.

	US dollars
Ethylene plant	42,382,200.00
Ethyl chloride	33,000,000.00
Ethylene dichloride	55,627,800.00
Vinyl chloride	53,636,900.00
Acetaldehyde	57,818,400.00
Ethylene dibromide	32,940,600.00
Tetraethyl lead (fluid)	224,987,216.00
Bromine	20,000,000.00
Metallic sodium	23,250,000.00
Caustic soda 50 per cent	47,233,750.00
Chlorine	30,770,000.00
Hydrochloric acid	6,684,000.00
Sodium carbonate	78,517,500.00
Soda ash in flakes	38,500,000.00

G. *Economic benefits for the country derived from the Pajaritos Development*

(1) Once the plants being constructed are on stream, it is estimated that the following values of imports would be eliminated, thus saving foreign exchange.

	US dollars
(*a*) Vinyl chloride (monomer)	47,800,000.00
(*b*) Acetaldehyde	25,667,000.00
(*c*) Tetraethyl lead	142,491,216.00
(*d*) Sodium carbonate	70,500,000.00
(*e*) Soda ash in flakes	34,650,000.00
	321,108,216.00



Reynosa Petrochemical Complex

Figure II

(2) It is estimated that once the plants being constructed are on stream, the following values of exports could be developed, thus earning foreign exchange.

	US dollars
(*a*) Vinyl chloride (monomer)	5,836,000.00
(*b*) Acetaldehyde	32,151,400.00
(*c*) Tetraethyl lead	82,496,000.00
(*d*) Sodium carbonate	8,017,000.00
(*e*) Soda ash in flakes	3,350,000.00
	131,850,400.00

H. *Estimated labour requirements*

1. *Direct labour*

The following personnel will be employed:

	Men
(*a*) Administration labour	240
(*b*) Operation and maintenance labour	850
	1,090

2. *Indirect labour*

It is estimated that indirect labour, which will be employed will be the following:

	Men
(*a*) Labour in transportation, shipping, handling operations of loading and unloading, etc.	120
(*b*) Distribution and services labour	250
(*c*) Publicity and promotions	150
	520

I. *Demands of the products from the Pajaritos Development*

The Pajaritos Development, as has been mentioned before, is constituted basically by the production of tetraethyl lead, so that the demand of this compound defines in principle the demands of the intermediate products in the following manner.

Tetraethyl lead consumption

Year	*Domestic consumption, gasolene (million Bls/year)*	*R. O. octanes*	*[illegible] octane [illegible] TEL/gallon*	*Required [illegible] per year*
1962	38.8	68.6	82.9	11,188
1963	42.1	71.3	84.8	9,500
1964	45.8	70.4	84.0	12,410
1965	49.9	70.6	84.6	13,818
1966	54.3	70.6	84.4	1[illegible],182
1967	59.1	71.3	84.9	18,682
1968	64.1	70.5	84.5	21,818

Chlorine and hydrochloric acid demands

The production of chlorine and hydrochloric acid [illegible] balanced so as to use that necessary to manufacture the chlorine derivatives. Only if it is required, will there be enough production for the market. This situation [illegible] shown in figure I.

Caustic soda and sodium carbonate demands (there is a shortage in the national production)

Year	*Caustic soda in tons year*	*Sodium carbonate, tons year*
1962	118,200	176,200
1963	131,500	195,600
1964	146,300	217,100
1965	162,600	241,000
1966	175,000	267,500
1967	190,000	296,900
1968	205,000	329,600

Ethyl chloride and ethylene dichloride for T.E.L. consumption

Year	*Ethylic fluid (tons year)*	*Ethyl chloride (tons year)*	*Ethylene dichloride (tons year)*
1962	11,188	6,091	2,091
1963	9,500	5,182	1,773
1964	12,910	7,046	2,409
1965	13,818	7,545	2,591
1966	17,182	9,364	3,227
1967	18,682	10,227	3,500
1968	21,818	11,909	4,091

P.V.C. and vinyl chloride monomer consumption

Year	*P.V.C. in tons year*	*V.C. monomer, tons year*
1962	8,200	9,200
1963	10,900	11,200
1964	12,600	14,100
1965	14,400	16,200
1966	16,200	18,200
1967	18,200	20,400
1968	19,800	22,200

Ethylene dichloride demand for vinyl chloride monomer and that necessary for T.E.L.

Year	*Ethylene dichloride in tons year*
1962	18,880
1963	21,960
1964	25,500
1965	31,980
1966	37,900
1967	40,500
1968	45,000

Acetaldehyde consumption for anhydrate and acetic acid, ethyl acetate, butyl acetate, vinyl acetate, N-butanol, methyl-ethyl-ketone, cellulose acetate, chlorid-acetic acid and various.

	Tons year
1963	11,750
1964	13,150
1965	15,600
1966	16,875
1967	19,925
1968	21,315

IX. REYNOSA PETROCHEMICAL DEVELOPMENT

A. *Basic description*

Ethylene constitutes the basic raw material for the Reynosa Petrochemical development. Ethylene will be produced by Petróleos Mexicanos at installations within the gasolene plant by pyrolysis of ethane, at Reynosa. The feed to the ethylene plant will be ethane obtained from the gasolene plant. Ethylene will be the feed-stock to the following plants:

(a) *Ethylene oxide plant.* This plant will produce ethylene oxide by controlled oxidation of ethylene by air. Ethylene oxide is a basic component for further chemical manufactures. This plant will use a Scientific Design Process and will have a nominal capacity of 12,000 tons per year. Provisions have been made to expand this capacity to a total of 24,000 tons per year of ethylene oxide.

(b) *Ethyleneglycols plant.* In this plant, ethylene oxide will be hydrolized to monethyleneglycole. A part of the monoethyleneglycole produced will be reacted again with ethylene oxide to give diethyleneglycole and triethyleneglycole. This plant will use a Scientific Design Process and will have a nominal capacity of 8,000 tons per year of ethyleneglycole.

