OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

06957

Distr.
RESTRICTED

UNIDO/ICD.12
15 March 1976

ENGLISH

UNITED NATIONS INDUSTRIAL
DEVELOPMENT ORGANIZATION

(R) REPORT ON MISSION TO KUWAIT:

DEVELOPMENT PROSPECTS OF PETROCHEMICAL INDUSTRIES IN KUWAIT[1]. (1976).

(RP/INT/73/003/11-01)

by

M. El Halfawy
Senior Interregional Adviser
UNIDO

23 January - 15 February 1976

1/ This document has been reproduced without formal editing.

id.76-1310

SUMMARY

This report attempts to formulate an immediate, and a long-term plan for the development of petrochemical industries in Kuwait. World trends and the supply and demand situation for the major petrochemicals have been emphasized.

In the first phase (1977-1982), an integrated olefine-aromatics complex is proposed with the following annual capacities:

- Ethylene (based on cracking ethane from LPG plant)	454000 ton
- Ethylene glycol	150000 ton
- High density polyethylene	105000 ton
- Low density polyethylene	105000 ton
- Benzene	277000 ton
- O-xylene	42500 ton
- P-xylene	100000 ton
- Styrene	360000 ton

(Expected yearly production for all units is assumed 90% of these capacities except for the xylenes and benzene where the figures indicate expected yearly production).

This programme differs from the PIC tentative plan in the following aspects:

(1) The ethylene plant has a designed capacity 40% higher than that propoeed in the PIC plan. This higher capacity is the standard now adopted in Europe, Japan and U.S.A., giving the maximum economy of scale.

(2) To absorb this excess capacity the suggestion is made to produce 95,000 tons/year high density polyethylene.

In fact this was shown to be a more attractive proposition than the production of ethylene glycol, the export market prospects of which are rather uncertain.

The second phase (1983-1990) concentrates on the production of butadiene and the two synthetic rubbers, polybutadiene and butadiene-styrere rubber, together with carbon black for the tyre industry. It is also considered opportune to produce further 1720 t/day Urea, as strong world demand is anticipated between 1983 and 1990. The possibility of producing single cell protein during this phase is also considered.

Emphasis on producing monomers and polymers for the production of polyester and acrylic fibres is characterestic of the third phase (1990-2000). The proposal is also made to produce two of the most popular plastics resins viz. polypropylene and polyvinyl chloride (PVC). This production requires another ethylene plant based on cracking propane. To absorb half of the ethylene production, two new lines of HDPE and LDPE as in phase I are suggested since the per capita consumption would have considerably increased by then. A caustic soda-chlorine plant is also proposed to provide the chlorine necessary for the production of vinyl chloride.

The report concludes by emphasizing the importance of setting up downstream (tertiary) industries - particularly by the private sector - in order to provide some degree of domestic support for the export-oriented petrochemicals. These tertiary sector industries can be set-up either in Kuwait, in Arab countries or in other developing countries. Opportunities for private sector investment in this field are listed in Appendix 'I'.

CONTENTS

Page

EXPLANATORY NOTE

The following definitions are given:

"Dollar" ($)	means the United States Dollar
" K.D. "	means Kuwaiti Dinar equivalent to 3.4$
" Ton " (t)	means metric ton.

The following abbreviations are used:

OAPEC	Organization of Arab Petroleum Exporting Countries
b/d	Barrels per day
BR	Butadiene Rubber
DMT	Dimethyl Terephthalate
HDPE	High density polyethylene
KNPC	Kuwait National Petroleum Company
KOC	Kuwait Oil Company
LDPE	Low density polyethylene
LPG	Liquefied petroleum gas
MEG	(Mono) ethylene glycol
MVC	(Mono) vinyl chloride
PIC	The Petrochemical Industries Company
PP	Polypropylene
PVC	Polyvinyl Chloride
PS	Polystyrene
SBR	Styrene-butadiene rubber
SCF/D	Standard cubic foot per day
TPA	Terephthalic acid
t/y	Metric ton per year.

DEVELOPMENT PROSPECTS OF PETROCHEMICAL INDUSTRIES IN KUWAIT

1. INTRODUCTION

A. BACKGROUND

Kuwait is a petroleum producing and exporting country with a population of about one million. Its proven reserves of petroleum, including its share in the Neutral Zone, has been estimated at 72.8 billion barrels of oil and 32 000 billion cubic feet of natural gas. Oil production reached an average of 2.8 million barrels per day in 1974 and dropped to 2.1 million in 1975.

The management of the entire oil and gas sector, including gas and oil-based industries and projects has been entrusted to a Committee within the Oil Ministry, headed by the Minister of Oil, and includes the heads of KOC, KNPC, PIC, the Natural Gas Exploitation Project, and the Undersecretaries and Assistant Undersecretaries of the Ministry.

The Minister of Oil, Mr. A.M. Al Kazimi, outlined in a recent statement(1) (12 July 1975) Kuwait's plans to gradually turn away from exporting crude oil and towards the export of the refined products, LPG and of the petrochemical industry products.

The petrochemical industry has become one of the most dynamic industrial sectors in developed and developing countries. Whereas half of the world output of organic chemicals was petroleum derived in the early 1950's, about 90% is now from petroleum. The petrochemical industry includes the manufacture of basic petrochemicals (i.e. chemicals made directly from petroleum and natural gas fractions e.g. ethylene, propylene, benzene and the xylenes), intermediates e.g. vinyl chloride and acrylonitrile) and end products such as synthetic fibres, plastic resins, synthetic rubber and Urea.

The output of the petrochemical industry is increasingly penetrating the technology of other producing sectors to meet basic human needs such as clothing, housing and transportation, apart from agricultural and food production. In view of such wide applications, countries with abundant petroleum and natural gas resources, have shown increasing interest in establishing viable petrochemical industries.

In response to a request from the Government, the UNIDO Senior Inter-regional Adviser on petrochemicals arrived in Kuwait on a two-weeks mission, to assist in identifying potential opportunities for the manufacture of petrochemical products in Kuwait. The author proposes, in the present report, to offer some views on how a petrochemical industry in Kuwait could systematically develop, over the next twenty years or so, on sound economic and technical basis.

B. GENERAL CONSIDERATIONS

In formulating a general plan for Kuwait's petrochemical industry development, the following considerations should be emphasized:-

(1) With the waves of technological innovation, the petrochemical industry has been building bigger and bigger plants. The economics of the large-size plant have been the dictating factor in this upward trend. In order to take full advantage of the very considerable economies of scale available, it would be advisable, during the first phase of development, to concentrate on the production of a limited number of petrochemical products produced in large-capacity plants.

(2) Due to the very small size of the Kuwait market, it will be necessary to secure large and steady export markets for the various petrochemical products produced.

(3) The petrochemicals chosen to be manufactured, in the initial phase of development, should, therefore, be those for which large world wide markets exist, and where raw materials and energy cost is dominant so that they can meet competition in the export market.

(4) In view of the large-scale petrochemical projects that members of the OAPEC intend to build, it would seem advisable for these countries to coordinate their plans, particularly in product selection to avoid excessive conflict and competition in world markets. It might also be possible to establish a joint marketing organization.

(5) A serious shortage of professional and technical manpower, at all levels, already exists in Kuwait. To service the needs of a developing petrochemical industry, Kuwait must realistically look for partnerships with major integrated chemical companies who can supply adequate numbers of engineers and technicians to supplement and strengthen local talent and assist in training national counterparts so they can take over more and more responsibilities in due time.

Partnership with a foreign company may take the form of a conventional joint venture or alternatively a contract for technical management and marketing.

II. BASIC PETROCHEMICALS

Olefines and aromatics comprise the basic building blocks of the petrochemical industry. They are, therefore, referred to as basic petrochemicals or primary products and are converted, often through the production of intermediates (secondary products), chiefly into polymers required by the plastics, synthetic fibres and synthetic rubber industries (end products or tertiary sector).

The primary products include ethylene, propylene, butadiene (olefines), and benzene, ortho-xylene and para-xylene (aromatics). It is proposed to summarize below international market forecasts and production technologies of these primary products.

A. ETHYLENE

A.1 Supply and Demand Prospects

Ethylene (C_2H_4) is undoubtedly one of the most, if not the most, important basic product of the petroleum chemicals industry and in the forseeable future looks certain to remain so. It is today the largest volume petroleum based organic chemical in the world. It enters in the production of about 30% of all petrochemicals and is a major determinant in their cost. Ethylene is used mainly in the production of polyethylene, vinyl chloride, ethylene glycol and styrene. Table A(1) in Appendix II gives the Ethylene demand by end use in West Europe, Japan and U.S.A.

The rapid increases in demand for ethylene have been brought about by the rapid growth rate of plastics and polyester fibres. Table (I) below summarises, the forecast of world capacities, supply and demand, classified by region.

