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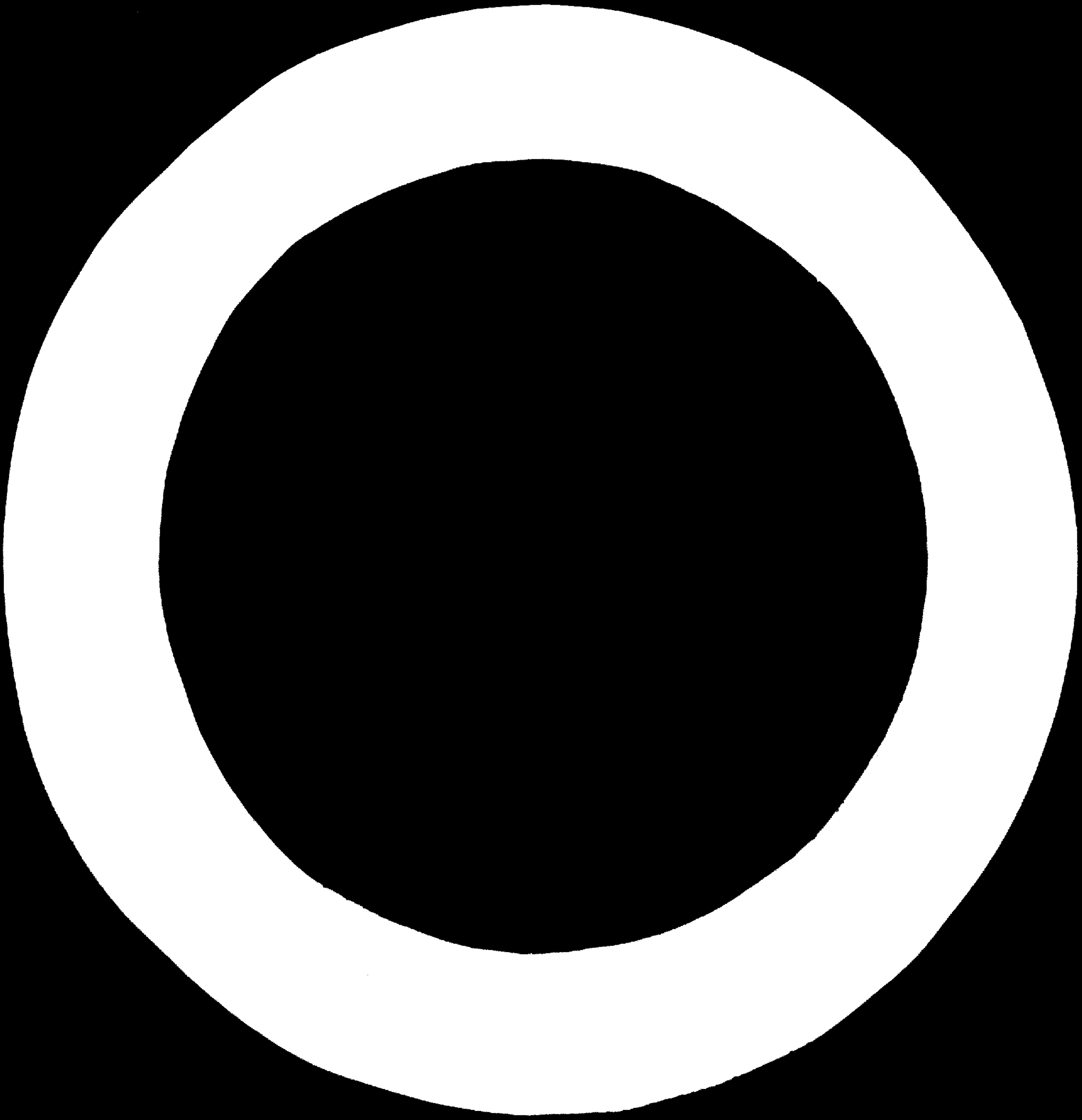
DEVELOPMENT OF PLASTICS INDUSTRIES IN DEVELOPING COUNTRIES

Report and Selected Papers presented to the Expert Group Meeting on Plastics Industries

Vienna, 11 - 15 November 1968



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DEVELOPMENT OF PLASTICS INDUSTRIES IN DEVELOPING COUNTRIES

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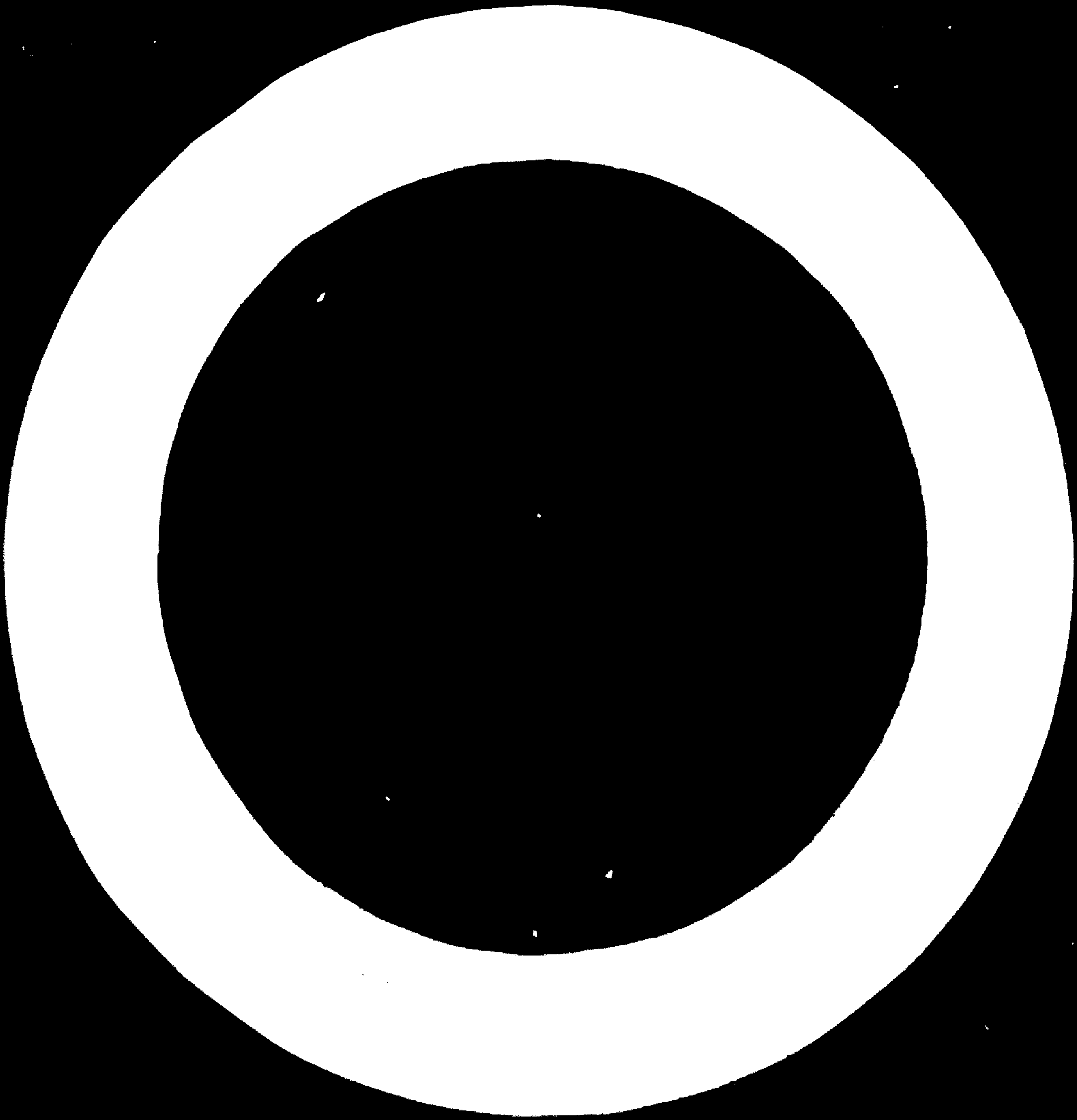
UNITED NATIONS
New York, 1970



Explanatory Notes

Reference to tons is to metric tons unless otherwise stated.

Reference to dollars ($) is to United States dollars unless otherwise indicated. One cent (¢) equals $0.01.

Billion refers to thousand million.

A one-year period that is not a calendar year is indicated as follows: 1965/1966.

A period of two years or more is indicated as follows: 1965-1966, 1965-1968 etc.