(c) *Ethanolamines plant.* In this plant, ethylene oxide will be reacted with ammonia to produce the different ethanolamines. The different types of ethanolamines will be produced in this plant merely by changing the operating conditions (mainly pressure and temperature). The operation of the plant would be in accordance with the Mexican market for these products, as follows: 78.3 per cent monoethanolamine, 16 per cent of diethanolamine, and 4.4. per cent of triethanolamine. This plant will use a Scientific Design and will have a nominal capacity of 2,000 tons per year of ethanolamines.

(d) *Polyethylene plant.* In this plant ethylene will be polymerized at high pressure to produce low density polyethylene. This plant will use the Imperial Chemical Industries Process and will have a nominal capacity of 18,000 tons per year of polyethylene. Provisions have been made to expand this plant to an ultimate capacity of 48,000 tons per year of polyethylene.

B. *Flow diagram of the Reynosa Development*

The general flow diagram of the Reynosa Development is shown in figure II.

C. *Investors in the Reynosa Development*

Several companies participate in the operation of this petrochemical development:

1. *Derivados Etilicos, S.A.* This company will operate the ethylene oxide plant. The investors in this company are the following:

	Per cent
Petróleos Mexicanos	50
Industria Nacional Químicofarmacéutica	50

2. *Industrias Derivadas del Etileno, S.A.* This company will operate the ethyleneglycoles plant and the ethanol-

amines plant. This plant is within the private sector and thus the investors in this company are private.

3. *PoliRey, S.A.* This company will operate the polyethylene plant. The investors in this company are the following:

	Per cent
Petróleos Mexicanos	33
Celulosa y Derivados, S.A.	33
Imperial Chemical Industries	33

D. *Estimated investments in the Reynosa Petrochemical Development*

	US dollars
Total estimated investments in the Reynosa Petrochemical Development	351,700,000.00
1. ***Petróleos Mexicanos***	
(*a*) Ethylene plant	104,500,000.00
(*b*) Ethylene pipelines etc.	25,500,000.00
	130,000,000.00
2. ***PoliRey, S.A.***	
(*a*) Polyethylene plant	109,200,000.00
3. ***Derivados Etílicos, S.A.***	
(*a*) Ethylene oxide plant	41,500,000.00
4. ***Industrias Derivados del Etileno, S.A.***	
(*a*) Ethanolamines and ethyleneglycoles plants	21,000,000.00
5. ***Instalaciones Inmobiliarias para Industrias, S.A.***	
(*a*) Land, housing, boilers, sewers	50,000,000.00

E. *Production value of the Reynosa Development*

Production data taken from the general flow diagram shown in figure 11.

	US dollars
Ethylene plant	37,501,800.00
Ethylene oxide plant	20,812,500.00
Ethyleneglycoles plant	29,680,000.00
Ethanolamines plant	16,098,000.00
Polyethylene plant	123,611,000.00

F. *Economic Benefits for the country derived from the Reynosa Development*

(*a*) Once the plants under construction are on stream, it is estimated that the following import values would be eliminated, thus saving foreign exchange.

	US dollars
1. **Ethyleneglycoles**	26,500,000.00
2. **Ethanolamines**	12,750,000.00
3. **Polyethylene (low density)**	104,594,000.00
	143,844,000.00

(*b*) It is estimated that once the plants being constructed are on stream, the following export values could be developed, thus earning foreign exchange.

	US dollars
1. Ethyleneglycoles	3,180,000.00
2. Ethanolamines	3,348,000.00
3. Polyethylene (low density)	19,017,000.00
	25,545,000.00

G. *Estimated labour requirements*

1. *Direct labour*

The following personnel will be employed:

	Men
(*a*) Administration labour	90
(*b*) Operation and maintenance labour	305
	395

2. *Indirect labour*

It is estimated that indirect labour, which will be employed will be the following:

	Men
(*a*) Labour in transportation, shipping, handling operations etc	58
(*b*) Distribution and services labour	120
(*c*) Publicity and promotions	85
	263

H. *Demands of the products of the Reynosa Development*

The Reynosa Development is constituted basically by the production of ethylene and the demands of the intermediate products are as follows:

Ethanolamines and ethyleneglycoles demands

Year	*Ethyleneglycoles tons year*	*Ethanolamines Tons year*
1962	1,288	1,401
1963	1,663	1,783
1964	2,147	2,270
1965	2,772	2,890
1966	3,579	3,679
1967	4,620	4,683

Ethylene oxide demands

Year	*Ethyleneglycoles ethanolamines (tons year)*	*Various (tons year)*	*Total (tons year)*
1962	2,121	1,200	3,321
1963	2,717	1,700	4,417
1964	3,483	2,250	5,733
1965	4,463	2,890	7,353
1966	5,730	3,490	9,220
1967	7,331	4,050	11,381

Polyethylene demands (high pressure and low density)

Year	*Tons year*
1962	11,200
1963	14,600
1964	18,500
1965	24,000
1966	31,000
1967	40,000
1968	50,500

12. PLANT SIZE, LOCATION, AND TIME-PHASING : INTRODUCTION

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I. GENERAL CONSIDERATIONS

This is the first in a series of studies.[1] Each report will deal with selected aspects of plant size, location, and time-phasing. Particular emphasis will be placed upon the implications of economies-of-scale in manufacturing industrial products. The basic viewpoint is normative rather than descriptive. These reports are concerned with planning for economic efficiency.

In a political democracy whether the economic system be capitalist or socialist it is inevitable that various regional and industrial groups will create demands for departures from economic efficiency. In each of these studies, we hope to make rough estimates of the cost of satisfying such pressure groups. With better knowledge of the magnitude of costs involved, it should be possible to reduce, though not to eliminate, the emotional aspect of India's political decisions on plant size and location.

II. SCOPE

Each of these reports deals with multi-plant investment decisions within an individual manufacturing industry. These reports are not intended to be fully realistic and detailed. Instead, an attempt is made to concentrate only upon those factors that are believed essential for planning the industry's growth over time and space. The level of aggregation is quite different from that of either a project report or an inter-industry study. In a typical project report, the analysis is narrowed to a specific location and often to a specific size of plant and date of construction. Within the scope of a project report, it is feasible to consider detailed alternatives for the individual plant with respect to its product-mix, processes, and raw materials. In an inter-industry model, the scope is much broader than either a single project or an industry. The inter-industry framework is particularly desirable in India for the job of forecasting aggregate demands and investment requirements for such intermediate goods as steel, machinery, fuel, and electricity.