TABLE (1)

FORECASTS OF ETHYLENE CAPACITIES, SUPPLY AND DEMAND

(THOUSAND METRIC TONS)

	1975			1980			1985		
	Capacity	Supply +	Demand	Capacity	Supply +	Demand	Capacity	Supply +	Demand
Western Europe	13245	11200	9950	15815	14200	14490	18105	16300	19980
Eastern Europe	2040	1632	2060	3540	2730	2800	5240	4200	4470
North America (a)	12597	11300	11050	15137	13600	14570	18000	16200	19520
Japan	5065	4500	4000	7700	6930	6150	8750	7870	9050
Latin America	1172	940	1040	1972	1600	1880	2319	1900	3275
Asia * (b))			1295			2038			3326
and)	1317	800		2946	1900		5016	3350	
Middle East *)			162			357			687
Africa *	150	120	213	275	190	355	1500	1050	580
Australia/N.Z.	275	208	208	275	208	345	1100	880	514
TOTAL	35861	30700	29978	47660	41358	42985	60030	51750	61402

a) Includes U.S.A., Canada and Puerto Rico.

*) Based on highly realizable plans.

b) Includes China.

+) In developing countries capacity utilization expected to be 60-70% on the average, whereas in Western Europe and Japan and North America 90%, and in Eastern Europe and Latin America 80%.

SOURCE: Chemical Economy and Engineering Review (Japan)[2] Vol. 6, No. 12, December 1974 (pages 33-38).

According to these estimates, ethylene will run short, and in 1980 a total of 1,610,000 tons will be in short supply in the four areas- Western Europe, Eastern Europe, North America and Latin America. In the long run ethylene is estimated to be in short supply in practically all districts.

It has to be noted however that most of the ethylene produced in petrochemical complexes is consumed captively and that relatively small quantities are transported by ship and by ethylene pipelines. Two pipeline systems exist in Western Europe, the large connects Belgium, Holland and Germany and the other traverses central France from near Marseille northwards to Dijon. There are two smaller systems in the U.K. and a minor one in Japan. The largest ethylene pipeline system exists in the U.S. Gulf coast area.

In spite of the forecasted shortage of ethylene in most regions, it is economically unattractive to export liquid ethylene from Kuwait in view of the very high costs of shipping over the long distances involved (e.g. to South Europe or Japan). These high transportation charges (about 150-190 $ per ton) would offset the advantage of low feed - stock costs. The basic conclusion to be drawn is that although market prospects for the export of liquid ethylene look quite attractive, economic considerations dictate that all the ethylene produced in Kuwait should be consumed captively as feed to the local derivative units (LDPE, Styrene, MEG...)

A.2 Feedstock

Ethylene is manufactured by the steam cracking of hydro-carbon feedstocks. Ethane, propane, n-butane, naphtha, gas oil or even crude oil can be used a feed for ethylene production; so can a mixture of these hydrocarbons be used.

Generally, the heavier the feedstock to an ethylene plant, the greater are the quantities of by-products produced over and above the required ethylene-production quantity (Table 2), which makes it apparent that the value placed on these " co-products " will have a very marked effect on ethylene costs. Table (2) shows the yields of various feedstocks.

TABLE (2)

TYPICAL YIELD STRUCTURE FOR DIFFERENT FEED-STOCKS (FOR PRODUCING 1000 MILLION lb/year ETHYLENE)

(i.e. 454000 Metric Tons/Year)

Feedstock Product in mil.lb.	Ethane	Propane	n-Butane	Kuwait Naphtha	Kuwait Gas oil
Residue (Oil) gas (H_2+CH_4)	175	663	665	484	513
Ethylene	1000	1000	1000	1000	1000
C_3's Cut (includes propylene)	31	353	499	392	480
C_4 Cut (includes butadiene)	25	61	216	205	310
C_5 -400°F Gasoline	19	193	350	644	677
Cracked fuel oil				175	740
Total Feed requirement	1250	2270	2740	2900	3720
% Feed conversion or severity	60%	90%	96%	High	High

Source: G.J. Hayward and P.N. Hogget[1] (Stone & Webster Engineering Corporation) The Oil and Gas Journal, July 28, 1975, p. 81 - 84).

Examination of Table (2) shows that ethane cracking gives almost negligible amounts of propylene, butadiene and liquid product. Propane and butane cracking yield rather more of these products (but are not major sources of butadiene). Heavier feedstocks mean a vastly increased yield of products that must be sold for a project to be economically competitive.

In the U.S. the lighter domestic feedstocks (ethane, propane and n-butane) obtained from natural gas liquids accounted for 67% of ethylene production in 1973 but are becoming more and more difficult to obtain. New ethylene plants under construction or planned are designed for using heavier feedstocks (naphtha, natural gasoline, and particularly gas oil). In Western Europe and Japan naphtha has been the predominant feedstock as no gas liquids were available. As the supply of naphtha is becoming tighter, the trend is towards building new ethylene plants flexible enough to operate on gas oil feedstock. It is now rare for a new plant in Europe or the U.S. to be designed to operate execlusively on a single feedstock, owing to the uncertain and fluctuating feedstock situation prevailing in those countries.

The situation in Kuwait is quite different. Any of the above mentioned feedstocks could be made available to any ethylene plant built in Kuwait. In the first phase of developing the petrochemical industry, there would be no need, in the writer's opinion, to incorporate in the plant design the flexibility required for cracking alternate feedstocks, as this would unnecessarily add to the capital cost of the plant.

The choice of a feedstock for the Kuwait ethylene plant depends on the range of products to be manufactured. The writer suggests that, in the first phase of petrochemical development, no propylene derivatives are to be produced. The present plans of PIC are in agreement with this view. In this case, ethane would be the feedstock par excellence for the ethylene plant. Reasons for reaching this conclusion are:-

(a) The processing scheme used for ethane cracking has a very low production of liquid by-products (Table 2 above). Accordingly the number of processing steps involved in purifying the ethylene product is considerably reduced in comparison with cracking propane and heavier feedstocks. This allows for the design of a simple plant resulting in much lower capital costs than naphtha or gas oil feeds. In a paper published in March 1975 Bruce F. Greek[5)] gave the following battery limits capital costs of 454000 metric tons/year (1 billion pounds/year) of ethylene plants constructed in the U.S. (estimates supplied by Stone and Webster Engineering).

	FEEDSTOCK		
	Ethane	Naphtha	Gas Oil
Capital Costs in Million U.S.$. of 1000 million pounds/year Ethylene plant.	85	110	135

Assuming an inflation rate of 10% per annum (in plant cost and labour), and assuming that a plant erected in Kuwait costs 25% above the U.S. cost, the capital costs of ethylene plants erected in Kuwait in 1980 would be about twice the costs given above. It is clear, therefore, that a naphtha - based plant is 30% more costly than a comparable ethane - based plant.

(b) Naphtha produced in Kuwait refineries will be used for making gasoline, and as a feedstock for the production of aromatics

(BTX). The balance of the local production of naphtha can be easily and relatively cheaply shipped to export markets where demand is expected to continue to grow. Similarly propane and butane produced in the planned LPG plant will be exported. Ethane produced in this plant could profitably be used as an ethylene feed since the alternative option for ethane would be to leave it in the lean gas to be used as fuel or synthesis gas feedstock.

The Natural Gas Exploitation project which will be executed by KOC shall produce in an LPG plant an ethane stream (deethanizer off gas) with a composition of about 85% Ethane. In this project the associated gas collected from the three fields viz. Burgan (South East), Manakeash (West) and North Kuwait, will be fed into three processing lines in the LPC plant. Table (3) gives a summary of the expected product yield. Detailed yield data and product analysis are given in Table A (2) Appendix II.

TABLE (3)

NATURAL GAS EXPLOITATION PROJECT (LPG PLANT)
SUMMARY OF PRODUCT YIELD

Basis: 3 million barrels per day of crude oil production.
Natural Gas feed to liquefaction plant 1680 million SCF/D.
Product Streams:

Natural Gasoline	41000	Barrels/day
C_3 LPG	100000	"
C_4 LPG	55000	"
Absorber off Gas (about 88% G)	885	Million SCF/D
Deethanizer off Gas (about 85% Ethane)	141	"

Source: Ministry of Oil, Kuwait.

The C_3 and C_4 LPG is destined for export, the absorber off gas will be used for public utilities, for injection into oil wells, as a feedstock for the ammonia plants and to produce the hydrogen requirements of the refineries. The deethanizer off gas is the ideal feedstock for the ethylene plant in Kuwait. It will easily be seen from Table (2) and Table A(2) that one of the three lines of the LPG plant has capacity enough to provide all the ethane required for 1 million lb/year ethylene plant (required 1250 million lb/year or 568000 ton/year ethane).

A.3 <u>Capacity and Cost</u>

PIC is planning to produce 325000 tons of ethylene to be used captively in the production of low density polyethylene (LDPE), polystyrene (PS), and mono-ethylene glycol (MEG). An annual ethylene capacity of 700 million lb (318000 tons) is now regarded as the lower capacity limit for a company to launch an ethylene project and still be competitive. An annual capacity of 1000 million lb/year (454000 metric tons/year)* has become a standard for new plants in the industrialized countries, giving the maximum economy of scale within limits of available equipment size. The writer recommends that this would be the capacity of the Kuwait ethylene plant. As shown earlier the cost of such a plant (1980 price) would be about $ 170 millions (battery limits). Ethylene would then be produced at a cost of approximately 200$ per ton (assuming ethane at 70$ per ton). The average contract price for ethylene in the U.S. is in the range of 12-15 cents per pound. Most price predictions for 1980 suggested by industry sources are in the range of 15-17 cents per pound[4)] (i.e. 330-374$ per ton).