The following abbreviations have been used:

United Nations

ECAFE	Economic Commission for Asia and the Far East
GATT	General Agreement on Tariffs and Trade
UNCTAD	United Nations Conference on Trade and Development
UNIDO	United Nations Industrial Development Organization

Other organizations

BASF	Badische Anilin- und Soda-Fabrik AG
BP	British Petroleum Co. Ltd.
CMEA, formerly COMECON	Council for Mutual Economic Assistance
EEC	European Economic Community
EFTA	European Free Trade Association
GEIQUIM	Grupo Executivo da Industria Química
ICI	Imperial Chemical Industrial Ltd.
OECD	Organisation for Economic Co-operation and Development
ÖSW	Österreichische Stickstoff-Werke AG
UOP	Universal Oil Products
USI	United States Industries

Other abbreviations

ABS	acrylonitrile-butadiene-styrene
atm	atmosphere
Ci	curie
c.i.f.	cost, insurance, freight

Other abbreviations (cont'd)

DMT	dimethyl terephthalate
EPR	ethylene-propylene rubber
f.o.b.	free on board
LPG	liquified petroleum gas
MeV	million electronvolts
NBR	acrylonitrile-butadiene rubber
PVA	polyvinyl acetate
PVC	polyvinyl chloride
rad	rad (unit of absorbed dose)
SBR	styrene-butadiene rubber
VCM	vinyl chloride monomer
WPC	wood-plastic combination

PART I REPORT OF THE MEETING

Letter of transmittal to the Executive Director of UNIDO

We have the honour to submit herewith the report of the Expert Group Meeting on the Development of the Plastics Industries in Developing Countries. The report contains the discussion papers presented by us as well as the recommendations and conclusions of the Expert Group. The meeting took place at the headquarters of the United Nations Industrial Development Organization in Vienna from 11-13 November 1968. The Expert Group elected Ahmad Shah Nawaz, Chairman, Chemical Consultants (Pakistan) Ltd., Lahore, as its Chairman. The members of the Expert Group were:

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Shiba, Minato-ku
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Acknowledgement is made to H. C. Yuan, staff member of the International Atomic Energy Agency, Vienna; F. Vachez of Institut français du pétrole, Paris; and R. Gattoni-Celli, Economic Commission for Europe, Geneva, who also took an active part in the meeting.

The terms of reference given to us were to review developments in the plastics industry on a world basis and to discuss the many pressing problems relating to the economic and technical aspects of production and utilization of plastics in developing countries.

Based on the technical papers presented at the meeting and the ensuing discussions, recommendations and guidelines for future development were made and are included in this report.

In submitting this report we have acted in a personal capacity and not as official representatives of organization or Governments.

Signed:

H. Adachi
K. M. Czeija
E. G. Hancock
R. M. Kossoff
L. Kumar
A. G. Litvinenko
C. L. Mercier
R. Schiffino
A. Shah Nawaz
J. Skarka

Organization of the meeting

1. The Expert Group on the Development of the Plastics Industries in Developing Countries met under the auspices of the United Nations Industrial Development Organization at UNIDO headquarters in Vienna from 11-13 November 1968 to review recent world-wide developments in the plastics industries. Problems relating to the economic and technical aspects of production and the utilization of plastics in developing countries were reviewed and discussed.

2. Mr. Ibrahim H. Abdel-Rahman, the Executive Director of UNIDO, in opening the meeting and welcoming the participants, pointed out that the petrochemical and plastics industries are widely recognized as one of the fastest growing industrial sectors, with an annual growth of over 10 per cent in many developing countries. Mr. Abdel-Rahman's statement is presented in the annex to this report.

3. Ten consultants from as many countries were among the participants of the meeting: one each from Austria, Brazil, Czechoslovakia, France, India, Japan, Pakistan, the Union of Soviet Socialist Republics, the United Kingdom and the United States.

4. Mr. Ahmad Shah Nawaz of Pakistan was elected Chairman of the meeting.

5. The report and conclusions of the Expert Group Meeting are presented in Part I of this publication. Part II includes seven of the papers presented to the meeting as background for the discussions and summaries of three oral presentations by consultants attending the meeting. Three of the background papers have been published by UNIDO in Monograph No.3 of the Petrochemical Industry Series (Sales No: 69.II.B.32).

6. The meeting was arranged through the services of the Industrial Technology Division of UNIDO, whose Director, Mr. Nikolai Grigoriev, addressed the group. His statement is attached in the annex. Mr. Maliyil C. Verghese, Chief of the Fertilisers, Pesticides and Petrochemicals Industries Section, attended the meeting, and Mr Herbert May of that section served as Technical Secretary. Participants attended the meeting in a personal capacity and not as official representatives of their organizations or Governments.

7. The views and opinions expressed in this publication are those of the group or of the individual contributors and do not necessarily reflect the views of the secretariat of UNIDO.

Conclusions and recommendations of the Expert Group

8. The Expert Group noted with interest the development of new processes in the petrochemical industry since the petrochemical conference in Tehran in 1964.[1] The group recommended that developing countries give particular attention to the technological changes that have influenced the selection of processes and the size of units in recent years.

9. The Expert Group called attention to the constant increase in demands for plastics in both developed and developing countries. On a volume basis it is anticipated that world plastics production may overtake steel production by the 1980s. The group recommended that in planning economic growth, developing countries should consider building materials as a whole and evaluate the relative importance to be given to the steel and plastics industries. The advantages of establishing a plastics industry, which can be established at lower capital cost and on a smaller scale of production than a steel industry, should be kept in mind.

10. It was recommended that countries standardize nomenclature to identify imports, consumption, production etc. to expedite planning for the establishment of petrochemical industries. The Expert Group noted that present classification of chemical products is rapidly becoming outdated and recommended that a group of experts under UNIDO suggest modifications to this nomenclature for discussion at the forthcoming petrochemical meeting in Baku in October 1969.

11. It was recommended that all countries, and particularly developing countries, establish criteria for the minimum size of plants to be established. The exact size of plants should be guided by prevailing conditions and the selling prices of products that a country is willing to tolerate.

12. The Expert Group noted that some countries are establishing petrochemical operations behind relatively high tariff walls. While this may be an acceptable method of initiating a petrochemical industry, the Expert Group recommended that these plants be designed to reach an economic operating level comparable to international standards as quickly as possible.

1/ See the Report of the First United Nations Interregional Conference on the Development of Petrochemical Industries in Developing Countries, United Nations publication, Sales No.: 66.II.B.14.

13. The Expert Group noted that in small petrochemical operations the foreign-exchange savings, particularly where profits are remitted abroad, are marginal, but where substantial quantities of local equipment are used or profit remittances abroad are not involved, the foreign-exchange savings are substantial. Savings are further increased by the import-substitution value of the products of the plastics industry.

14. The Expert Group noted that some developing countries are converting alcohol- and carbide-based operations to petrochemical feedstocks. Newly developing countries should consider establishing operations based on alcohol or carbide only in very exceptional circumstances.

15. The Expert Group suggested that before petrochemical projects are undertaken, detailed market and feasibility studies should be carried out. The group recommended that UNIDO provide experts and facilities for carrying out such studies and that the studies include detailed surveys on markets and applications. Before it has been decided to manufacture products, feasibility studies should reveal:

(a) Current prices of the contemplated products on the internal market in developed countries versus prices of imported products;

(b) Share structure of the petrochemical company, financing possibilities and incentives that might be granted public or private investors;

(c) Prices of raw materials, utilities and manpower.

16. The Expert Group suggested that when a plastics industry is being built up in a developing country the logical sequence of operations is:

(a) To establish a fabricating industry for moulding, extrusion etc. based on the use of imported machinery and tools, imported raw materials and know-how supplied along with the machinery and materials;

(b) To set up a plant to make moulds or recondition second-hand moulds;

(c) To commence production of thermosetting resins and moulding powders from imported chemicals; if fertilizer interests will co-operate, to set up an ammonia-urea methanol-formaldehyde complex;

(d) In some cases - subject to availability of foreign exchange - to import base polymer, particularly polyvinyl chloride (PVC), and to compound or colour it;

(e) To undertake economic studies for the manufacture of plastics considering time phasing, which takes into account term imports of certain monomers for the domestic manufacture of selected polymers, possible manufacture of certain monomers from imported olefins on a viable basis and erection of olefin plants, if advantageous, in co-operation with neighbouring countries.

17. The Expert Group noted the development of plastic raw materials and synthetic fibres that are penetrating traditional fields of natural products. Countries with interest in industries such as furniture, jute and surgical instruments should keep watch on developments in each field in order to develop their own fabricating facilities. It was felt that plastic products would augment the versatility of traditional products rather than replace them.

18. It was recommended that developing countries concentrate on a limited number of plastics for domestic production in order to establish plants of an economic size and make intensive efforts to use the plastic materials to the utmost. The group recommended that UNIDO undertake studies on the economics of plant size and on the selection of plastics to be manufactured first in newly developing countries; these studies should be available for the next petrochemical seminar. These studies should consider fabricating techniques to minimize the number of resin products selected for manufacture in a country.

19. To lower investment and operating costs of petrochemical plants in developing countries, the Expert Group recommended that these countries:

(a) Prepare for the plant start-up by training engineers, operators and other personnel during the design and construction stages of the plant;

(b) Develop civil engineering and construction services early;

(c) Develop engineering design facilities as soon as feasible to reduce expenditures for foreign engineers, expenditures that in time may be limited to basic engineering fees;

(d) Develop as soon as possible facilities to produce equipment and catalysts and auxiliary materials;

(e) Emphasize training for better maintenance and for inspection of plants already in operation.

20. The Expert Group noted that expenditures for foreign know-how and engineering fees represent a high percentage of construction costs of petrochemical plants, sometimes as much as 25 to 30 per cent. Methods for lowering such costs should be considered at the next petrochemical seminar. The group requested UNIDO to consider ways of helping developing countries to lower these costs.