In the current series of studies, with the individual *industry* as the unit of analysis, it becomes possible to focus upon still another range of investment policy problems. Here we shall be specifically concerned with economies-of-scale in manufacturing. By itself, this factor makes it desirable to set up large individual plants isolated from each other by long intervals in both time and space. Offsetting this factor are the costs of transport and of building capacity ahead of demand. By analysing the costs and benefits of alternative plant sizes and locations, it should be possible to draw some conclusions with respect to India's current industrial licensing policies.

The viewpoint adopted here is that of "partial equilibrium" neglecting feed-back effects *via* other sectors. Typically, it is assumed that the demand for the industry's products is a datum, and that all of the industry's inputs may be procured by paying a sufficiently high price. (E.g., in the case of caustic soda, it is assumed that domestic production is the only source of the product. It is also assumed that the caustic soda industry takes a small enough input of electricity, rail transport, capital funds, etc. so that its demands do not affect the relative scarcities of these items.) The optimizing models are formulated in terms of minimizing cost, subject to the constraint of meeting the given demands at various points in space and time.

III. TIME DISCOUNTING

In the problems we are to discuss, time plays an essential role. Under conditions of growing demand and of economies of scale in plant construction, there will typically be a choice between several time-streams of expenditure. If a single large plant is built, advantage can be taken of economies-of-scale in construction. alternatively, if several smaller plants are built at different points of time, there is the advantage of delaying a portion of the total investment outlays.

To make comparisons between expenditures incurred at different dates, we shall always use the discounted cash flow (present value) criterion. For inter-temporal comparisons, there is no longer much doubt that this has both theoretical and practical advantages over the more traditional measures payout period or accounting profits after depreciation.

Although economists tend to agree that there is some positive rate at which future costs and benefits should be discounted, there is widespread disagreement on the elements that are relevant to the determination of that rate. In the Indian context, I am impressed by the arguments in favour of self-financing taking the public

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[1] The author is much indebted to his colleague Stephen Marglin, who has patiently and persistently blue pencilled earlier drafts of this report.

and private sectors as a whole. Making the further assumptions of (*a*) a constant aggregate capital-output ratio, (*b*) a desired GNP growth rate in the neighbourhood of 5 per cent per annum, and (*c*) a reinvestment coefficient of 50 per cent out of profits, one comes up with a magic number to be used in investment and pricing decisions: a rate of return of 10 per cent per annum. No theoretical significance can be attached to the coincidence that this rate happens to be in the neighbourhood of the aftertax return on net worth in the private sector — as measured by financial accountants. Generally, this 10 per cent rate will be the one applied in subsequent calculations. In order to allow for extraordinarily rapid obsolescence in a few cases (e.g., petrochemicals), it may be appropriate to use a higher figure.

IV. TIME HORIZONS

In evaluating alternative investment programmes, the discounted cash flows will have to be summed up over some predetermined time horizon, say over 25 years, 100 years, or over an infinite span of time. The question that naturally arises is: our immediate decisions refer only to those investments that have to be made over the next 5-10 years. Why be concerned with a horizon of 25 or more years when it is so difficult to forecast technological developments, costs, and demand patterns over such a long span of time?

For the purpose of these studies, a time horizon of ten years or less would be distinctly unsatisfactory. The reason is this: a fixed ten-year horizon rules out many of the alternative plant sizes which would otherwise be reasonable to consider. If we are to build a series of plants at *equidistant* time intervals, the horizon of one decade restricts us to the following intervals: 10.0 years or 5.0 or 3.3 or 2.5 or . . . Within this harmonic series, there is no possibility of choosing a time interval of 4.0 or 6.0 years between plants — although both of these intervals would fit in if the horizon were lengthened slightly from 10 to 12 years.

The harmonic series restriction is not at all inherent in the technology of plant construction, and seems irrelevant for purposes of economic evaluation. This is a significant argument in favour of postulating an infinite time horizon. No restrictions upon plant size are then imposed by the horizon itself. For many practical purposes, however, even a twenty-five year horizon would seem sufficiently long to overcome the harmonic series problem.

V. COMPUTATIONAL ASPECTS — GROWTH PATTERNS

In the initial phase of these studies, elaborate electronic computing equipment will not be available. For this reason, it will be convenient to make some simplifying assumptions with respect to the pattern of demand growth over time, the market areas to be served by individual plants, and also the time-phasing of new units. These particular simplifications can be dropped whenever large-scale computers become available and the appropriate programmes are written for these machines.

Within any particular region of India, it will be supposed that the demand for an industry's product grows at a constant annual arithmetic rate over an infinite time horizon. This permits us to confine our analysis to simple periodic patterns of plant construction. With constant arithmetic growth in demand over an infinite horizon, a constant investment cost function, and a constant discount rate, it will minimize the discounted total investment costs if a constant time interval is maintained between successive plant installations. E.g., if the annual demand for caustic soda in West Bengal is increasing by five thousand tons from one year to the next, and if plants are built every three years to serve this demand, then each plant will have to be 15 thousand tons per year in size.

Let

D	annual increase in demand ((tons/year)/year)
t	time interval between successive plants (years)
tD	plant size (tons/year)
$C(tD)$	investment cost for building a plant of size tD (*Rs.*)
r	annual discount rate, compounded continuously (1/year).