---

* Rate only 4000 tons (90% capacity utilisation)

B. AROMATICS

Benzene and xylene (ortho- and para-) are the most important basic aromatic petrochemicals. Benzene C_6H_6 is used mainly for the manufacture of styrene, phenol and polyamide (Nylon-6) fibres. Para-xylene is used in the manufacture of polyester fibres while ortho-xylene is used to produce phthalic anhydride, the major uses of which are in plasticizers, alkyd resins and unsaturated polyester resins.

B.1 Supply and Demand Prospects

a) Benzene : Depending on the availability of feedstocks, West Europe may have a surplus of 1.5 million tons of benzene in 1980 but would be self sufficient in 1985[6a]. The U.S. was a net importer of benzene in 1975 and will continue[4] to have a deficit amounting to over 3 (three) million tons in 1985 (present U.S. benzene capacity 5.8 million tons/year). The situation in Japan is almost similar to that of the U.S. Present capacity is about 2.5 million t/y [4] but demand will exceed supply by about 0.6 million tons in 1980 and 1.7 million tons in 1985. It can be concluded that there are good prospects for export of benzene produced in Kuwait to Japan, the U.S. (and probably to Europe should feedstock supply problems become tight). Exports to developing regions and to East Europe are doubtful. However, the Kuwait complex will utilize all produced benzene for styrene production.

b) p-Xylene World capacity of para-xylene was about 3.2 million tons as of October 1975 and planned expansions would bring it up to 5.5 million tons by 1978[4]. Para-xylene is mostly used in the production of dimethyl terphthalate (DMT) and terephthalic acid (TPA) both of which are intermediates for the production of polyester fibre. World capacities of DMT and TPA were 3048 and

862 thousand tons respectively as of January 1974 but planned expansions would raise them to 5493 and 2065 thousand tons by 1977[4]. Polyester fibre and film demand continues strong, and hence demand for p-xylene also continues strong.

It appears likely, therefore, that in 1980 world supply of p-xylene is sufficient to meet demand. However, by 1985 deficits could be significant mainly in Japan and U.S.A. There are good prospects for the export of p-xylene from Kuwait to U.S.A., Japan and probably Europe in the early eighties especially if long-term export contracts could be arranged to assure DMT and TPA manufacturers of their feedstock.

c) <u>O-Xylene</u> World supply of o-xylene will be just adequate to meet demand in 1980. In the early eighties, the increased demand for phthalic anhydride will result in an expanding demand for o-xylene and it is expected that a world deficit of about one million tons will develop 1985, mainly in West Europe and U.S.A. Potential markets exist, therefore, in these two regions for Kuwait produced o-xylene particularly if long term contracts could be established owing to fluctuating market prices of this product. O-xylene production improves the economics of p-xylene production and both could be produced in Kuwait at a competitive cost.

B.2 Aromatics Feedstocks and Technology

Benzene, toluene and the xylenes (BTX) are produced by the catalytic reforming of naphtha, a refinery operation developed in the early 1940's for the production of high-octane number gasoline. For BTX production, the full range naphtha used in the production of high octane gasoline is not normally used. Rather, a narrower fraction of boiling-range approximately 75-140°C is used as feedstock, catalytically reformed to yield a reformate which is distilled to give a heart cut of about the same boiling-range but in which the required C_6-C_8 aromatics are more concentrated. This fraction is fed to a BTX solvent extraction unit (e.g. using sulfolane as solvent) to separate aromatics from non-aromatics, and this is followed by a fractional distillation to separate benzene, toluene and mixed xylenes. The toluene produced is hydrodealkylated (treated with hydrogen) to produce benzene and methane (fuel gas). O-xylene (produced in the reformer) boiling point 144.4°C is separated from meta-xylene (b.p 139.1°C) and para-xylene (b.p 138.3°C), by fractional distillation of the mixed xylenes, followed by a selective absorption process to separate the p-xylene. The liquids are further fed to an isomerization unit to convert the meta-xylene into o- and p-xylenes which is then recycled.

The naphtha feedstock for the aromatics complex can be provided by the refinery of the KNPC in the Shuaiba area. In fact it is planned to construct this complex immediately south of the refinery and west of the present PIC fertilizer plants. The olefin complex will be constructed south of the aromatics one.

KNPC now processes 200,000 b/d of crude and produces 45000 b/d of straight run naphtha. Sulphur is removed from 35000 b/d of this naphtha by feeding this quantity into a unifiner. The heavier cut from the unifiner (b.p. 200-340°F), about 15000 b/d constitute the feed to the catalytic reformer of KNPC which produces high octane gasoline, 2000 b/d of which are consumed locally and the rest exported.

For the production of aromatics, the narrow fraction of boiling range 75-140°C can be obtained from the unifiner. However, this would be at the expense of the production of high octane gasoline. Alternatively, PIC might be provided with straight run naphtha, the PIC aromatics complex produces the narrowcut and returns the lighter paraffinic naphtha to the KNPC pool.

In this connection, it has to be noted that KOC operates a a refinery of 250,000 b/d capacity but processes on the average 70,000-100,000 b/d and produces about 17,000 b/d of straight run naphtha, probably due to the relatively high sulphur content in the products and hence the difficulty of exporting them. About 10,000 b/d of KOC gasoline are consumed locally. A programme for modernization of KOC refinery has been approved and might be completed at the same time of the start-up of the Aromatics Complex.

Naphtha is also produced by the American Independent Oil Co. in their refinery of 120,000 b/d capacity. It is proposed that the competent authorities in the Ministry of Oil, together with representatives of PIC and the three refineries would work out a programme for the supply of feedstocks to both the olefin and aromatics complexes, and determine a basis for the valuation of these feedstocks and for the by-products returned from the petrochemical complexes to the refinery. The total aromatics produced from a reformer amounts to only about 40% of the naphtha feedstock. Therefore, the valuation of the remaining 60% (by products) has a pronounced effect on the net production cost of the aromatics.

B.3 Proposed Aromatics Complex: European Chemical News[6b)] reported on October 1975 that W.R. Grace Co. is close to concluding negotiations with PIC for the construction of a joint aromatics complex in which about $200 million will be invested. However, no prefeasibility studies or offers for constructing such a complex were made available to the writer, probably because final agreement has not yet been reached regarding the spectrum of products, capacity of units and financial and marketing arrangements. In the circumstances, the following data regarding a proposed catalytic reformer complex producing benzene, ortho and para-o-xylene are presented as guidlines. They are based on the assumption that the complex would start up in 1980, and that a narrow fraction of straight run naphtha (boiling range 75-140°C) would be provided by KNPC at a cost of U.S.$ 155 per metric ton.

The complex would comprise the following units:

	Units and Process routes	Battery limits capital cost Million U.S.$
a)	Naphtha hydrotreater; catalytic reformer	35
b)	Heart cut distillation, sulfolane extraction, BTX distillation; toluene hydrodealkylation	40
c)	Mixed xylenes distillation; selective adsorption; isomerization; total recycle	49
	TOTAL	124

Offsite items are difficult to assess in this short study. Utilities will presumably be provided by Shuaiba Area Authority. However, other offsite costs are to be added to the above battery limit costs e.g. storage of products, workshops, laboratory, loading station, effluent treatment, tie-in piping, lighting.. etc. The cost of these may be 35-40% of the battery limit cost.

a) About 780000 t/y (20,000 b/d) naphtha would be reformed producing 640,000 t/y reformate, and fuel gas (net) equivalent to 1210000 x 10^6 K calories.

b) From this reformate 225,000 t/y of benzene are produced at a cost of about US$ 365 (this benzene will be the feedstock for styrene production at $ 431/ton - see page 24). Co-products produced are:-

- C_8 aromatics (mixed xylenes)	158,000 t/y valued at 223 $/ton
- Raffinate (naphtha)	172,000 t/y valued at 155 $/ton
- C_9 Reformate	67,800 t/y valued at 200 $/ton
- Fuel gas (net)	237,000 x 10^6 K cal valued at 2$ per 10^6 K cal.

c) From 158,000 t/y mixed xylenes, 100,000 t/y para-xylene and 42500 t/y ortho-xylene are produced (together with 6500 tons of aromatics to be recycled and 4800 tons of heavy aromatics). The expected ex-factory sales price about 516 and 365 $/ton respectively.

B.4 Integrated Complex

An aromatics complex of the type just described when combined with an ethylene plant in which ethane is cracked would form an integrated complex which has the advantage of adjusting operations of either ethane cracking or naphtha reforming respectively so that production may follow the fluctuations in the demands for olefins and demands for aromatics. Moreover such a complex is essential for the development of an integrated petrochemical industry.