21. The Expert Group felt that it may be possible to reduce engineering fees by having countries themselves undertake the detailed engineering of the plants in developing countries, or in other countries with lower engineering costs. The Expert Group noted that in some countries, the Government taxes remittance of these fees, with the result that the fees are raised to cover the tax. The Expert Group recommended that countries study the possibility of lowering

capital costs by making the remittance of fees tax-free; customs duties should also be payable only on the net cost of the machinery excluding engineering fees.

22. It was recommended that UNIDO set up a documentation centre where documentation would be available on problems connected with petrochemical technology and other information in this field on the experience of developing countries. It was recommended that UNIDO maintain a list of experts who could evaluate technology and processes for use in developing countries.

23. Developing countries purchasing new plants should have direct access to the process licensers so that they could obtain competitive bids. In doing so the countries would be able to benefit continuously from the expertise of the licensers over a relatively long period, and would have access to better training facilities than those provided by machinery suppliers.

24. The Expert Group noted that many developing countries lack information on current techniques and therefore use out-of-date methods to manufacture plastics. It was recommended that UNIDO give serious consideration to this problem and it was suggested that:

(a) UNIDO organize a touring exhibition that could visit developing countries to demonstrate new techniques;

(b) UNIDO provide experts to assist developing countries in establishing competent extension services for small plastics fabricators, to visit their plants and to give advice on production and processing techniques and designs;

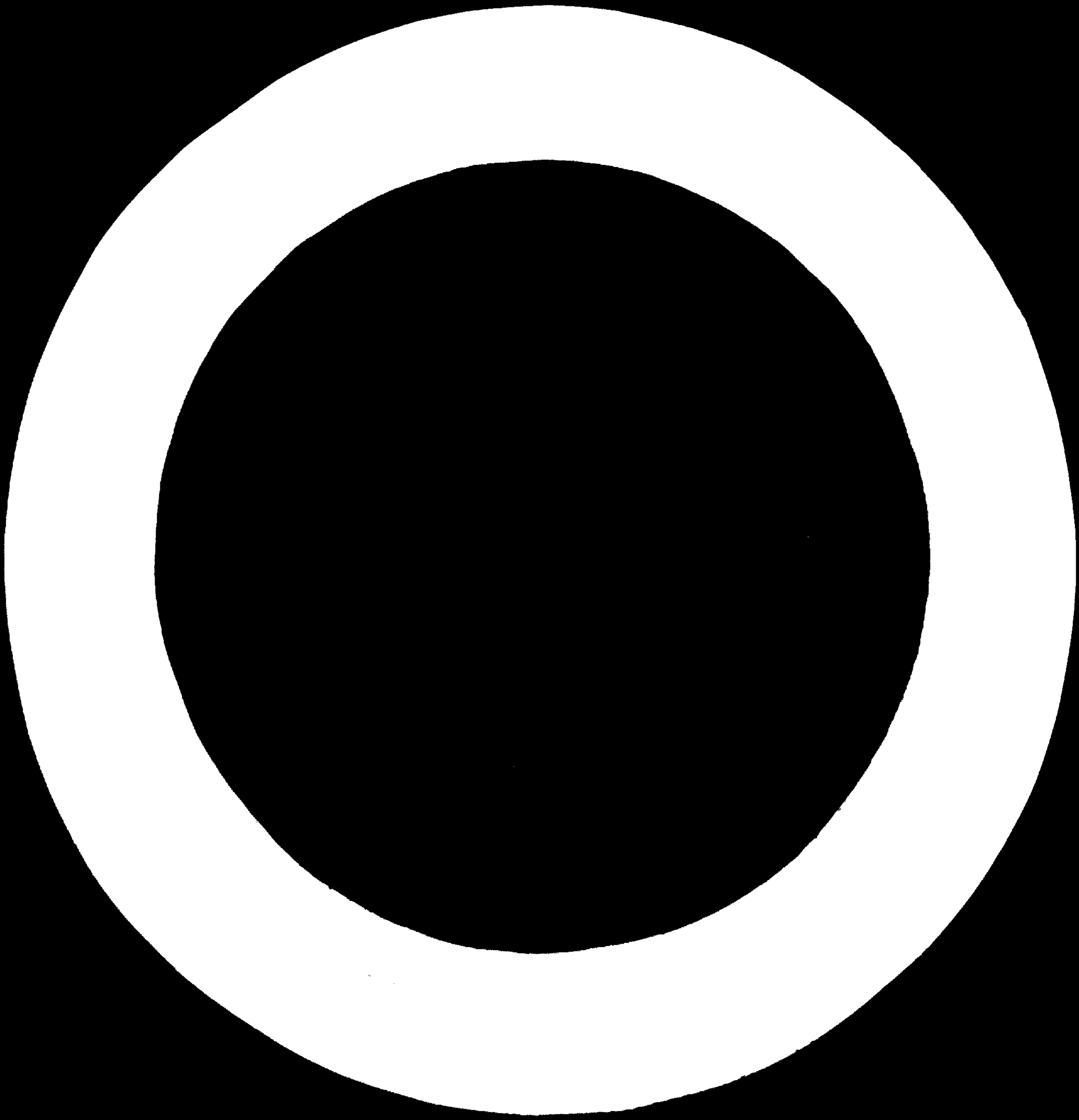
(c) UNIDO help to make experts available and help to locate training facilities for the establishment of mould centres.

25. Because of the significant progress made in the use of radioisotopes for polymerisation, UNIDO, in co-operation with the International Atomic Energy Agency (IAEA), should examine the various production processes such as those for wood-plastics and those for plastics about to be produced commercially (polyethylene and polyformaldehyde) in order to keep developing countries informed of the new possibilities. Since the manufacture of wood-plastics combinations as building materials is receiving considerable attention from many developing countries, UNIDO, in co-operation with IAEA, should undertake feasibility studies to consider further possibilities of developing such manufacture in developing countries.

26. The Expert Group noted with interest that several petrochemical organizations have offered training facilities to UNIDO. It was recommended that these facilities be used and that UNIDO arrange for additional facilities for start-up, maintenance and processing in operating plants.

[illegible] exchange of experience. The results of the discussions and recommendations will be carefully considered in relation to UNIDO's present and future work programme of UNIDO operations and supporting activities.

The petrochemical and plastics industries have been widely recognized as one of the fastest growing industrial sectors today. The production of petrochemicals including plastics is growing at an annual rate of over 10 per cent in many developing countries. Technical assistance by UNIDO in this field is correspondingly increasing. The United Nations has also devoted an increasing number of regional and interregional symposia to specific technical



ANNEX

STATEMENTS TO THE MEETING

Opening statement of Mr. I. H. Abdel-Rahman, Executive Director of UNIDO

On the opening day of the Expert Group Meeting on the Development of the Plastics Industries in Developing Countries and the Preparatory Meeting on the Development of the Petrochemical Industries in Developing Countries, I wish to convey to you my greetings and thank you for your participation.

The purpose of UNIDO, as formulated by the General Assembly Resolution of 17 November 1966, is to promote industrial development and assist in accelerating industrialization of the developing countries, with particular emphasis on the manufacturing sector. In the fulfilment of this purpose, UNIDO carries out two basic types of activities, namely, promotional and operational activities, and studies and research relevant to these activities.

Under this first category, UNIDO provides assistance to developing countries in many areas such as in the application of modern industrial methods of production; programming and planning; strengthening and restructuring technological institutions; preparation of specific industrial projects; efficient use of natural resources; training technical personnel; and the transfer of technology.

The second category of UNIDO's activities includes the compilation, analysis, publication and dissemination of data concerning various aspects of industrialization. UNIDO also organizes international gatherings to enable government officials or experts to exchange views and experience on specific issues and problems of industrial development. The present meeting comes under this category and is for the purpose of obtaining advice, information and exchange of experience. The results of your discussions and recommendations will be carefully considered in relation to UNIDO's present and future work programmes in both operational and supporting activities.

The petrochemical and plastics industries have been widely recognized as one of the fastest growing industrial sectors today. The production of petrochemicals including plastics is growing at an annual rate of over 10 per cent in many developing countries. Technical assistance by UNIDO in this field is correspondingly increasing. The United Nations has also devoted an increasing number of regional and interregional symposia to specific technical and economic features of this industry and to technical assistance projects in petrochemicals in developing countries. In 1969, the Second Interregional Seminar on the Petrochemical Industry will be convened by UNIDO. The news of holding the Seminar has already received world-wide interest, and inquiries about details are increasing rapidly from both developed and developing countries.

In the course of your deliberations, you will study many aspects of the petrochemical and plastics industries. The developing countries, whether they have their own petroleum or natural gas resources or have only refineries or end-product fabrication plants, all face an important problem of finding practical ways for expanding or establishing and running viable petrochemical complexes as a part of their industrial development. I am confident the exchange of experience and information among you will be of great value in finding a proper solution to many economic and technical aspects of this question.

I wish you a successful and productive meeting.