Every t years over an infinite horizon, a plant is to be built. Each of these plants will have the identical undiscounted investment cost of $C(tD)$. The first of these plants is to be built at time zero, and its investment cost has a present value of $C(tD)$. The second is to be built at time t, the third at time $2t$, and these costs have a present value of $e^{-rt}\,C(tD)$ and $e^{-2rt}\,C(tD)$ respectively. Counting up the discounted value of all future investment costs over an infinite horizon, the sum S is as follows:

$$S = C(tD) + e^{-rt}\,C(tD) + e^{-2rt}\,C(tD) + \cdots \qquad (1.1)$$

Since equation (1.1) contains a convergent infinite geometric series, we may also write

$$S = \frac{C(tD)}{1 - e^{-rt}} \qquad (1.2)$$

Equation (1.2) gives us a simple — though not fully realistic — model of the stream of investment costs required in order to meet a steady rate of growth in demand. Some numerical results may be obtained by replacing the general function $C(tD)$ by a specific one that is popular in the engineering literature for such process industries as chemicals, cement, petroleum, electricity generation and primary metals:

$$C(tD) = k\,(tD)^{a} \qquad (1.3)$$

In expression (1.3), if the exponent a is set at the numerical value of .6, the function is termed the "six-tenths rule". With $a = .6$, there are significant economies-of-scale. Doubling the plant size will result in an increase of 52 per cent in the investment cost. With $a = 1.0$, there are no longer any economies of scale. Doubling the plant size will increase the investment cost by 100 per cent. The specific expression for total discounted costs is now

$$S = \frac{k\,(tD)^{a}}{1 - e^{-rt}} \qquad (1.4)$$

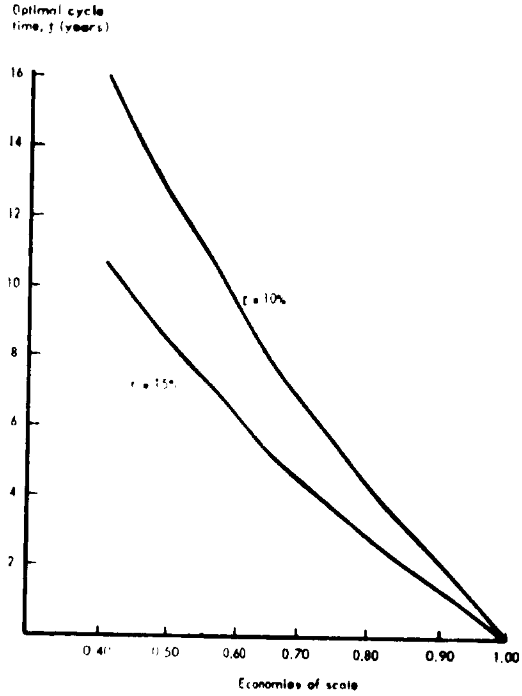

Figure 1

Now if the plant size is to be chosen so as to minimize the discounted investment costs S, one obtains the results shown in figure 1. These results are independent of the cost constant k and of the annual increment in demand, D. Keeping the economies-of-scale parameter a constant at .70 and raising the discount rate r from 10 per cent to 15 per cent, the *optimal* interval between successive plant installations drops from 6.8 to 4.5 years. The higher the discount rate, the less it pays to take advantage of the economies-of-scale.

VI. SOME QUESTIONS ABOUT THE MODEL

This analysis is all quite tidy as far as it goes, but there are several questions that will immediately suggest themselves to a practical decision-maker:

(a) *Question.* Why have the operating costs for fuel, raw materials, labour and overheads been omitted from the cost equation (1.2)?

Answer. Typically, these costs are considered proportional to the output at each plant. Typically, it is also to be supposed that the combined output from all plants is equal to the total demand target for each future point of time. The total physical quantity of each proportional input is therefore fixed by the demand target independent of the plant sizes or locations chosen. Hence, in problems involving a single producing location or when all locations purchase their inputs at identical unit prices the combined value of these inputs is a fixed charge, and may be omitted from the criterion for optimization of plant size, location, and timing. Of course, if there are any regional variations in the input prices or if there are any economies-of-scale associated with the operating costs (e.g., wages, salaries, and overheads), these elements must be introduced into the cost criterion.

(b) *Question.* What provision has been made for taxes?

Answer. None. From an economy-wide viewpoint, taxes are not real economic costs but transfer payments from the enterprise to the government. Presumably, investment licensing decisions are to be made upon the basis of social rather than private costs.

(c) *Question.* What is the meaning of the term "plant size", and how does this fit in with the licensing authorities' definitions of "new unit" and "substantial expansion"?

Answer. As used in the industrial engineering cost estimation literature, the term "plant size" usually refers to a *balanced* plant built at a single point of time. In actual practice, it is seldom that a completely balanced expansion takes place. For example, with caustic soda, the investment required for a "new unit" would probably include the cell house, the chlorine recovery unit, and the initial group of mercury cells. In a "substantial expansion", the only equipment required might be the additional mercury cells. For purposes of these studies, we shall generally assume that the entire ultimate investment cost for a balanced plant is incurred at the time the plant is first brought on-stream. If information becomes available for supporting a more refined analysis, this factor can be incorporated within the cost equation.

(d) *Question.* From the viewpoint of equipment supply and maintenance, it is usually desirable to standardize the alternative plant sizes. What provision is made for this?

Answer. If there are just a few predetermined plant sizes available to an industry, the selection from within this set may be made through equation (1.2). The model contains no restriction that the plant size be either a continuous or a discrete variable. The problem of standardization may also be posed in a reverse form: given the regional pattern of growth in demand, what would be the best range of standard plant sizes? In order to answer this question in a fully satisfactory fashion, information is needed from the equipment-supplying industries on *their* economies-of-scale. Some clues may, however, be obtained from an analysis confined to the equipment-using industry.

(e) *Question.* Why is it assumed that demand grows at a steady arithmetic rate? Most Indian demand forecasts are based upon constant geometric rates of growth.

Answer. The arithmetic growth assumption is made both for the sake of convenience in computations and also because of doubts that geometric growth rates of 10-15 per cent per annum can be extrapolated into the indefinite future. It is conjectured but not yet demonstrated – that if the model indicates that it is optimal to install a plant to handle t years' worth of arithmetic growth, this plant size will also be approximately correct for the *first* installation to satisfy a geometric growth curve—provided that the annual average growth is the same over the first t years. This conjecture is not intended to apply when the demand growth rate takes on bizarre values, e.g., 50 per cent *per annum* over the indefinite future.

(f) *Question.* Can imports and exports be included in this model?