III. INTERMEDIATES AND END PRODUCTS

A. PLASTIC RESINS

The consumption of plastics on a world wide basis has about doubled every five years since 1955. Prospects for continued growth of the major plastics are assured and are little changed as a result of increased oil and feedstock prices. There will be little risk of substitution of plastics by traditional materials. These conclusions were arrived at by major chemical companies e.g. Imperial Chemical Industries[7], Dupont[9], Shell International Chemical[8] and Dow Chemical[10]. Traditional materials themselves are in short supply and their prices, too, have been rising sharply.

Doscher[10] has given the following summary (Table 4) of the growth outlook of demand for major ethylene derivatives through 1983.

TABLE (4)

GROWTH OUTLOOK OF DEMAND FOR MAJOR ETHYLENE DERIVATIVES THROUGH 1983

Plastic Resin	Percent Growth to 1983
High Density Polyethylene	14%
Low Density Polyethylene	10%
Polystyrene	9%
Polyvinyl Chloride	8%

World consumption of polyolefines has been forecast until 1980 as follows[11] in Table (5).

TABLE (5)

POLYOLEFINES SHARE OF WORLD CONSUMPTION

(1000 Metric Tons)

	1965	1970	1975	1980
Low Density Polyethylene	2300	5000	9700	17000
High Density Polyethylene	700	1700	3500	6500
Poly propylene	300	1300	2800	6500
Total Polyolefines	3300	8000	16000	30000
Total World Consumption of Plastics	14500	30000	53500	92000
Olefines % of Total World Consumption	23%	27%	30%	32.6%

A forecast of world consumption of all plastics by type was made by an Expert Group Meeting on the Development of Plastics Industries held by UNIDO in November 1968 in Vienna. These figures are given in Table (6). However, the expected figures for consumption of PVC and polystyrene given are considered at present 20-25% too high, whereas that for polyolefines is 15% lower than present forecasts.

TABLE (6)

1980 FORECAST OF WORLD CONSUMPTION OF PLASTICS BY TYPE

	Million Tons
Polyolefins, including copolymers containing a major proportion of olefins	26
PVC and copolymers	23
Polystyrene and other styrene plastics, including ABS	12
Phenolic resins	4
Urea-formaldehyde and melamine-formaldehyde resins	5
Polyurethanes	5
Acrylics	1
PVA	2
Cellulosics	3
Alkyds	4
Unsaturated polyesters	6
Nylon plastics	1
TOTAL	92

Published data in the technical literature [2),4)] and in various expert reports submitted to UNIDO indicate the following forecasts of supply/demand situation

a) High density polyethylene (HDPE)

In 1980 a slight surplus of supply over demand. However, serious shortages are expected in the early eighties in all regions, developed and developing (except Japan). The deficit in supply would amount to about 2.4 million tons unless new capacities are added within the next few years.

b) Low density Polyethylene (LDPE)

In 1980 there might be a world deficit of supply about 250,000 tons. Without the addition of new capacities, particularly in Europe and U.S.A., there will be a world deficit of about 4.5 million tons in 1985.

c) Styrene and polystyrene

A deficit of world supply in 1980 of nearly 1 million tons of styrene is expected. Considering that about half a million tons of styrene might be produced in the Arab countries by 1985, a deficit situation is expected to develop in all other regions of the world of the order of 2.5 million tons. The situation regarding polystyrene is expected to be similar, with a world deficit (particularly Europe and Japan) of about one million tons in 1980 and a deficit in 1985 of about three million tons.

d) Vinyl chloride Monomer VCM

World shortage amounting to about 400,000 tons is expected in 1980. Considerable investment will be needed if the demand in the early eighties is to be met. It is likely that in 1985 substantial shortages (of about 1.5 million tons) in West Europe, U.S.A. and Japan will develop.

e) Polypropylene

In Japan and the U.K. the present consumption of polypropylene exceeds that of high density polyethylene. In the U.S.A. the average annual rate of growth of output is 11-13% between 1973 and 1979.

In general a world surplus of about [illegible],000 tons is foreseen for 1980 but a deficit in practically all regions (except Japan) amounting to about 3.7 million tons is expected. It is most likely, however, that new capacities will be added in U.S.A. and Europe.

CONCLUSIONS

a) Market potential exists in all regions for export of LDPE and HDPE from Kuwait. However, it is advisable to have a partnership with a company well established in the polyethylene business in an industrially advanced country to provide worldwide marketing facilities, in addition to technical services.

b) The vast and strongly growing market of styrene makes it a prime prospect for production in-and export from-Kuwait. This is due to the energy intensive nature of the manufacturing process. However, since a large proportion of the styrene produced in industrialized countries is consumed captively, it is recommended that long term marketing arrangements be made with a partner who will guarantee off-take of most of the production.

Polymerization plants for the production of polystyrene, to serve mainly Arab markets, can be left to the second phase of petrochemical development. Export marketing of polystyrere is likely to meet with considerable problems.

c) Export markets will be available during the eighties for vinyl chloride monomer. However, due to recent doubts about the use of PVC in food industries, the production of VCM and PVC in Kuwait might be undertaken at a later phase of petrochemical development. It will be necessary to investigate the economics of local production of salt particularly by solar evaporation of sea water, so that the production of chlorine, from salt by electrolysis, can be envisaged.

d) Although there is a strong market potential for polypropylene, the cracking of ethane in Kuwait, to produce ethylene, does not produce co-product propylene for polymerization. The production of polypropylene should therefore, be left to a later stage.

B. First Phase of Petrochemical Development (1977-1982)

In the light of the above remarks it is proposed that the PIC integrated complex would comprise, in addition to the ethylene and aromatics plants referred to in Chapter II, the following four plants in the first phase of petrochemical development (1977-1982).

(1) **Low density polyethylene**

Capacity 105000 t/y, Rate* 95000 t/y LDPE
Battery limits capital cost U.S.$. 100 million**
Ethylene feed 100000 t/y at a cost of U.S.$. 366 per ton.
Expected production cost about 710 $ per ton
Expected European selling price $ 1090 per ton.

(2) **High density polyethylene HDPE**

Capacity 105000 t/y, Rate 95000 t/y
Battery limits capital cost U.S.$. 108 million

---

* **90% capacity utilization is always assumed in these calculations though for the first few years it might be less.**

** **Assumptions on page 9 regarding inflation and construction.**

Ethylene feed 100000 t/y at a cost of US$ 366

Expected production cost about US$ 792 per ton

Expected C.I.F. cost in Europe about US$ 1197 per ton

(3) Styrene $C_6H_5 . CH:CH_2$

The production of styrene involves two major steps

(i) Direct alkylation of benzene by ethylene to produce ethyl benzene $C_6H_5C_2H_5$

(ii) Catalytic dehydrogenation of ethyl benzene to produce styrene:

- Capacity 360000 t/y; Rate 325000 t/y of styrene
- Battery limits cost US$ 63 million.

Raw materials:

- Ethylene 100000 t/y at a cost of US$ 366 per ton
- Benzene* 277000 t/y at a cost of US$ 431 per ton

Expected production cost US$ 593 per ton

Expected European selling price US$ 720 per ton

---

* The aromatics complex proposed on pages 16-17 is based on a catalytic reformer capacity of 20,000 b/d to be compatible with the naphtha produced from 100,000 b/d crude. However, the reformer, benzene and xylenes production units can be scaled up by about 20% to produce the 277 000 tons of benzene required by the styrene capacity here selected (to consume 100,000 tons of ethylene).

(4) Ethylene glycol (mono-ethylene glycol, MEG)

Ethylene glycol is produced by the reaction of water with ethylene oxide. The latter is manufactured by the direct oxidation of ethylene with oxygen. MEG is a raw material in the manufacture of polyester, and is also the principal component of anti-freeze liquids for internal combustion engines.

If no ethylene shortages develop, forecasts show that there will be enough ethylene glycol to meet world demand in the early and mid-eighties. It is propoeed that capital may be committed to this unit only if a partner ie prepared to guarantee offtake of all the product. Otherwise, the proposed ethylene plant capacity page 11 should be reduced to 340,0000 tons/year and this product deleted from the complex until a later phase of development, e.g. until sufficient polyester capacity in the Arab world is establiehed and committed to utilize the output.

Proposed plant capacity 150000 t/y MEG

Rate 135000 b/y

Battery limits capital coet U.S.$. 75 million

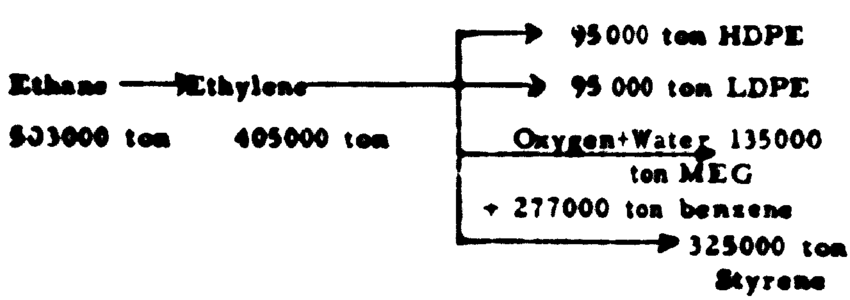
Raw materials 100000 tons/y ethylene at U.S.$. 366 per ton

Estimated production coet about U.S.$ 407 per ton

Expected European selling price US$ 650 per ton

Summary of Phase 1: Integrated Complex

a) Ethylene Plant



b) Aromatics Plant

Naphtha B.P 75-140° → Benzene 277000 ton (for Styrene production)
→ p-xylene 123000 ton
→ o-xylene 52320 ton

24620 b/d or
960260 ton/y

Total Battery limit cost of all plants about U.S. $ 655 million or about 138 million K.D. Since utilities will be provided by Shuaiba Area Authority, offsites cost can be assumed 35% of Battery limits cost i.e. 67 million K.D.