Opening statement of Mr. N. Grigoriev, Director, Industrial Technology Division, UNIDO

It gives me great pleasure in welcoming you to Vienna and on behalf of UNIDO I wish to thank you most warmly for having made available your valuable time in attending our two meetings. Many of you have come from great distances and some of you have made substantial financial sacrifices in order to make available your experiences and contributions to the meetings. The reason for holding the Expert Group Meeting on the Development of the Plastics Industries in Developing Countries and the Preparatory Meeting for the Second Interregional Petrochemical Seminar (1969) concurrently, is that the two are closely related. The first meeting deals with the techno-economic aspect of plastics and petrochemicals in developing countries and the latter meeting deals with the organisational aspects of the 1969 petrochemical seminar.

The development of the plastics and allied industries is receiving increasing emphasis in many developing countries. There has also been a steady increase in UNIDO Technical Assistance projects related to plastics and petrochemicals. These projects cover many subjects such as pre-investment and market studies on the utilization of indigenous raw materials, feasibility reports on establishment of plastics production facilities, improvement of production processes, fabrication and application of plastics products, and design of moulds for plastics processing.

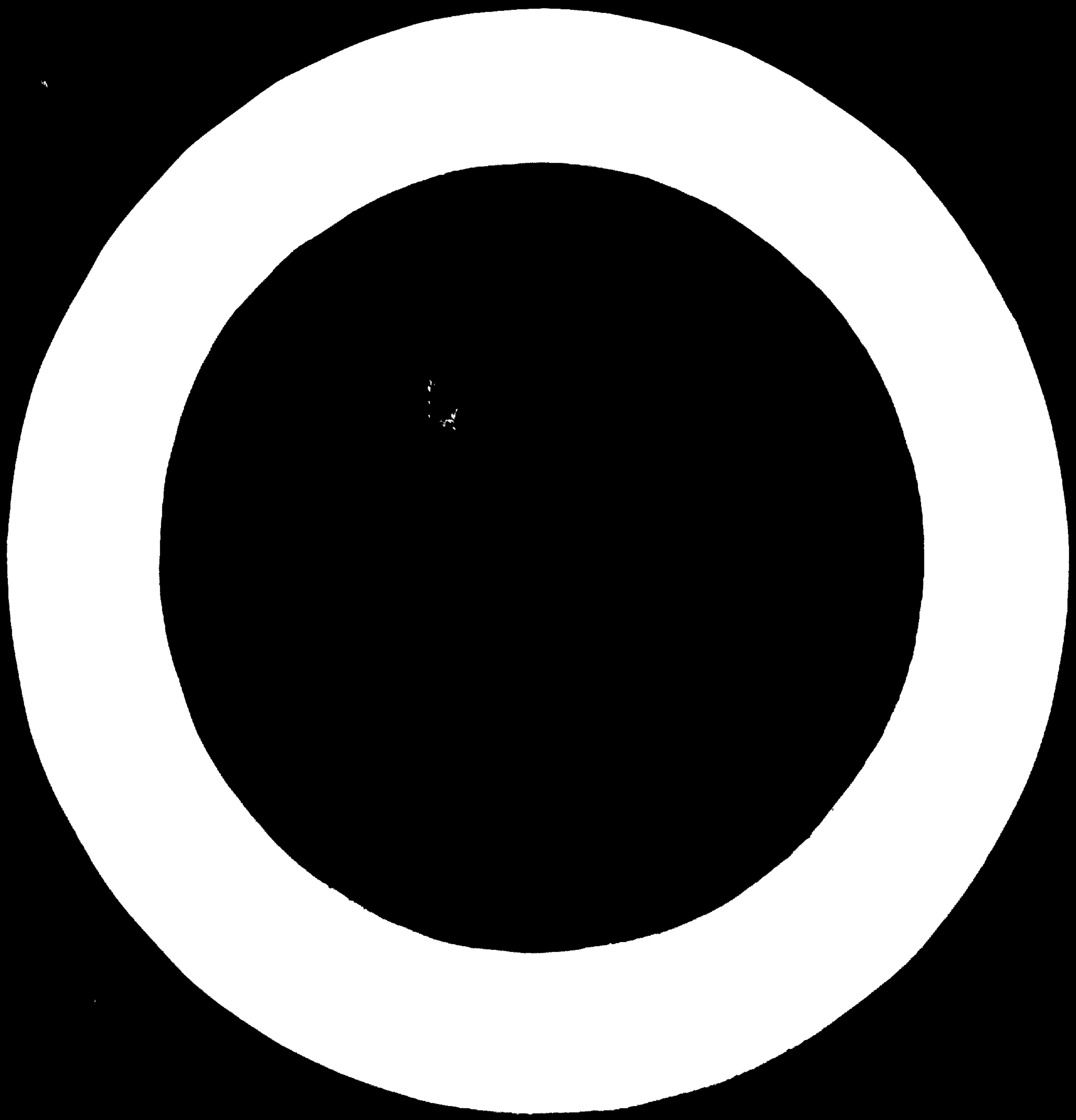
For these reasons, the present Expert Group Meeting is held in order to discuss many pressing problems related to the plastics industries in developing countries. Results of the discussion are expected to assist UNIDO in improving its present programme of technical assistance activities in plastics, and to generate new ideas about future projects.

It should be noted that the purpose of the present meeting is not merely to present a survey of the technology and economics of the plastics and petrochemical industries in the highly industrialized countries, but to consider and reappraise various aspects from the particular point of view of the requirements and natural resources of the developing countries. In this connexion, contributions from consultants describing their experience in developing countries will be of particular value.

The purposes of the Preparatory Meeting for the 1969 petrochemical seminar are to finalize the provisional agenda and to discuss how best the seminar may be conducted. The objectives and suggested topics for discussion are contained in the draft plan before you. The discussions on the first meeting on the development of the plastics industries in developing countries will serve a very useful purpose regarding the subject matter to be discussed in the agenda for the 1969 petrochemical seminar.

You might be interested in knowing that the Government of the Union of Soviet Socialist Republics has agreed to be the host country for the 1969 petrochemical seminar, which will probably take place in September 1969. Because of the large number of topics planned for discussion, the seminar is likely to be extended from two weeks to three weeks.

Finally, may I thank you once again for giving so much of your valuable time in coming to Vienna and wish you a very fruitful discussion and happy stay in Vienna.



PART II

PAPERS PRESENTED TO THE EXPERT GROUP AND SUMMARIES OF THREE PAPERS

1. PETROCHEMICAL DEVELOPMENT SINCE 1964

Claude L. Mercier

The United Nations Conference on the Development of the Petrochemical Industry, held in Tehran in September 1964, concluded that petrochemistry will probably undergo wide expansion. It was thought that developing countries, some of which have large petroleum resources, will account for a large share of this expansion. An initial review of the expansion of the petrochemical industry between 1963 and 1967, the last four-year period for which statistics are available, is given below.

Table 1

New petrochemical units
(built between 1963 and 1967)

Country or region	Number of new units	Total number of units in operation	
		1963	1967
Industrialised			
United States and Canada	122		
Western Europe	104		
Japan	13		
Australia	12		
Total	251	749	1,000
Developing			
Latin America	37		
Africa and Middle East	5		
Asia and Far East (excluding Japan)	16		
Total	58	61	119

Source: World Petroleum, September 1964–September 1968.

During the period examined (1963-1967), the number of new units in developing countries increased from 61 to 119; during the same period, the industrialized countries increased their units from 749 to 1,000.

Although the disparity between these two groups of countries in decreasing in relative value (8.5 times more units in highly industrialized countries than in developing countries in 1967, compared with over 12 times more in 1963), this disparity is increasing even more in absolute value (nearly 200 more units were built in industrialized countries). It must not be forgotten that these figures on the number of units built are misleading because of the much higher average investment level per unit in highly industrialized countries (despite lower construction costs in developing countries). The average investment per petrochemical unit built during the period from 1963 to 1967 was about $16 million in the industrialized countries and $11 million in the developing countries.

New processes and technological developments

Developments in the research area

The dynamism of the petrochemical industry and the constant research by manufacturing companies for lower production costs have led to the appearance of numerous new techniques that can substantially transform production and the market for certain products. Although the new processes derived from these techniques have led to only a limited number of industrial applications, it seems useful to describe their main characteristics and to try to estimate their value.

New techniques may be grouped according to the products they produce: olefins; diolefins; aromatics; oxygenated compounds; polymers; and proteins.

Olefins

Dimerisation and codimerisation. As early as 1964, numerous publications (and in 1966 the World Congress on Petroleum in Mexico City) introduced new methods for the production of C_6, C_7 and C_8 olefins from propylene or butenes. These methods are designed to obtain specific structures through the use of special catalysts. The catalysts obtained as a result of investigations conducted on co-ordination complexes - whose most important application involved stereospecific polymerisation - have the advantage of enhancing a given structure, in the combination of olefins with one another, while conventional phosphoric acid-based catalysts give products having all the possible hydrocarbon structures.

For example, with a catalyst consisting of potassium deposited on an alumina support, the British Petroleum Company (BP), using propylene as feedstock, has succeeded in producing methyl 1-4 pentene-1, whose polymerization leads to a transparent and heat-resistant polymer now being produced at Imperial Chemical Industries Ltd. (ICI) under the name TPX.