Answer. Implicitly, these have been excluded from equation (1.2). By suitable modifications, however, they can be included. For each industry studied, it will be specifically stated just what assumptions are made with respect to imports and exports. In an earlier paper (*Econometrica*, October 1961), I have already covered the computational details for one way of looking at imports—as a high-cost, temporary means of deferring the investment in domestic production capacity until a date when the domestic demand grows sufficiently to justify a new plant.

This type of calculation could be modified to take account of one practice which is being introduced in response to the rationing of foreign exchange: prior to the construction of a domestic plant, a foreign collaborator "lends" a specified quantity of the product to an Indian enterprise. Once the plant goes on-stream, and while the domestic demand is still below the plant's capacity, the foreign collaborator's commodity loan is repaid with interest—in kind. Through this barter device, no foreign exchange (aside from shipping costs) is either spent or earned by India. This practice is intended only as a temporary means of satisfying current demands by borrowing against the capacity that will be built in the near future.

VII. COMPUTATIONAL ASPECTS—MARKET AREAS

In our models, it will be convenient to suppose that all production and consumption takes place at a finite number of locations—not a continuum in space. Because of the difficulty of making demand forecasts in any greater detail, it will generally be the practice to consider an entire state as the unit of analysis, and to suppose that the demand is concentrated at a single "representative point" within that state—either the largest or the most centrally located city. Table I contains a list of these points, and indicates the rail distances between each possible pair. This table is intended for use in industries where a single plant is likely to serve more than one state. It is not a general-purpose geographical classification, and would be inappropriate for industries that are known to be oriented toward intrastate markets, e.g. bricks.

From each representative point to its closest neighbour, it will be noted that the distance ranges from 310 to 690 kilometres. With two exceptions (Patna and Bhopal), the closest neighbour also lies within the same general region of the country—either East, North, West, or South. This regional grouping of states fits in conveniently with the location of the four major cities of India—Calcutta, Bombay, Delhi, and Madras. Each of these metropolitan areas is known to be a point of large-scale demand for industrial products.

Using the geographical classification of table I, it will generally be convenient to perform hand calculations of optimal plant sizes on the assumption that a plant is built to serve one of three alternative market areas: (1) a state, (2) a region, or (3) the entire nation. The lower the transport costs in relation to economies-of-scale in manufacturing, the more favourable will cases (2) or (3) become. Both cases (2) and (3) are bound to arouse political opposition from individual states—each of which is seeking to maximize its own industrial growth.

VIII. COMPUTATIONAL ASPECTS—TIME-PHASING

The question of *when* to build interacts with the question of where and how large a plant. Time phasing considerations may alter the optimal size of plant and market area to be served. By proper phasing of the construction programme for different areas, it will usually be possible to achieve significant cost savings.

Hand computational methods can take advantage of simple, but not complex periodicities over the infinite horizon. These methods will be illustrated with a hypothetical example based upon two market areas—each with its own appropriate point of production. It will be assumed that these areas cannot import the product from outside, and that the installed capacity must always be at least as large as the combined demand. Within area j, demand is growing at the annual rate of D_j, and plants are to be built that will satisfy t years' worth of growth in demand. For concreteness, we shall suppose that $D_1 = 10$, $D_2 = 5$ thousand tons per year, that the [illegible] time $t = 3$ years, and that the plant sizes tD_j are therefore 30 and 15 thousand tons respectively. The analysis is being conducted at a date sufficiently early so that plants can be built in either location at or after time zero. The initial conditions are such that there is no excess capacity available in either region at time zero.

One timing possibility is shown in figure IIa—a diagram of what will hereafter be termed "single-phase cycles." At time zero, a 30-thousand-ton plant is built in the first area, and a 15-thousand-ton plant in the second. Excess capacities immediately jump up to 30 and 15 at time 0. They drift gradually down to 20 and 10 at time 1, to 10 and 5 at time 2, and to zero in both areas at time 3. The second cycle begins at time 3 with the simultaneous construction of new plants in both areas. The third cycle begins at time 6, and so on indefinitely. Note that these single-phase cycles create a large amount of excess capacity in both areas simultaneously, but that they make it possible to eliminate all transport between the two.

An altogether different possibility is shown on figure IIb—a diagram of "two phase cycles." Here the second area plant is deferred until the end of the first phase, and so there is less excess capacity in the system. On the other hand, this pattern has the drawback that transport costs are incurred in order to make up for the second area deficit during the first phase of the cycle.

TABLE I. RAIL DISTANCE BETWEEN REPRESENTATIVE POINTS

Thousands of kilometres

	East				*North*					*West*			*South*			
	ASSAM *Gauhati*	BIHAR *Patna*	ORISSA *Cuttack*	WEST BENGAL *Calcutta*	JAMMU & KASHMIR *Srinagar* [a]	PUNJAB *Jullundur*	RAJASTHAN *Jaipur*	UTTAR PRADESH *Kanpur*	DELHI *Delhi*	GUJARAT *Ahmadabad*	MADHYA PRADESH *Bhopal*	MAHARASHTRA *Bombay*	ANDHRA PRADESH *Hyderabad*	KERALA *Cochin*	MYSORE *Bangalore*	MADRAS *Madras*
East																
Gauhati		0.61	1.44	1.03	1.47	1.36	1.59	1.09	1.53	2.21	1.58	2.99	2.42	3.38	3.04	2.68
Patna	0.61[b]		0.94	0.53	1.21	1.09	0.97	0.47	0.91	1.59	.96	1.63	1.78	2.89	2.48	2.19
Cuttack	1.44	0.94		0.41[b]	2.28	2.16	1.91	1.42	1.85	2.54	1.92	1.97	1.18	1.95	1.61	1.25
Calcutta	1.03	0.53	0.41[b]		1.87	1.75	1.50	1.01	1.44	2.13	1.51	1.97	1.59	2.36	2.01	1.66
North																
Srinagar [a]	1.47	1.21	2.28	1.87		0.12	0.79	0.92	0.48	1.4	1.19	1.87	2.16	3.37	2.85	2.67
Jullundur	1.36	1.09	2.16	1.75	0.12[b]		0.67	0.80	0.37	1.30	1.07	1.75	2.04	3.25	2.74	2.55
Jaipur	1.59	0.97	1.91	1.50	0.79	0.67		0.50	0.31[b]	0.63	0.57	1.12	1.55	2.86	2.27	2.23
Kanpur	1.09	0.47[b]	1.42	1.01	0.92	0.80	0.50	—	0.43	1.12	0.55[b]	1.35	1.49	2.69	2.18	1.99
Delhi	1.53	0.91	1.85	1.44	0.48	0.37[b]	0.31[b]	0.43[b]		0.93	0.70	1.38	1.68	2.89	2.38	2.19
West																
Ahmadabad	2.21	1.59	2.54	2.13	1.42	1.30	0.63	1.12	0.93	—	0.58	0.49[b]	1.28	2.24	1.61	1.77
Bhopal	1.58	0.96	1.92	1.51	1.19	1.07	0.57	0.55	0.70	0.58	—	0.84	0.97	2.29	1.67	1.48
Bombay	2.99	1.63	1.97	1.97	1.87	1.75	1.12	1.35	1.38	0.49[b]	0.84		.79	1.74	1.11	1.28
South																
Hyderabad	2.42	1.78	1.18	1.59	2.16	2.04	1.55	1.49	1.68	1.28	0.97	0.79	–	1.32	.69	.79
Cochin	3.38	2.89	1.95	2.36	3.37	3.25	2.86	2.69	2.89	2.24	2.29	1.74	1.32	—	.62	.70
Bangalore	3.04	2.48	1.61	2.01	2.85	2.74	2.27	2.18	2.38	1.61	1.67	1.11	.69[b]	.62[b]	—	.36[b]
Madras	2.68	2.19	1.25	1.66	2.67	2.55	2.23	1.99	2.19	1.77	1.48	1.28	.79	.70	.36[b]	—