Hence total Fixed Capital of Complex = 260 million K.D. This does not include the working capital which can be assumed as roughly about 10% of total fixed capital i.e. 26 million K.D.

IV. SECOND PHASE OF PETROCHEMICAL DEVELOPMENT (1983-1990)

A. NITROGEN FERTILIZER

The world population which was 3000 million in 1960 reached nearly 4000 million in 1973 and is estimated to reach 5000 million in 1985 and 6800 million at the end of this century. The problem of meeting the food requirements of the rapidly increasing world population is becoming increasingly acute particularly as the current per capita level of food consumption is expected to rise as economic development occurs. Increased use of chemical fertilizers will undoubtedly be the most important factor in increasing world food production during the next 25 years.

Ewell[13)] in a paper presented to an international meeting in Madrid (10-14 November 1975) on "Scientific Research and Agricultural Problems" has given the following forecasts for the world's demand of nitrogen fertilizers between now and the end of the century (Table 7) and calculated how many new plants need to be added to meet this demand.

TABLE (7)

NEW WORLD NITROGEN CAPACITY NEEDED TO MEET ESTIMATED DEMAND FOR NITROGEN FERTILIZER - 1975-2000

	Nitrogen fertiliser demand at beginning and end of each 5-year period. million tons N*	Increase in nitrogen demand during each 5-year period. million tons*	Number of new 1000 T/D plants needed to meet increased nitrogen demand*
1975-1980	42 – 59	17	85
1980-1985	59 – 79	20	100
1985-1990	79 – 102	23	115
1990-1995	102 – 128	26	130
1995-2000	128 – 157	29	145
1975-2000	42 – 157	115	575

* All figures in this Table refer to fertilizer nitrogen only. Demand for industrial nitrogen would add about 20 percent to all figures.

It is hoped that by 1982 some, or most of the public utilities (electricity and water), as well as industrial plants using gas as fuel, would have switched over to heavier fuels, thus releasing enough gas for petrochemical use. It is proposed that feasibility studies be undertaken in a year or two with the object of constructing at least one 1000 ton/day ammonia plant and a urea plant of 1720 tons/day to convert all this ammonia to urea. Production would be based on lean gas from the LPG plant, and would be scheduled to start-up in 1982/1983.

B. BUTADIENE

Butadiene is a basic petrochemical for the manufacture of synthetic rubber. It is proposed to be produced by dehydrogenation of normal butane (Houdry process). The latter is separated from isobutane by fractional distillation of the C_4 fraction produced by the LPG plant. The proposed capacity of this unit is 100,000 ton/year of butadiene and would require about 196000 ton/year of n-butane. All this butadiene would be used for the production of synthetic rubber.

C. SYNTHETIC RUBBER PLANT

It is proposed in the second phase of development to produce synthetic rubber for tyre manufacture and for the production of mechanical rubber goods e.g. belt conveyers, hose, gaskets and molded and extruded items used in the industrial, household, and appliance fields.

Two types of synthetic rubber are proposed to be produced:

(1) Butadiene-Styrene rubber (SBR)

The suggested capacity of production is 60,000 tons/y which would require 45000 tons of butadiene and 25000 tons of styrene.

(2) Polybutadiene rubber (BR) with a capacity of 50000 tons/year.

World natural rubber consumption (excluding the socialist world), is expected to increase from 2.3 million tons in 1973 to 4 million tons in 1980. Synthetic rubber consumption is expected to grow from 4.2 million tons in 1973 to 5.7 million tons in 1980[8]. The consumption of synthetic rubber in Western Europe, Japan and the U.S. is expected to increase by 50% between 1976 and 1986. For example the U.S. consumption[14] is expected to increase from approximately 2.4 million metric tons in 1976 to about 3.6 million tons in 1986.

D. CARBON BLACK

The major use of carbon black is as a reinforcing filler in rubber products to improve their strength and wearing properties. Rubber products (including tyres) consume 90% of carbon black production. The remainder is primarily used as pigment in paint, plastics printing inks and paper. About 30-40% of the rubber compound used in tyres consists of carbon black and several millions of tons go into tyre manufacture every year, which give some indication of the importance of carbon black.

Carbon black is produced by burning, in a limited supply of air, heavy aromatic oils obtained from catalytic cracking. A smaller and declining amount is produced from natural gas.

It is proposed to erect an economic size plant, during this second phase, provided a detailed techno-economic study proves that it is a viable venture.

E. SINGLE-CELL PROTEIN (SCP)

Single-cell protein refers to protein substances produced through the growth of yeasts or bacteria on hydrocarbons or their derivatives. Commercial interest in single-cell protein for animal feed appears to be increasing. There is a range of substrates and a variety of organisms used by industrial companies for producing single-cell protein. Examples are:[15)]

(1) In England, Imperial Chemical Industries has been operating since 1973 a 1000 metric tons per year plant growing bacteria on methanol and is planning to develop a major production unit by 1978.

(2) In Lavera, France British Petroleum is operating a 20,000 metric tons/year plant that grows yeast on gasoil.

(3) In the U.S. Amoco Foods has presumably started last (1975) summer a 10 million lb/year plant growing yeast on ethylalcohol.

(4) A Japanese group is designing a 60,000 metric tons per year plant to be operated in Romania that will grow yeast on normal paraffins.

(5) In Italy the first 100,000 ton/year plant at Montebello started production last (1975) summer for Liquichimica Biosintesi SpA., using a process developed by Kanegafuchi of Japan, growing yeast on normal paraffins.

(6) Also in Italy, a similar plant in Sardinia growing yeast on normal paraffins is due to go on stream this summer (1976) for the BP-ANIC joint venture, Italoproteine.

(7) B.P. Also concluded arrangements early in 1975 for a 100,000 ton/year plant in Venzuela to be operated by a joint company (20% B.P.).

(8) In the Netherlands, Shell is constructing a pilot plant for growing mixed cultures on methane.

(9) At least five or six other concerns are located in Japan, U.S.S.R and Czchekoslovakia.

However, the Italian Government has decided last summer to suspend the production and sale of SCP for use in animal feed as a safeguard pending the additional testing to establish the safety of the material in humans[16]. The Kanegafuchi process referred to under (5) above, is said to have aroused controversy in Japan based on charges that the bacterial strain used in the process may be pathogenic.

Furthermore, it has been calculated[17+19] that the cost of producing one ton of protein for animal feed by e.g. the B.P process amounts today to 350-400£ per ton whereas more conventional sources of protein like soybeans and fishmeal is about 300-350 £.

It is expected that by 1982, the technology, economics and profitability of SCP processes would have been improved and the non-harmfulness of SCP for human health would have been ascertained. A feasibility study of constructing an SCP plant is recommended to be undertaken about 1980. However, until wider markets can be opened, major investments in this area must be approached with extreme caution.

V. THE THIRD PHASE OF PETROCHEMICAL DEVELOPMENT (1990-2000)

The petrochemical industry is a highly dynamic industry, characterized by a high rate of technological change as a result of intensive research and development. Many processes and products frequently undergo revolutionary changes. Consequently, it will be rather difficult to formulate a plan for the development of this sector in Kuwait 15-20 years from now, and to project its growth prospects. However, certain products have become so well established in world markets that recommending their consideration for manufacture would be quite appropriate.

Such products are polypropylene, polyvinyl chloride, and the two groups of synthetic fibres viz. the polyesters and the acrylics. Accordingly, it is proposed that these would form the basis of the third phase.

By 1990 the percapita level of consumption of plastics and synthetic fibres is expected to rise considerably, particularly in developing countries, as economic development occurs. It is anticipated that Kuwait's production and export of polyethylene could be doubled. It is suggested, therefore, that a second ethylene plant would form the basis of the third phase development plan, but based on propane cracking. The propane feedstock would be provided by the C_3 fraction of the LPG plant (page 10). It will be seen from Table (2) on page 7 that the production of 400,000 tons of ethylene by the steam cracking of propane, will result in 142000 tons of propylene. The following production facilities are thus proposed:-

(1) Ethylene plant based on propane cracking to produce annually 400,000 tons of ethylene and 142,000 tons of propylene.

(2) Chlorine-caustic soda plant with an annual production of 125,000 tons of chlorine and 138,000 tons of caustic soda. 217,000 tons of salt, and 436 million kwh of electrical power will be required.

(3) Vinyl chloride (VCM) plant to produce annually 210,000 tons of VCM, utilizing 100,000 tons of ethylene and 125,000 tons of chlorine.

(4) Polyvinyl Chloride plant to process all the VCM.

(5) Polypropylene plant to produce 87,000 tons/year polypropylene from 95,000 tons of propylene.