Other investigations, in particular those on the Wilke process, lead to products having different structures. These investigations, oriented towards the production of a high octane rating fuel mixture, have yielded C_6 olefin mixtures in which dimethylbutene is the major constituent. Taking into account current prices for light olefins and fuel, it seems that such a technique is too costly for the manufacture of oil constituents. Therefore, with a different orientation of the reaction by a modification of the catalyst, the Institute français du pétrole has developed a process leading to an olefin mixture particularly well suited for the production of primary alcohols by the oxosynthesis process. In particular, these are hexenes or heptenes leading to heptanols and octanols, respectively, which, owing to their quality and cost of production, can compete with ethylhexanol and isooctanols currently produced, either from propylene, by the oxo process to produce butanol, which is then dimerized, or from propylene and butenes by "codimerization" to obtain isoheptenes in the presence of a phosphoric acid catalyst; the isoheptenes so obtained are converted by the oxo process to isooctanols.

This selectivity of co-ordination catalysts has been used advantageously to produce straight chain hexenes, which are possible intermediates in the synthesis of straight chain dodecenes to be used in the production of biodegradable detergents.

Dehydrogenation of n-paraffins. Studies on the dehydrogenation of *n*-paraffins run into practical difficulties owing to the low reaction rate of hexenes, which has led to a more direct route for the production of C_{10} - C_{13} straight chain olefins; the dehydrogenated *n*-paraffins are then obtained by extraction with molecular sieves. This process, first studied by Universal Oil Products (UOP), is called Pacol and is used in a plant now operating in Japan. The process converts n-paraffins, using a catalyst consisting of cobalt thiomolybdate, with a limited conversion (10-15 per cent) of paraffins into olefins, thus forming a mixture which, without any separation, is used to alkylate benzene through conventional routes in the presence of hydrofluoric acid or sulphuric acid.

Such a method, leading to a straight chain alkylbenzene, which produces through sulphonation a detergent that can be biologically degraded, competes with the chlorine method (Hüls, Sarda Industria Resine), which consists in producing a n-paraffin monochloro compound and subsequently alkylating benzene using aluminium chloride. This last method has the disadvantage of consuming chlorine, which remains at the end of the operation as an almost equivalent quantity of hydrochloric acid for which (besides the synthesis of vinyl chloride) it is difficult to find a profitable use.

Diolefins

The production of butadiene was appreciably modified by the development of steam cracking methods, which produce this compound at the average rate of 4 per cent of the charging stock. The main improvement, therefore, has occurred in the solvent extraction process. Besides the older processes, using acetonitrile (Shell), furfural (Phillips), a new solvent has become available, dimethylformamide (Geon). This new solvent allows the extraction of isoprene from the C_5 fractions.

Aromatics

Owing largely to the development of synthetic fibres (nylon and tergal) and partially to that of resins (polyesters and phenolics), the chemistry of aromatic hydrocarbons has made substantial progress in the past few years. The increase in available quantities of benzene and para-xylene - to the detriment of other aromatic hydrocarbons derived either from reforming or steam cracking - has brought about the major part of research and led to the advent of new processes.

Solvent treatment. In the field of extraction, substantial progress had already been made when sulfolane (UOP, Shell) replaced glycol as an extraction solvent for aromatics. Since then the value of new solvents has been well been well confirmed by the building of industrial plants: dimethyl sulfoxide (Institut français du pétrole), N-methyl pyrrolidone (Lurgi).

Together with this technique leading to the production of all aromatics from C_6 to C_8, various techniques specific to a single compound have drawn increasing interest; in particular, extractive distillation or azeotropic distillation, which leads to benzene from a rich fraction (85 per cent derived from highly severe steam cracking, for example).

A new process has been developed by Japan Gas Chemical for the treatment of xylenes. This incorporates, in addition to a superfractionating unit designed to produce ortho-xylene and possibly ethylbenzene, the crystallization of para-xylene associated with the isomerization of the mother liquors (mixture of para- and meta-xylene). This is a new technique in which the extraction of meta-xylene is carried out with an acid solvent consisting of hydrofluoric acid and boron trifluoride. As a result, it is no longer necessary to use crystallization, and each of the aromatic hydrocarbons can be obtained in the pure state. This process appears to be particularly attractive because it yields pure meta-xylene. The market for this product, which on oxidation produces isophthalic acid for polyester production has up to now been limited because of the high cost of producing high-purity meta-xylene.

<u>Crystallization</u>. Production through crystallization has advanced significantly both with respect to the over-all economy of this technique and to the purity of the product obtained. While existing processes were being made increasingly more efficient (Phillips, Amoco), a new technique of crystallization through direct contact with a cold solution was announced by the Institut français du pétrole. Furthermore, this technique takes advantage of crystallization and washing counter-current systems, which not only reduce refrigeration costs but also produce high-purity para-xylene (more than 99.5 per cent pure).

<u>Chemical transformation of aromatics</u>. The improvement of recovery techniques, however, did not meet increasing demands, which could only be satisfied if production methods were improved or new conversions conceived.

High-severity steam cracking, which provides an aromatic oil in which benzene predominates, has led to improvement in the situation of this product. In order to increase xylenes production, catalytic reforming operating conditions were modified and led to a C_8 fraction consisting of almost only aromatic hydrocarbons, thus eliminating the necessity for solvent extraction.

Together with the already known techniques, hydrodealkylation and isomerization, the dismutation of toluene to benzene and a mixture of xylenes (Toyo Rayon) is now possible. This process, for which the first industrial plant is under construction, increases, to the detriment of toluene, the quantities of benzene and xylene mixtures. In association with isomerization and crystallization of para-xylene, it leads to the production of additional quantities of ortho-xylene and para-xylene without requiring the construction of large-capacity special reforming plants.

Oxygenated compounds

This report does not attempt to quote from all research work that has led to the improvement of existing processes but only from work related to the most important products with respect to tonnage or increase in consumption.

Methanol. The synthesis of methanol has been improved (ICI) through the use of new catalysts that have reduced operating pressures from 300 atm to 50 atm while at the same time reducing temperatures from 350°-400°C to 250°-300°C. The value of this new process can be seen from two main standpoints:

(a) At low pressures and large capacity (150,000 - 200,000 tons per year) it becomes beneficial to use centrifugal compressors, used to advantage in the synthesis of ammonia;

(b) Owing to low pressures, it is possible to design a methanol synthesis plant in which the expense of gas compression is minimal. Naphtha steam reforming, which produces the H_2 - CO mixtures, can be carried out up to pressures of 20 atm to 25 atm; the separation train can, taking pressure losses into account, operate advantageously at the same pressure, and it is only then necessary to bring the effluent at the synthesis pressure with a compressor having a compression ratio of approximately 2.

This beneficial effect is still more significant if partial oxidation is used (Texaco, Shell), which may be carried out at 50 atm and higher. In this case the over-all operation is at the same pressure: oxygen alone has had to be compressed.

Acetic acid. In the synthesis of acetic acid, the oxidation of light oil (Distillers) has not eliminated other oxidation methods because of the low selectivity (1.5 tons of naphtha per ton of acid), and the large production of by-products that have to be economically disposed of (formic acid, propionic acid and succinic acid).

Among the new routes, the oxidation of butenes (Bayer) has a high selectivity, owing to an indirect route through butyl acetate. In this process, butyl acetate is first synthesized and then oxidized to three acetic acid molecules, one of which is recycled and returns to the ester synthesis stage; this brings a yield of up to 1.24 tons of acetic acid per ton of butene.

Using a completely different route, acetic acid may be produced by the reaction of methanol and carbon monoxide under high pressure (Badische Anilin und Soda Fabrik (BASF)). Although this method appears to be costly because of the high pressures used (600 atm - 700 atm), the price of methanol obtained from large-capacity plants using the ICI technique is advantageously low.

Vinyl acetate. The synthesis of vinyl acetate from ethylene is the subject of numerous investigations in which attempts have been made to obtain the most direct synthesis. Although this objective has not been reached, one of the most recent developments is oxidizing ethylene in the presence of acetic acid into vinyl acetate and acetaldehyde. This latter product, after separation, is in turn oxidized into the acetic acid required for the operation, making it unnecessary to use an external source of acetic acid.

The direct oxidation of propylene to propylene oxide, in spite of much research, has not yet been carried out satisfactorily. The use of organic peroxides as oxidizing agents (Scientific Design, Arco) has led to particularly high yields related to propylene, but by-products formed by the decomposition of the organic peroxide tend to make the process uneconomic. Two solutions appear to be particularly promising:

(a) Organic peroxide is obtained from ethylbenzene, which subsequently leads to a mixture of methylphenylketone and methylphenylcarbinol. Hydrogenation followed by dehydration gives styrene. Although it is possible, to a certain extent, to adjust the propylene oxide-styrene ratio, 2.5 tons of styrene per ton of propylene oxide are generally produced.

(b) Organic peroxide is prepared by oxidation of isobutane and by a process identical to that used with ethylbenzene. Tertiary butyl alcohol is produced and then dehydrogenated into isobutene. In this case, 1.6 tons of isobutene are associated with each ton of propylene oxide.

Phthalic anhydride. Gas phase catalytic oxidiation of ortho-xylene had already improved when the technique of fluidization came into use, leading to greater homogenization of temperature and a more efficient control of operating variables. By using a liquid phase oxidation technique (Profil) it was possible to bring the consumption of para-xylene per ton of phthalic anhydride from

1 ton down to 0.8 ton. This new process, although probably requiring greater capital investment, will in the final analysis no doubt become the preferred process, especially for large plants, because of its economic use of raw materials.