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[a] Rail distance is shown only to Pathankot. From Pathankot to Srinagar, the road distance is an additional 480 kilometres.

[b] Closest neighbouring point to city specified in column heading.

The idealized sequence of events is this: at time zero, a 30-thousand-ton plant is built in the first area, and none in the second. Shipments are made from the first to the second area in gradually increasing amounts. At time 2, it becomes necessary to build the second plant. During the second phase between time 2 and 3, there are small amounts of excess capacity in both areas, and no transport is required in either direction. At time 3, the excess capacity drops to zero in both places, a 30-thousand-ton plant is constructed in the first area, and the first phase of the second cycle begins. Each of these two-phase cycles has the same total span, t years, as the single-phase cycles for plant construction.

The duration of the first phase will be known as t^*, where $t^* = t\,D_1/(D_1 + D_2)$. It is during this phase that we defer the construction of the second plant, and incur transport costs from the first to the second area. For future reference, a formula is noted down for the money value of the transport costs incurred within the first phase and discounted back to the beginning of the cycle. This expression is based upon the assumption that it costs p_2 for each ton shipped into area 2:

$$\left.\begin{array}{l}\text{Present value of transport}\\ \text{costs incurred within a}\\ \text{cycle}\end{array}\right\} = \int_0^{t^*} (p_2 D_2 \tau)\, e^{-r\tau} d\tau$$

$$= p_2 D_2 F(r, t^*) \qquad (1.5)$$

Examples:

$F(.100, .500)$	.120
$F(.100, .600)$	.172
$F(.100, .900)$	.381

where the transport penalty function, $F(r, t^*)$, is defined as follows:

$$F(r, t^*) = \frac{1 - e^{-rt^*}}{r^2} - \frac{t^* e^{-rt^*}}{r} \qquad (1.6)$$

If the transport penalty function $F(r, t^*)$ is tabulated once for all, the burden of hand calculations becomes considerably lighter. Table 2 contains this function evaluated for the discount rate $r = 10$ per cent per annum[4].

One major restriction should be noted in connexion with the two-phase model. Since the time interval between successive plants has to be identical from one area to the other and since the demands are growing at different rates, it will generally be impossible to standardize the plant sizes between areas. Potentially, this is a serious disadvantage in the use of two-phase cycles. With a restricted set of standard plant sizes, it may be necessary to consider time sequences with much more complex periodicities than can be analysed by hand.

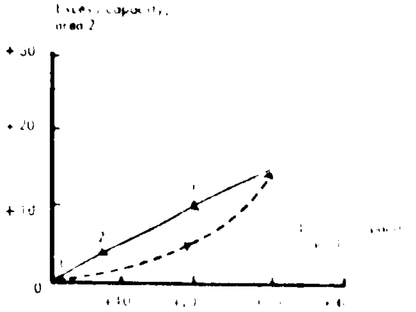

Figure 11a. *Single phase cycle*

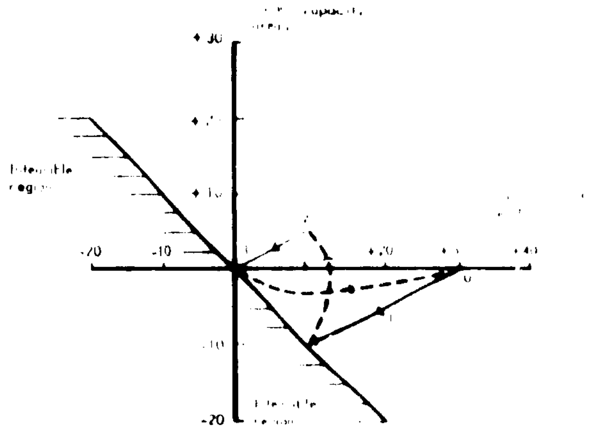

Figure 11b. *Two-phase cycle*

TABLE 2. TRANSPORT PENALTY FUNCTION, $F(r, t^*)$

$r = .100$

t^*	.000	[illegible]	[illegible]	[illegible]	[illegible]
500	120	172	233	303	381
1 000	467	562	664	775	893
1 500	1 018	1 151	1 291	1 438	1 591
2 000	1 752	1 919	2 092	2 272	2 458
2 500	2 649	2 847	3 050	3 259	3 474
3 000	3 693	3 918	4 148	4 383	4 622
3 500	4 867	5 116	5 369	5 627	5 889
4 000	6 155	6 425	6 699	6 977	7 258
4 500	7 543	7 832	8 124	8 420	8 718
5 000	9 020	9 325	9 632	9 943	10 256
5 500	10 572	10 891	11 212	11 536	11 861
6 000	12 190	12 520	12 853	13 187	13 524
6 500	13 862	14 202	14 544	14 888	15 233
7 000	15 580	15 928	16 278	16 629	16 982
7 500	17 335	17 690	18 046	18 403	18 761
8 000	19 120	19 480	19 841	20 202	20 565
8 500	20 928	21 291	21 656	22 020	22 386
9 000	22 751	23 117	23 484	23 851	24 218
9 500	24 585	24 952	25 320	25 688	26 056
10 000	26 424	26 791	27 159	27 527	27 895