(6) Acrylonitrile plant to produce 35,000 tons of acrylonitrile from the remainder of propylene (47,000 tons) and 20,000 tons of ammonia (from the fertilizer plants).

(7) Polyacrylonitrile plant to process all the acrylonitrile.

(8) HDPE plant to produce 95,000 t/y. This would absorb one quarter of the ethylene output (100,000 t/y).

(9) LDPE plant to produce 95,000 t/y using 100,000 tons of ethylene.

(10) Ethylene glycol (MEG) plant to produce 135,000 t/y MEG, absorbing the remainder of the ethylene (100,000 t/y).

(11) Dimethyl terephthalate plant to produce 90,000 t/y from 60750 tons para-xylene, and 40,000 tons methyl alcohol. Terephthalic acid may be an alternative.

(12) Polyester plant using DMT (or TPA) and ethylene glycol. Capacity to be determined according to export potential and local Arab markets.

Emphasis on the synthetic fibre sector in the third phase of development is due to the fact that it represents an important outlet for petrochemicals. For example, out of the total tonnage of ethylene, propylene and aromatics produced in West Europe, one ton in every six currently is used for production of synthetic fibres. Van der Vlugt[18] of Herecules Inc., U.S.A. has projected that by the year 2000 the world will be using 8 Kg. of fibre percapita, made up of 2.50 kg. cotton, 0.75 kg. rayon, 0.30 kg. wool and 4.50 kg. synthetic fibres. If, by the year 2000, the world population reaches 6000 million, then the world consumption of synthetic fibres would be about 27 million tons, out of which 16 million tons are estimated to be polyester. If this is to be met, a new capacity every year of 400,000 ton DMT and 120,000 tons MEG has to be added from now on until the year 2000.

VI. DOWNSTREAM INDUSTRIES

Generally, in developing countries, petrochemical complexes producing basic and intermediate olefines and aromatics are executed by the public sector, due to the capital intensive nature of petrochemical manufacturing. The public sector, as a principle, should be primarily concerned with those projects which are beyond the resources or experience of private business, because of the very large investment involved and the need of massive infrastructure to support such projects. The fact that such projects are executed by the public sector does not mean that they need be entirely Government owned. In fact, in the case of Kuwait, it is recommended that some international chemical company be associated with the project as a foreign equity partner. In this way, the considerable organizational and management resources of the international company is committed to the rapid and economic implementation and operation of the project, and to the marketing of its products.

On the other hand, all activities that can be safely left to private initiative should be left to the private sector. This is particularly true of the downstream industries (or the tertiary sector of petrochemicals) such as plastic products, synthetic fibres and rubber products. Development of the tertiary sector has the advantage that it is easier and quicker to carry out, and provides opportunities for private sector investment. Economies of scale are of less importance for the relatively inexpensive plants involved, as compared with the highly capital intensive basic petrochemical plants. Accordingly, several such plants can be installed by the private sector to serve the local Kuwait market and the markets of other developing countries.

In general, in evolving a strategy for petrochemical development, great caution must be excercised in implementing projects that depend heavily on export for their viability. Even with the involvment of an international company, difficulties in export marketing might arise in the future. The large petrochemical plants must, and better sooner than later, have an established and growing domestic downstream market to support them. Since the Kuwait market is too small to support a fully integrated petrochemical complex, either now or in future, the prospects of setting up downstream industries as joint ventures in various Arab and other developing countries, having large demands of products, must be seriously considered. The Kuwait private sector should be encouraged and motivated to participate in such joint-ventures with small and medium sized companies in the Arab and developing world.

Appendix I lists examples of tertiary sector industries that could be examined as investment opportunities in Kuwait or as joint-ventures abroad. It is quite likely that many entrepreneurs have already initiated efforts in planning or implementing some of them. It goes without saying that the development of the tertiary sector should immediately start and continue step by step throughout all three phases of petrochemical development in Kuwait.

REFERENCES

1) Petroleum Intelligence Weekly, 12 July, 1975.

2) Chemical Economy and Engineering Review (Japan) 6 Dec. 1974, 33"Prospects for Domestic Overseas Supply and Demand up to 1985."

3) Gardner J. Hayward and Peter N. Hogget, The Oil and Gas Journal, July 28, 1975, 81 "Etnylene-plant feedstock flexibility is justified"

4) Chemical Economics Handbook (Stanford Research Institute)

5) Bruce F. Greek, Chemical and Engineering News, March 31, 1975 page 8 "Feedstock shift would change olefin economics".

6a) European Chemical News September 19, 1975, page 12 " West European benzene capacity set for major expansion".

6b) European Chemical News October 10, 1975, page 18 "Grace invests in Kuwait aromatics project".

7) European Chemical News, August 30, 1974. "I.C.I. Study confident on plastics prospects".

8) Chemical and Engineering News, June 17, 1974. "Growth of oil derived products to continue"

9) Chemical and Engineering News, November 10, 1975. "Plastics to maintain their competitive edge".

10) C.M. Doscher (Dow Chemical Europe), " Demand for chemicals from petroleum" Proceedings of a Conference on world petrochemicals organized by Financial Times, London (February 1975) page 42.

11) Europlastics Year Book 1973, page 1 "Future Demands for Plastics - Further Scope for Polyolefines".

12) UNIDO ID/55 "Development of plastics industries in developing countries". Expert group meeting, Vienna, November 1968.

13) R. Ewell " Future production and use of fertilizers" paper presented to meeting on Scientific Research and Agricultural Problems, Madrid, Spain, 10-14 November, 1975.

14) Chemical Marketing Reporter 29 December, 1975.

15) K.J. Skinner Chemical and Engineering News, May 5, 1975. " Single cell protein moves towards market"

16) Chemical Marketing Reporter 30 June, 1975. "Italy halts output, sale of petroprotein pending added study".

17) C. Ratledge, "Chemistry and Industry" 1 November, 1975. " The economics of single cell protein production"

18) Van der Vlugt, Chemical Industries Development (India) September 1974.

19) European Chemical News, January 23, 1976 "France quits bioproteins race as soya prices plunge."

APPENDIX 'I'

EXAMPLES OF TERTIARY SECTOR INDUSTRIES

LDPE fertilizer sacks

LDPE shopping bags and transparent packaging

Sterilized plastic (disposable) Syringes (HDPE or PP)

Plastic houseware and toys

HDPE bottles for milk, edible oils, and household chemicals

HDPE returnable pallets and specialized trays for inter-company shipping

Plastic footwear

Plastic drums and shipping pails

Polystyrene polymerization plants

Polystyrene cups and packages for Yoghurt and ice cream

High impact polystyrene for refregirator parts and other household appliances

Polystyrene foam for packaging

Insulated electrical cables

Automobile and bicycle tyres

Mechanical Rubber goods (belts, hoses..)

Plastic pipes

PVC coated fabrics

PVC flooring

Plastic electrical conduits

Polypropylene fibres by melt spinning and fibrillating (fibre film)

Polypropylene carpets

Acrylic carpets

Acrylic yarn for knitwear

Knitwear and textile plants using polyesters and acrylics alone or in blends with cotton and wool

Acrylic fibres from polyacrylonitrile (wet spinning)

Phthalic anhydride

Plasticizers

PVC compounding

Alkyd resins for paints

Unsaturated polyester resins

Boats, corrugated sheets and furniture from polyester resin reinforced with glass fibre.

Low cost housing of polyester reinforced with glass fibres or other local fibres

Polypropylene woven sacs (jute replacement)

Acrylic blankets

APPENDIX 'II'

TABLE A (1)

ETHYLENE DEMAND, BY END USE

Derivatives	West Europe 1974 Percent Total Etylene %	Japan 1974 Percent Total Ethylene %	U.S.A. Percent Total Ethylene 1973 %	U.S.A. Percent Total Ethylene 1978 Estimate %
Low Density Polyethylene	38.6	29.7	27.4	29.1
High Density Polyethelene	14.5	16.1	13.0	14.0
Vinyl Chloride	16.5	16.5	11.4	11.4
Ethyl Benzene/Styrene	7.4	8.3	8.6	8.9
Ethylene Oxide/Glycol	13.9	9.7	19.5	18.4
Others	9.1	19.7	20.1	18.2
TOTAL	100	100	100	100

Source: Chemical Economics Handbook [4] (February 1975; p. 648.5051F)

APPENDIX 'II'

TABLE A (2)

YIELD DATA AND PRODUCT ANALYSIS OF LPG PLANT

(All Data Based on 560 Million SCF/D of Associated Gas from the Production of 1 Million b/d Crude Oil and Fed into one Processing Line Except for the Gasoline Figures which Represent the Yield from 3 Lines)

Composition	Gas Feed lb. Mole/hour	Lean Gas 1	Lean Gas 2	Deethaniser off gas	Propane Stream	Butane Stream	Gasoline
H_2	123.3	6.8	116.5	-	-	-	-
C_1	38404.1	5968.4	31803.5	632.2	-	-	-
C_2	10366.9	968.5	3407.7	6175.6	115.1	-	-
C_3	7034.1	45.0	132.0	137.3	6661.4	58.4	-
$i - C_4$	950.2	0.2	0.3	0.1	82.9	866.1	1.7
$n - C_4$	2434.2	1.3	5.25	-	32.8	2367.3	82.3
C_5+	1814.1	12.8	55.73	-	0.1	38.0	5122.5
TOTAL*	62498.2	7162.9	36167.6	7189.6	6892.6	3350.0	5206.5
lb / hour	1633800	134600	647400	212200	303900	194600	423300
Average Molecular Weight	26.1	18.8	17.9	29.5	44.1	58.1	81.3

* Includes: CO_2, H_2S and Water.