Polymers

Polyethylene. Just when new polymers or copolymers were appearing, polymerization techniques were being modified and improved. Among these improvements, those involving the polymerization of ethylene should be mentioned. As a result of this technique, through the use of organometallic catalysts (Solvay) placed on a support, it is possible to produce high-density polyethylene with very low catalyst consumption.

Ethylene-propylene rubber. Ethylene-propylene rubber (EPR), whose development was slowed down after difficulties in the vulcanization and the mixing with other rubbers occurred, is expected to capture a larger part of the rubber market with the introduction of a new copolymer, ethylidene norbornene, which, while enabling the vulcanization of this rubber, makes it compatible with the other synthetic rubbers.

Proteins

The fermentation of hydrocarbons, which in principle can find numerous applications in the synthesis of complex organic molecules, has found its first major application in the synthesis of protein concentrates (BP, Institut français du pétrole, Esso, Phillips) for animal feeds. Two solutions are now under study, the first uses gas oil as a source of paraffinic hydrocarbons, and the second involves pure paraffins or paraffinic concentrates.

Although it is still difficult to measure the impact of this process on the animal feed market, it may be estimated that after the initial product and process testing phase, plants with a capacity of about 100,000 tons per year will produce synthetically essential constituents of animal feeds.

Process improvements and most successful processes since 1964

Many petrochemical plants now in operation or under construction use manufacturing techniques based on new, low-cost processes and technology. It is not possible to discuss in detail all of these developments in this paper. They include improvements in aromatic extraction involving large units and the use of better solvents, successful results of simplified, less expensive direct routes to petrochemicals such as: acrylonitrile based on propylene and ammonia; vinyl chloride by ethylene oxychlorination; benzene by thermal dealkylation of toluene, which is spurring the catalytic dealkylation process; caprolactam by cyclohexane route versus toluene and phenol processes; and improved caprolactam yields.

The discussion that follows will be restricted to products that are playing a significant role in the field of elastomers and plastics: ethylene, which has the largest production and consumption of petrochemicals; polyolefins, which are the fastest growing segment of the chemical industry; and stereo-elastomers, which have a promising future in the manufacture of tires.

New steam cracking plants

Between 1964 and 1968, the technology of high-severity steam cracking was confirmed, and steam cracking capacity increased considerably. The large demand for ethylene-derived products (polyethylene, PVC, ethylene oxide) made possible the construction of several big crackers. During this period the tubular reactor technology for steam cracking became almost the sole technology to be used industrially, while the use of other pyrolysis techniques declined.

In all parts of the world, ethylene capacity increased considerably during this period, as indicated by table 2 below.

Table 2

World ethylene capacity
(thousand tons per year)

	1964	1968	After completion of known projects
Europe	2,150	6,378	11,500
North America	4,115	7,610	10,700
Latin America	33	356	2,474
Asia-Australia	576	2,340	6,482
Africa-Middle East	15	130	350
Total	6,889	16,814	31,506

The figures on future capacity are probably exaggerated because some projects will not be realized and some older units will be shut down.

Steam cracking capacity. Between 1964 and 1968, several huge ethylene units were constructed and started up. In Europe, about fifteen units with a capacity of more than 200,000 tons per year of ethylene are already operating or being constructed. The largest of them will produce 450,000 tons per year of ethylene. In the United States, several large units are in operation or being constructed; one of them will produce as much as 545,000 tons per year.

Very large units are known to have operating problems during start-up and generally do not function at full capacity during the first years of operation because of an insufficient market. Initial operating costs, therefore, are higher than expected. Nevertheless, units with a capacity of less than 200,000 tons per year of ethylene will probably not be competitive in the future.

High severity. During recent years cracking severity has also increased. Modern furnace design and tube manufacture have permitted gas temperature of more than 850°C. Residence time can now be less than 0.5 of a second. These performances have resulted in higher ethylene yields from naphtha: more than 30 per cent by weight.

Heat recovery and products separation. Very effective quench boilers have been developed to recover part of the heat content of the cracked gases at the outlet of the cracking furnace. High-pressure steam (more than 100 kg/cm^2) is thus generated, and this greatly improves process economy. A number of improvements have been introduced into the fractionation scheme, particularly in the selective hydrogenation of acetylenes, gas desulphurization and low-temperature fractionation design. Two low-temperature destillation schemes are still competing. The first uses a maximum pressure of 35 bars, corresponding to a maximum pressure of about 10 bars. The separation of the co-products propylene, butadiene, aromatics is generally practiced. Big steam crackers have thus become the main units of large petrochemical complexes.

Feedstocks. In the United States 65 per cent of the ethylene produced is from ethane or propane, 25 per cent from refinery gases and 10 per cent from other feedstocks, including naphtha. The increasing demand for naphtha has resulted in higher prices for this feedstock, and thus heavier feedstocks have been considered. Several units for which gas oil can be part of the feedstock have been constructed. They are more complex and expensive than naphtha crackers. In this case, more co-products have to be sold. In Europe and Japan, there appears to be a trend towards the use of LPG (liquefied petroleum gas).

Summary. High-severity and high-capacity naphtha crackers received wide acceptance by industry during the period 1964-1968. Some problems during starting-up operations or when heavier feedstocks are used have decreased the profitability of these units to some extent. However, the development of this process during this period has resulted in an important decrease in the price of ethylene and its derivatives.

New processes and improvements in the field of polyolefins and dienes

The relative importance of polyolefins among plastic materials has grown steadily, reaching in 1965 the top position of all polymers. At that time the total amount of polyolefins produced surpassed that of PVC. Within the polyolefins class, polyethylene has a leading position to such an extent that from 1966 it has held the top place in plastics production.

Continuing at this rate during the next years, total world production in thousands of tons will be as follows:

	1965	1970	1975
Low-density polyethylene	2,300	5,000	8,500
High-density polyethylene	700	1,600	2,800
Polypropylene	300	1,300	2,800

To reach these figures, production units will have increasingly larger capacities. Already some earlier units of low capacity have been closed, and nowhere in the world is there a single plant producing less than 10,000 tons per year of polyolefins. No company would now erect a low-density polyethylene plant of less than 50,000-tons-per-year capacity, using in the production line reactors of less than 25,000-tons-per-year individual capacity, or in the same way, a high-density polyethylene plant of below 20,000-tons-per-year capacity for a Ziegler process or below 40,000 tons-per-year-capacity for a Phillips process. Regarding polypropylene, the lowest single unit capacity is 12,000 tons per year when the individual units in the project are above 20,000 tons per year.

Low-density polyethylene. Of the various technological modifications that were under discussion in 1964, some have materialized in the last five years and have introduced unquestionable economic benefits.

Tubular reactors with numerous ethylene injections are found frequently. Many companies have erected plants using this type of reactor, introducing modifications according to the process (Société nationale des pétroles d'Aquitaine (SNPA), BASF, Du Pont). This system offers advantages for the manufacture of ethylene-based copolymers. The inner tube may reach a three-inch diameter and a 25-foot length.

Cylindrical reactors have been modified in two ways: by catalyst injections in various locations; and by allowing polymerization to occur in two distinct zones, one between 150° and 190°C and the other between 190° and 250°C. The quality of the films made with these polyethylenes is greatly improved. The internal volume of such reactors has been doubled, reaching 500 litres and higher.

For all types of reactors higher pressures are used; 2,000 kg/cm^2 is now a lower limit, making it possible to manufacture intermediate-density polyethylene. The present limitation of 2,500 kg/cm^2 is related only to the compressor possibilities.

Further minor improvements are also noticeable: stabilizer and carbon black addition directly in the polymerization reactor, which allows for a lower production cost and introduces an improved uniformity in the product quality; and direct production of polyethylene emulsions in the reactor by addition of water and 1-butanol.

New polymer compositions have been introduced on the market, mainly as ethylene-based copolymers with: (a) ethylene acrylate (Union Carbide, Monsanto); (b) methyl methacrylate (Du Pont); (c) vinyl acetate (USI); and (d) methacrylic acid and a metallic salt (Du Pont ionomer). Other ethylene-based copolymers are under investigation or are just starting marketing operations. These are: (a) vinyl chloride (Hercules); (b) acrylonitrile (USI); (c) vinyl silanes (Union Carbide).

High-density polyethylene. The Phillips and the Ziegler polymerization systems have maintained their respective positions from a commercial standpoint, and few improvements have been introduced in the various modified processes. The Phillips process has been improved mainly in its economics by using loop reactors and by a computer control system for continuous polymerization. The Ziegler system has been thoroughly studied, and the stage of possible catalysts has been widely extended, though titanium tetrachloride associated with aluminium alkyls is mostly used. Improvements deal with the integration of the activity, the stability and the reproductibility of the catalytic system. One of the ways to achieve this is to put it on a preformed polymer, which will result in raised monomer conversion. The Standard Oil of Indiana process has not reached the industrial stage although it has been under study for some years.

The problem of removing reaction heat, which used to be quite serious, has been solved by polymerizing in a low-boiling hydrocarbon as a solvent; the vaporized hydrocarbon is continuously recycled (Koppers). Use of a fluid-bed catalyst has been reported as a possibility, but no industrial plant is using this process. Alcohol washing for the polymer has gained wide acceptance as compared with water treatment. Ethylene-butene-1 copolymers are now on the market; they exhibit an improved resistance to stress cracking.