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[4] Grateful acknowledgment is made to the Physics Department, University of Delhi, for permission to use its IBM 1620 computer. This computer also evaluated $F(r, t^*)$ for discount rates of 8 and 12 % per annum, and the author will supply these tables to any interested party.

IX. EFFECT OF PARAMETER ERRORS AND OF POLITICAL CONSTRAINTS

These models require a considerable input of numerical data — cost functions, transport rates, demand projections, and a discount rate. Given the uncertainty in choosing each of these, it is prudent to be concerned with the effect of taking decisions on the basis of incorrect parameter estimates. Sensitivity to incorrect parameters — and also to political constraints — may be illustrated through the single-phase, single-location model summarized in equation (1.4).

Here there is a single decision variable, the cycle time t, and four numerical parameters k, D, a, r. It has already been noted that the choice of an optimal value of t is unaffected by the numerical parameter k. In what follows, it will be convenient to divide both sides of (1.4) by k, and to minimize the normalized costs S/k with respect to t:

$$S/k = \frac{(tD)^a}{1 - e^{-rt}} \qquad (1.7)$$

Figure III contains a plot of S/k for alternative values of the cycle time, assuming that the following are the true parameter values: the economies-of-scale factor a = .7; the growth rate D = 1.0 lakh tons; and the discount rate r = 10 per cent. For these parameter values, the optimal cycle time t = 5 years, and the optimal plant size tD = 5 lakh tons per year.

But now suppose that the demand forecasters are congenitally optimistic, and that they persist in forecasting the annual increment D as 2 lakh tons per year. (Over the infinite horizon, their growth rate forecasts are twice the true value.) Although unduly optimistic with respect to growth, let us assume that the analysts perform their plant size optimization with the correct values of the discount rate r and the economies of scale parameter a. The cycle time of 5 years will remain optimal, but the error in growth forecasts will keep leading to plant size recommendations of 10 lakh tons. From the viewpoint of the true parameter values, this amounts to a persistent recommendation in favour of a 10-year cycle time. The normalized cost quantity S/k then goes up from its minimum value by 6 per cent. Note that the percentage increase in costs is far smaller than the percentage error in the demand growth forecast.

Departures from the optimal cycle time may result from political considerations as well as from incorrect parameter estimates. For example, in India it is often considered desirable to build a large number of individual plants in order to spread industrialization over as many states as possible. (We continue to use the same illustrative parameter values as in figure III.) Now if it is believed expedient to build two and a half times as many individual plants as would be economically efficient, this amounts to choosing a time interval of two instead of the optimal five years between new plants. The cost increase is indicated at 7 per cent. Unlike a forecasting error, this increase in costs is avoidable. It is important that the decision-maker recognize explicitly that any political gains are purchased through this deliberate economic loss.