APPENDIX 'III'

LIST OF CONTACTS

During the mission discussions and consultations were held with the following:-

Ministry of Commerce and Industry:

- Mr. Moh[illegible]ed Madoh, — Assistant Undersecretary for Industry
- Mr. Issa Al-Masidi, — Director Industrial Development and Consulting Bureau (IDCB)
- Miss Souad Menais, — Chemical Engineer (IDCB)

Ministry of Oil:

- Mr. Ali Hassan Al-Kaoud, — Director, Technical Affairs Department and Deputy Chairman, PIC
- Mr. Mahmoud Fikry, — Controller of Processing and Export, Technical Affairs Department.

Petrochemical Industries Company:

- Mr. Abdul Baqi Al-Nouri, — Chairman and Managing Director
- Mr. Amir Behbehani, — Senior Corporate Planner, Planning and Development

Kuwait National Petroleum Company:

- Mr. Khalaf El-Khalaf, — Managing Director of the Refinery

- Mr. Mohamed Baki, International Marketing Department
- Mr. Mostafa Al-Imbaby, Senior Process Engineer, Refinery

Industrial Bank of Kuwait :

- Mr. Lucien Toutounji, Investment Department Manager
- Dr. Abdel Monem Omran, Chemical Engineer

Organization of Arab Petroleum Exporting Countries (OAPEC) :

- Mr. Ahmed Nour El-Deen, Director, Technical Affairs Department
- Mr. Mostafa Borham, Petrochemical Section, Technical Affairs Department.

United Nations Development Programme:

- Mr. Khalid Al Yassir, Resident Representative
- Mr. Abdalla Abdel Wahab, Senior Industrial Development Field Adviser

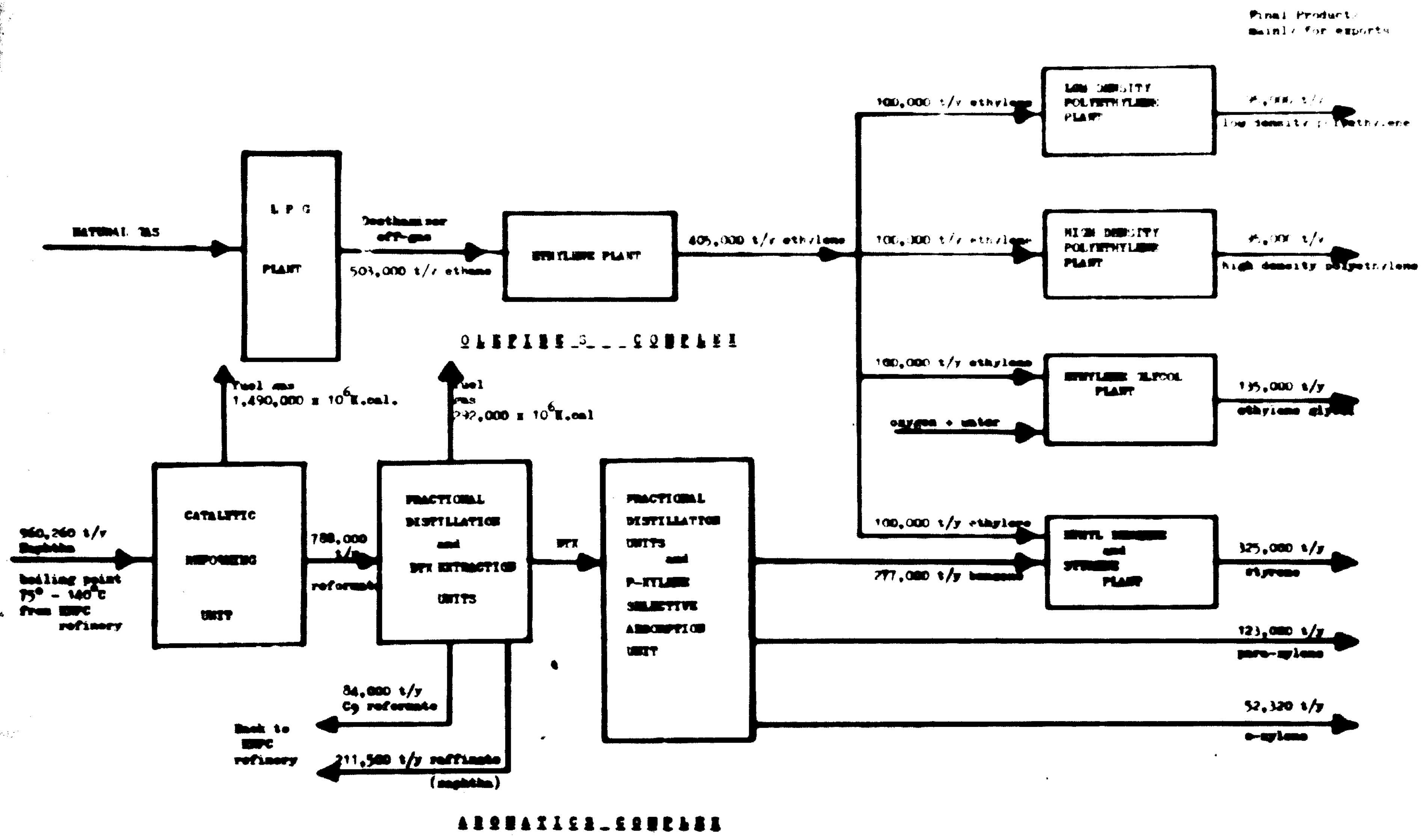
United Nations Industrial Development Organization (UNIDO):

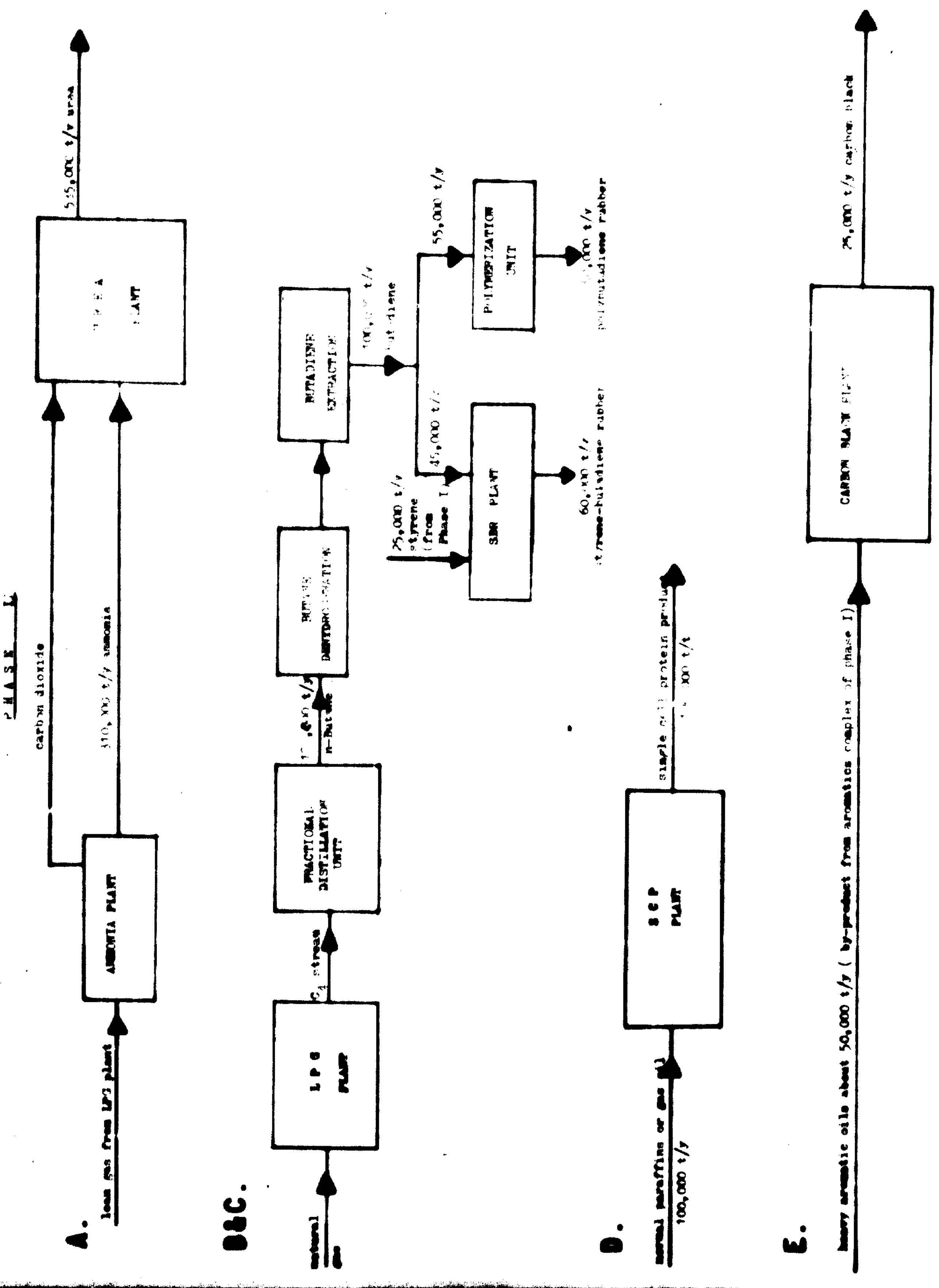
- Mr. Mohamed Khalil, Project Manager, IDCB and the team of UNIDO experts of IDCB.