<u>Polypropylene</u>. The salient fact concerning polypropylene is the great disappointment that followed the commercial marketing hopes and forecasts of the early 1960s. It is now clear that the true development of polypropylene is just starting, and it is expected that this polymer's share in the production of all polyolefins, which was 9 per cent in 1965, will grow to 16 per cent in 1970 and to 20 per cent in 1975. This rise has been delayed mainly for technical and legal reasons.

Technically, the same improvements in the process as for Ziegler type ethylene polymerisation have been recorded, with some modifications for polypropylene.

Titanium trichloride associated with aluminium alkyls is the most widely used catalytic system.

Polymerisation may be carried out continuously in cylindrical reactors, with a propylene stream turbulent mixing.

Use of a screw-type reactor is reported for a solvent-free polymerisation, while another process uses polymerisation in liquid propylene as solvent.

Polymer quality has been greatly improved - in fact, the propylene homopolymer has lost ground compared with the copolymers whose mechanical properties are more varied and are resistant to low temperature. Propylene is copolymerized with: ethylene at a level of 5 per cent; ethylene-propylene copolymer; butene-1; and higher olefins. These products have slightly different characteristics and are used for specific markets.

Other polyolefins. Since 1965, other products have been introduced on the market: polybutene-1, commercialized by Phillips and by Hüls; poly-4-methylpentene-1, commercialized by ICI. One company has studied poly-3-methylbutene-1, which would find an interesting market in cords for tires.

Stereo rubbers development. Highly stereospecific polybutadiene production started in 1961 in the United States. Commercial development of this type of synthetic elastomers rose in 1964, and forecasts of consumption in thousands of tons for the next few years are bright:

	1965	1970	1975
Polybutadiene *cis* 1-4	230	480	725
Polyisoprene	50	240	550

For each elastomer there are at least two different processes leading to high-quality products by solution-type polymerization in a hydrocarbon, requiring high-purity monomer and critical operating conditions. The relative importance of stereo rubbers to the total synthetic elastomer consumption is expected to grow from a low 5 per cent in 1965 to more than 11 per cent in 1975, with a ratio in this group of polybutadiene to polyisoprene tending towards 60:40.

Polybutadiene. The various processes each using a specific catalytic system yield polymers of different steric purity as indicated below. (This is not the only test of quality, as molecular distribution is also a major factor affecting the technological properties of the rubbers.)

Table 3
Production of polybutadiene

Process	Catalytic system	Per cent cis 1-4	Production 1967 (per cent)
Firestone	Organo lithium/pentane	51	25
Phillips	Ti 14 - Al Et 3	95	30.5
Goodrich Gulf	Cobalt salt - Al Et 2 Cl	97	32.5
Shell	Cobalt salt - Al Et 2 Cl	97	8
Hüls	Ti Br 4 - Al (iBu) 3	85	4
Japan Synthetic Rubber	Nickel salt - Al Et 3-X	98	0

The average size of the units erected since 1965 is about 25,000 tons per year, but recent projects are quoting units with a capacity of 60,000 tons per year. At these production levels polymerization is exclusively of the continuous type.

Polyisoprene. Highly stereospecific polyisoprene is very similar to natural rubber and may easily be substituted for it. Isoprene may be polymerized with lithium type catalysts or with Ziegler type, such as titanium tetrachloride and aluminium alkyls. At present, the industrial processes in exploitation are those of Goodyear, Shell, and Goodrich Gulf; the units have a capacity of 25,000 tons per year. If the problem of obtaining isoprene at a competitive price is solved, capacity of the polymer—producing units should be 50,000 tons per year.

World survey of economic developments

Production, investment and trade

Production

Considerable quantities of petrochemicals were available on the market from 1964 to 1967. In the United States in 1965, petrochemistry contributed one third of the tonnage produced by the chemical industry as a whole and 60 per cent of the value. This is equivalent to 42 million tons of products having a total value of $8.55 billion. In other highly industrialized countries, the petrochemical industry tends to hold a similar place.

Within the petrochemical sector, the largest segments are the basic intermediates: ethylen, propylen, butadiene and benzene. However, certain more elaborate production programmes such as that for vinyl chloride reach similar orders of magnitude.

The average cost of American petrochemical production is approximately 9¢ per lb, which is a relatively low price compared with the tonnage produced by a heavy industry.

Investment

Vast sums of capital are required for investment in the petrochemical industry. Table 4 below lists the investments planned for 1965-1970 and 1970-1975.

Table 4

Investments planned in the petrochemical industry
(million dollars)

	Period 1965-1970	Period 1970-1975
United States	5,210	7,280
Japan	2,280	3,700
European Economic Community (EEC)	4,000	5,350
European Free Trade Association (EFTA)	1,400	2,050
Latin America	895	1,445

As indicated in the introduction, there is a noticeable disparity between sums invested in highly industrialized countries (United States, Japan, EEC and EFTA countries) and in the developing countries of Latin America. For example, on the basis of the investments made in 1965, investments in 1975 will amount to approximately $22 billion in the United States and $17 to $18 billion in Western Europe.

Depending on the degree of elaboration of the product, investment per unit of capacity increases rapidly. To transform crude petroleum into petroleum products, approximately $20 per ton per year must be invested. The transformation of ammonia into urea and ammonium sulphate in a fertiliser production complex requires $50 per ton per year. The polymerization and spinning of caprolactam to obtain continuous filaments of fine denier nylon requires $3,000 per ton per year.

Trade

In international trade the value of products derived from the petrochemical industry is considerable. For example, for the United States, the chemical industry is responsible for 36 per cent of the balance-of-trade surplus, of which more than one third corresponds to petrochemical products. The average unit value of exported products varies according to country; the Federal Republic of Germany and France seem to export more products of higher value than Italy and Belgium (see table 5).

Table 5

Exports of organic chemicals in 1965

Country	Quantity (t)	Average value per lb (¢)
Belgium	242,317	7.5
France	589,445	15.3
Germany (Fed. Rep.)	1,193,000	17.0
Italy	805,106	8.0

The big exporting countries sell to many importers: the United States exports to over 80 countries (transactions of more than $100,000 per year); the Federal Republic of Germany to 77; France, Italy and the Netherlands to over 60 each. For these countries the dispersion leads to large supplies of stock per importing country: 7,000 to 15,000 tons per year. Smaller exporting countries such as Spain sell to over 30 countries an average of 850 tons per year per country. This diversification is due to permanent competition among exporters in quantities and prices and to a concern on the part of exporters to safeguard their outlets, or on the part of importers to guarantee a steady supply.

In countries such as Trinidad and Tobago, where foreign industrial groups have established large petrochemical complexes as subsidiaries because of the low cost of raw materials or taxation policies that are advantageous to business, the situation is radically different. Exports from these countries are absorbed by fewer buyers; one buyer alone may take the bulk of what is exported. This is because the subsidiary has become part of the production chain of the parent company, and the parent company absorbs most of the production of the subsidiary.

For countries having the largest export in absolute value, the most important customer is the internal market; compared with local production, exports are relatively small.

Of organic chemicals produced in the United States, 44 per cent are petrochemicals; in Japan, 30 per cent; and in the European Economic Community countries, 44.5 per cent. The United States exports 13 per cent of its organic chemicals, while Japan exports only 10 per cent. EEC exports to its member countries 27.5 per cent of its total production of organic chemicals; 19.5 per cent is exported to countries outside the Community.

For EEC, exports of organic petrochemicals, compared with production, are approximately on the average level of the total "chemistry" sector; for the United States and Japan, the "chemistry" sector exports only 6 to 7 per cent of its production. Within the Community, disparities are substantial. The Netherlands, for example, exports comparatively more than the average of the six countries in the Community.

The markets are reached through the distribution network of established firms in various countries. The establishment of larger economic communities maintaining efficient customs protection with respect to outside competition has prompted large producers to get a firm hold on markets through subsidiaries producing on the spot. This evolution is particularly clear for American firms specializing in chemicals, whose exports between 1960 and 1965 amounted to approximately 6 per cent of their production, while sales by subsidiaries in foreign countries increased from 6 per cent to 12 per cent of the value of this same production. Taking this situation into account, large firms were led to change the international structure of their organization by decentralizing the power to make certain decisions.

Competition on the world market. Prices for petrochemicals are subject to constant competitive pressure. International prices for the main petrochemicals show a continuous and steady fall. The rare increases are due to temporary causes: political, for example, a scarcity of a product consumed in large quantities by an army at war; or below capacity production such as that of ortho-xylene.

To maintain competitive prices, producers first decreased their margins, but the products to which such price reduction can be applied are becoming increasingly scarce. Attention is being directed at present towards the use of cheap raw materials and technical solutions leading to lower production costs.

The mechanisms of competition must take into account major factors such as monopoly or virtual monopoly situations. A monopoly may exist in a given country de jure or de facto with respect to the manufacture of a product or a range of products. It may be a state monopoly or a monopoly by a company benefiting from practically complete integration of a sector of activity for reasons related to history or to patent ownership.