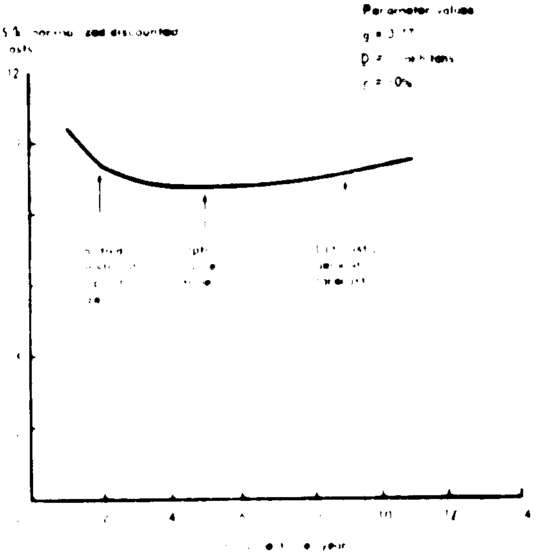

Figure III

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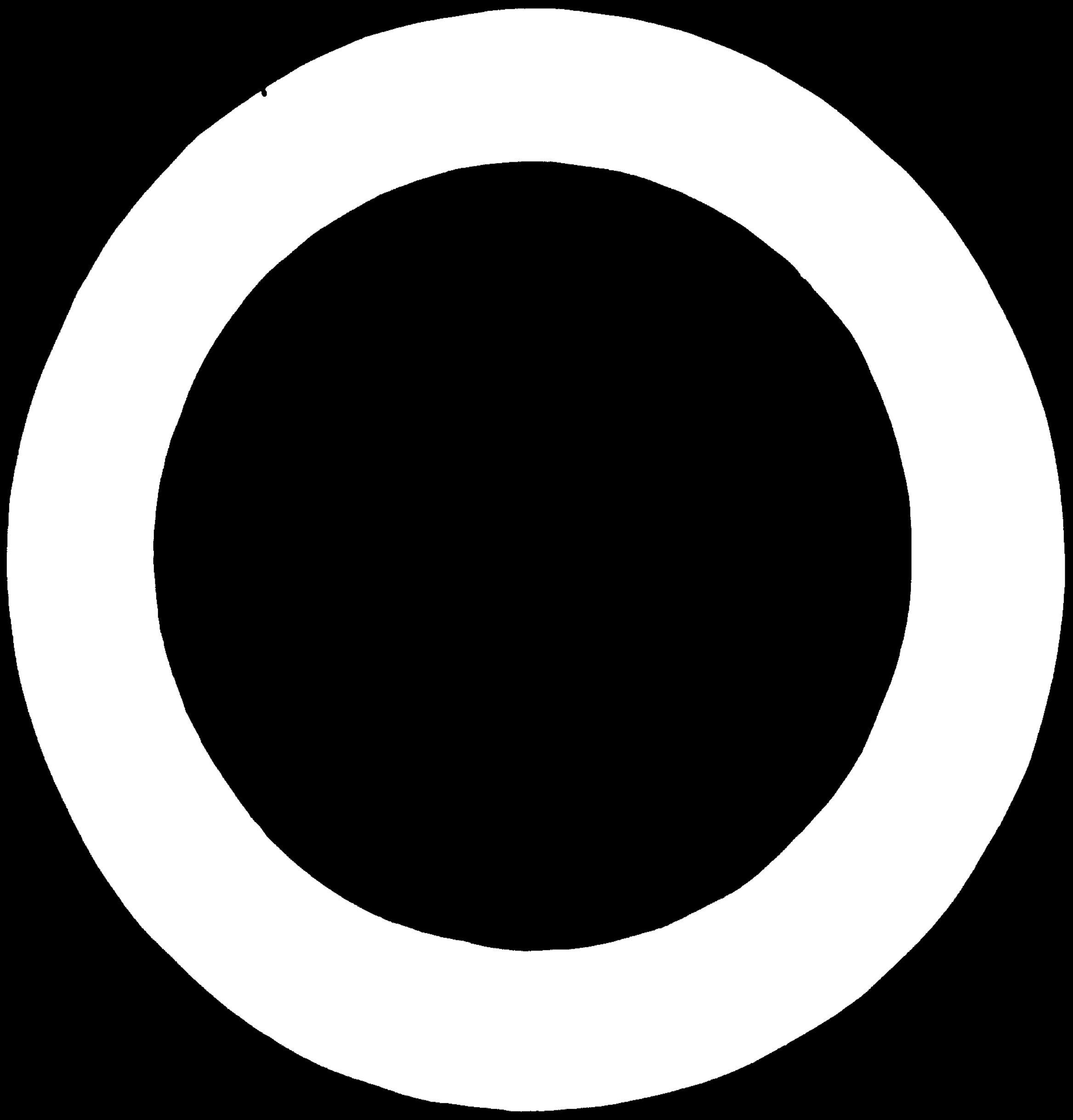

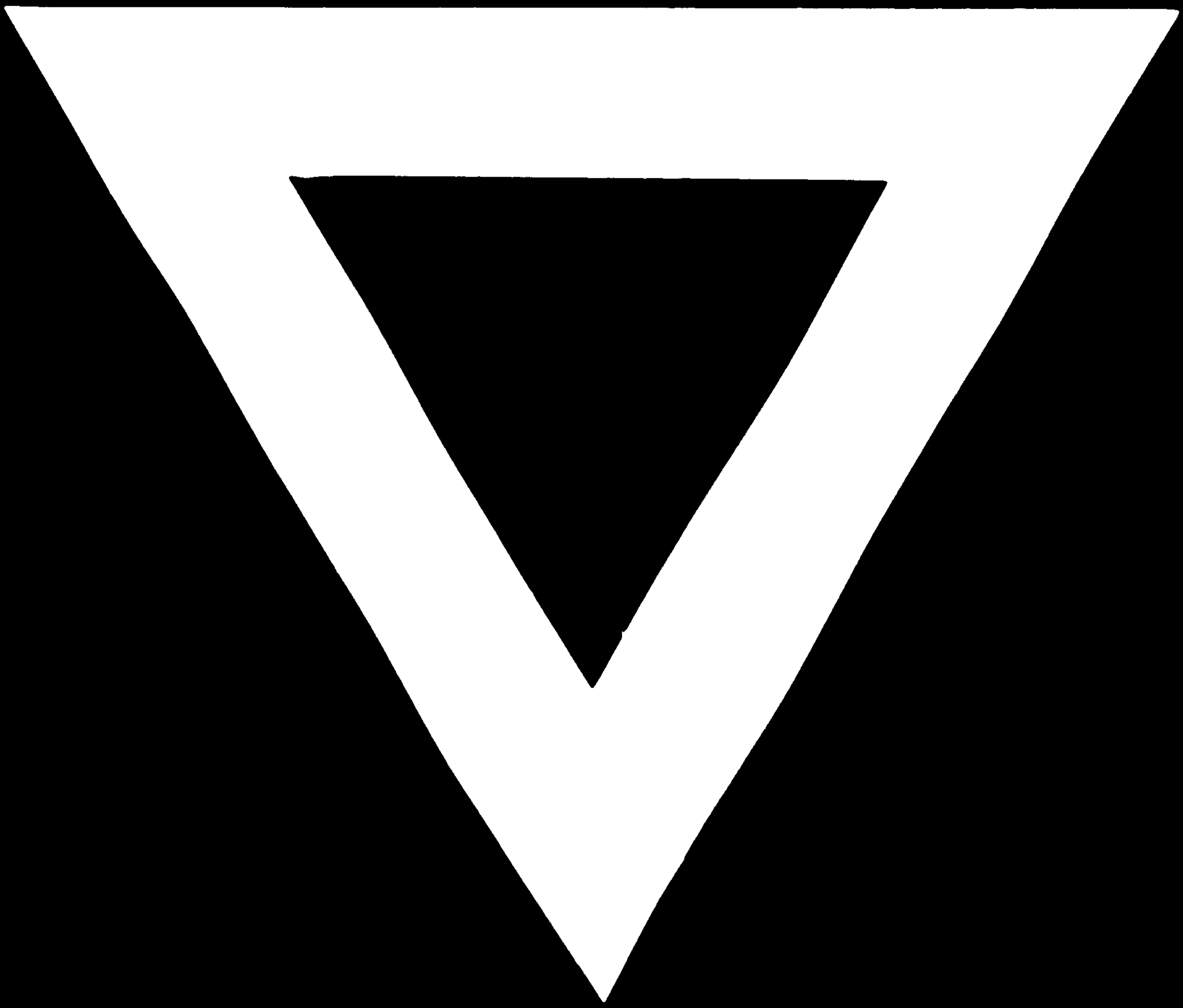

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