ACKNOWLEDGMENT

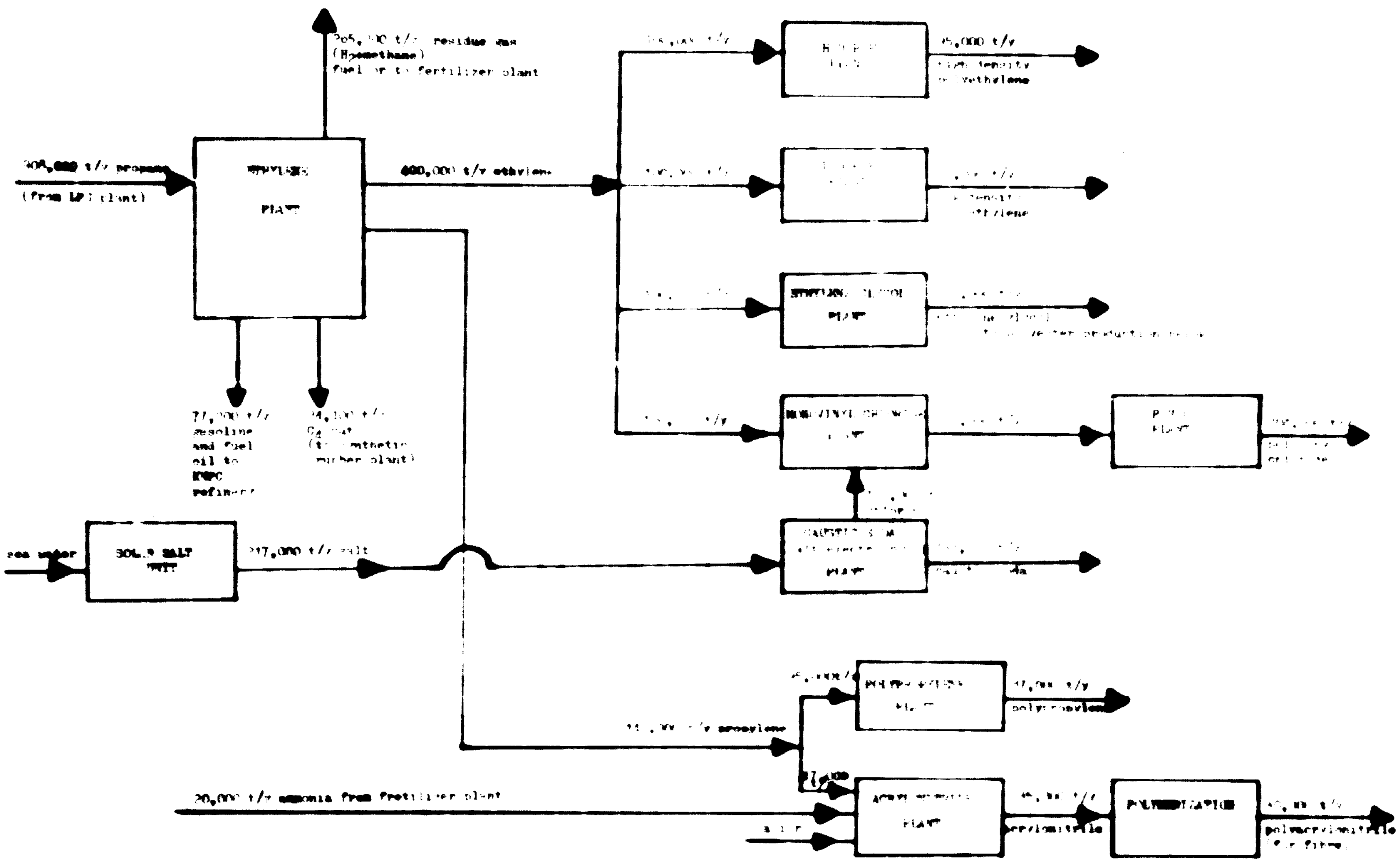
The information provided, and the free and open discussion with all above parties is sincerely appreciated.

PHASE I - INTEGRATED COMPLEX



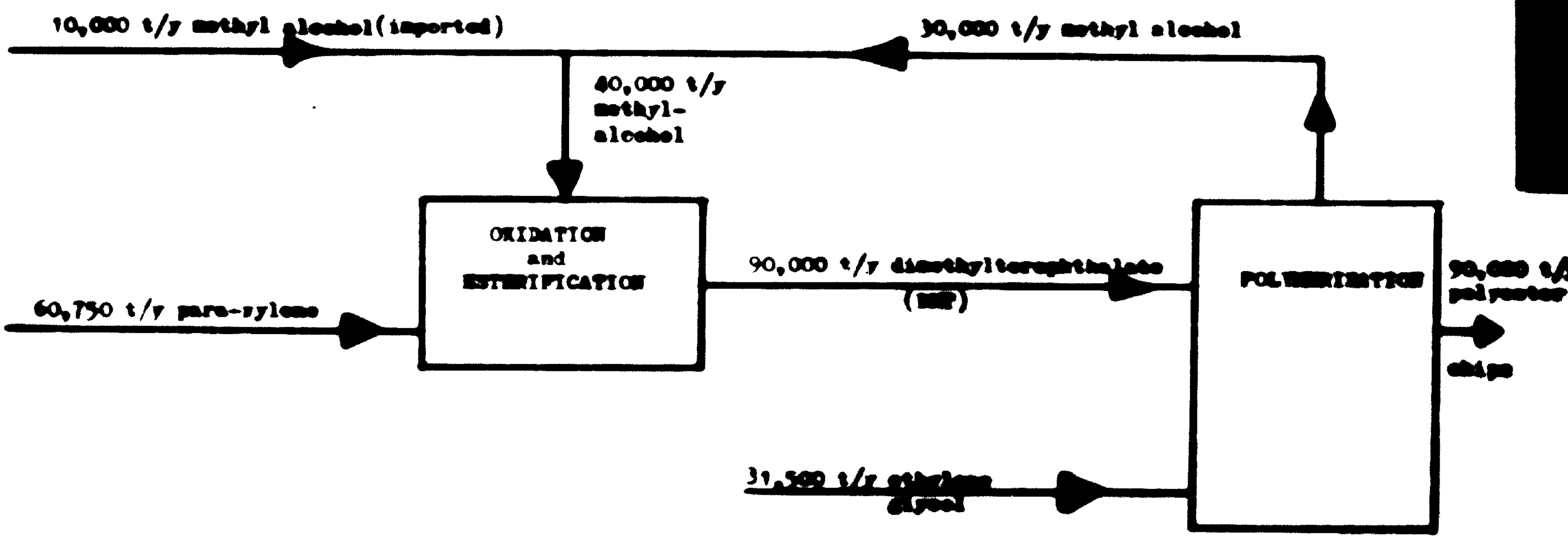

PHASE I
A.
lean gas from LPG plant
AMMONIA PLANT
carbon dioxide
310,000 t/y ammonia
UREA PLANT
525,000 t/y urea
B&C.
natural gas
L P G PLANT
C_4 stream
FRACTIONAL DISTILLATION UNIT
n-Butane
BUTENE DEHYDROGENATION
BUTADIENE EXTRACTION
butadiene
45,000 t/y
55,000 t/y
POLYMERIZATION UNIT
polybutadiene rubber
25,000 t/y styrene (from Phase I)
SBR PLANT
60,000 t/y
styrene-butadiene rubber
D.
normal paraffins or gas oil
100,000 t/y
S C P PLANT
single cell protein product
E.
heavy aromatic oils about 50,000 t/y (by-product from aromatics complex of phase I)
CARBON BLACK PLANT
25,000 t/y carbon black

PHASE III



t/y residue gas
fuel or to fertilizer plant
t/y propane
PLANT
400,000 t/y ethylene
77,000 t/y
gasoline
and fuel
oil to
refinery
t/y
(to synthetic
rubber plant)
45,000 t/y
high density
polyethylene
t/y
sea water
SOLAR SALT
UNIT
217,000 t/y salt
PLANT
t/y propylene
t/y
polypropylene
20,000 t/y ammonia from fertilizer plant
air
acrylonitrile
POLYMERIZATION
t/y
polyacrylonitrile
for fibre

PHASE III (cont'd)



76. 05. 20