On the international scene, since de jure monopolies do not exist, de facto monopolies have taken root. They may result from powerful marketing networks, or ownership by a company of the cheapest raw materials, enabling it to produce at lower cost or at a technical advantage and protecting it from competition. The technical advantage is often made possible by ownership of key patents for a well-defined production.

The processes for which basic patents have recently fallen into the public domain are still more or less protected by peripheral patents extending protection 15 to 20 years according to the country. The technical head start given to the holder of the process is so large that it often discourages competition. The royalties to be paid for the right to use processes of this type are often so high that it becomes impossible to consider production, and production is left to the holder of the process or to companies in its control. Investment requirements are increased frequently 10 to 15 per cent as a result of royalties, and production has to bear an additional 2 to 3 per cent of "know-how" costs over a period of ten to fifteen years.

Trade agreements and economic zones. The petrochemicals market is set in most cases within a network of international trade agreements regulating relationships between consumers and producers. The largest agreement affecting 80 per cent of the total volume of world trade is the General Agreement on Tariffs and Trade (GATT). It formulates general lines of behaviour by which the contracting parties agree to abide:

(a) Application of the most-favoured-nation clause between the parties;
(b) Elimination of any quota-fixing measures for protective purposes;
(c) Principle of consultation between the parties;
(d) Establishment of a general agreement; plan of negotiations for lowering customs duties.

Several economic zones have been created to eliminate customs barriers between countries; of these zones, the best known are: EEC, EFTA, the Central American Common Market (CACM) and the Council for Mutual Economic Assistance (CMEA). A first consequence of the creation of these zones was to give producers an economic hinterland having market possibilities better suited to large-scale production. It should be noted, however, that on the one hand, the size of created trade currents favours increased trade within the zone and on the other hand, association agreements that extend certain advantages to countries outside the zones may exist.

Technical factors affecting the petrochemicals market

Practical possibilities for meeting the demands of an existing market in the last analysis depend on techniques that permit production at competitive prices. The choice among processes depends on minimum economic capacities of production, size of the investment required, licence costs, cost of raw materials, utilities, manpower etc...

Transport costs may also determine the location of the plant with respect to the market. Depending on transport costs, petrochemicals may be cheaper to produce at the centre of the market, whether or not the raw material is imported. When raw material is available at the production site, the increase in price of a product owing to transport from the plant to the market may make local production more economical.

If a petrochemical product is prepared by particularly complex manufacturing processes, factors such as production secrets, know-how and royalties are of primary importance. It is very costly to be certain that the ideal technology is being used. In practice, it is most often acquired through experience in running production plants.

Market factors linked to production

An increasingly greater constraint on profit margins and production costs but at the same time a healthier market situation owing to more genuine competitive possibilities may be noted. This tendency will probably continue because *de facto* monopoly situations are being eliminated through extension of markets and production under the influence of new producers. Western European countries, CMEA countries and Japan are now large-scale producers, and by 1970 the petrochemicals industry of these countries will be in its maturity phase.

Original processes are being developed outside the United States owing to:

(a) The setting up of production programmes in economically favourable areas. Capital is being invested in other industrialized countries where construction costs are low and consumption zones are large. There is a trend to produce near the market because it is cheaper to ship raw materials than finished products.

(b) A decrease in the hold of process owners on the product market. The development of the petrochemical industry has increased considerably the range and number of processes and patents available.

(c) Anti-trust laws in many countries.

In certain cases developing countries may be assisted by anti-dumping measures, which help to maintain market prices. An example of this is the anti-dumping duty levied on United States polyethylene by the EEC countries in 1965.

Large complexes are being integrated with refineries to an increasing extent. For maximum profit, both petroleum and chemical companies are using crude oil as their raw material for petrochemicals.

Combination refinery-petrochemical plants have been set up. The refinery supplies several feedstocks to the adjacent petrochemical facility and uses the by-products of the petrochemical plant as fuel components in the manufacture of petroleum products.

Oil companies and producers of organic chemicals use different approaches to achieve their objectives. Integrated complexes are developed to: (a) provide flexibility in the choice of feedstocks; (b) provide flexibility in product distribution; and (c) realize the economies resulting from integration of the plant's components. Examples of each type of approach are: (a) the El Paso-Rexall arrangement in the United States, the BASF-Shell or Bayer-BP arrangements in the Federal Republic of Germany; and (b) Monsanto, Dow, Allied Chemical in the United States, ICI in the United Kingdom.

The refinery-petrochemical plant combination can be limited to production of a few major petrochemicals or expanded to include more end products by adding other process units. A good example is the Puerto Rico Petrochemical complex, which uses off-gases and naphthas from the Commonwealth Oil Refinery to produce building blocks as aromatics and olefins, but also intermediate and finished products as nylons, polyesters, plastic extrusions and mouldings.

This combination may be improved in the new petrochemical-refinery concept where the plants are designed to maximize chemical production and optimize the ratio of fuels to chemicals. The scheme can also be designed to make essentially only chemicals by extensive recycling or addition of more processing units, but for the time being this does not seem economic. In fact, if case studies carried out for many variations of the petrochemical-refinery concept have indicated some desirable combinations and integrations of processing units for maximum return on investment, these favourable economics depend heavily on by-product marketing from large steam crackers.

The price of petrochemicals

In the following evaluation of the sales possibilities for a product and of the profitability of the producing plants, the price referred to is the average price obtained on the world market.

Transport costs, which are relatively higher when the product is shipped c.i.f., vary considerably with the nature and quantity of the product (see table 6). For the importer, the c.i.f. price, which includes possible storage costs before shipping, may be increased in certain cases by storage costs upon arrival; these can be substantial (this is true of liquefied gases). Posted prices, which are generally f.o.b. prices from the factory or shipping harbour, are published in special periodicals.

The actual prices obtained in international trade are rarely published, so that it is difficult to know what they are. However, for large transactions they can be estimated if one has a thorough knowledge of the market and contacts with professionals. Foreign trade statistics of large importer or exporter countries also provide valuable information on this subject. (In the United States, these are collected by the United States Tariff Commission.)

The prices at which the products are available on the international market may be compared with the c.i.f. prices prevailing in industrialized zones (see table 7).

Table 6

Transport costs of petrochemicals

Product	Nature	Quantity (t/yr)	Distance (km)	Means of transport	Cost ($/t)	Price c.i.f. (%)
Ethylene [a]	Liquefied gas	50,000	1,200	Ship	13	15
			5,000	Ship	22	25
Ammonia [b]	Liquefied gas	50,000	1,200	Ship	11	22
			5,000	Ship	18.5	37
Nitrogen fertilizers	Solid (in bags)	1,500	1,500	Ship	3.5	4.5
		10,000	6,000	Ship	6.5	8.5
Chemicals [b]	Liquid	40	1,000	Rail	65-165	
			3,000	Rail	16-29	
Chemicals [b]	Liquid	20	1,000	Truck	33	
			2,000	Truck	66	

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[a] Additional storage and unloading costs: $6 to $9 per ton.
[b] In United States (1965).

Table 7

Estimated international market prices for 1968

Product	International market price (¢ per lb or per gallon where indicated)
Acrylonitrile	12 - 13
Benzene	25¢ per U.S. gallon
Butadiene	9
Caprolactam	23
Cyclohexane	24¢ per U.S. gallon
Dodecylbenzene	7.5
Ethylene	3.5
Phthalic anhydride	11 - 12
Cis-polybutadiene	18 - 19
Polyethylene (low-density)	10 - 11
Polyethylene (high-density)	15 - 16
Polyisoprene	19 - 20
Polypropylene	20
Polystyrene	10 - 10.5
Polyvinyl chloride	10 - 11
Propylene	2.2
Styrene	7.5
SBR (1500)	15 - 15.5
Toluene	19¢ per U.S. gallon
Ortho-xylene	3.5
Para-xylene	8.7

Factors affecting international prices

The price of the product is affected by production costs, which vary in a regular and easily predictable manner (production costs generally decrease with time); and market prices, which are much more difficult to predict. Production costs are subject to technical production factors, improvement in technology, use of low-cost manpower and building of plants of an economic size. Irregularity in the production cost structure may be due to changing raw material costs, since the market price of raw materials fluctuates. Market prices are subject to the law of supply and demand and depend on the availability of raw materials, manpower and utilities. Market prices are also affected by demand, which can be influenced by the economic or political situation or the appearance of new products on the market.

International prices may be influenced by large producers, who can either maintain prices at an artificially high level or cause a general decrease in prices. Advance selling and supply contracts for long periods of time have a stabilizing influence on prices. Generally, the more elaborate the product sold, the shorter the life of the contract.

Evolution of prices

Petrochemical prices change with time. Except for "anomalies", caused by economic or political factors, the general trend is for prices to decrease. This trend, which is more pronounced than in other sectors, is quite characteristic of petrochemistry.

After a product has appeared on the market, three price phases may be distinguished. When a product is introduced, its price reflects the technology used and research and development costs. Then, as a result of technological advances, marketing improvements, distribution among various sectors and competition, the price decreases. This decrease, which used to take six or seven years during the 1950s, now takes only two to four years owing to accelerated technological advances and established marketing networks. In the third phase the price of a product decreases only very slowly and depends on reductions in profit margins and lowering of production costs.

Evolution of the petrochemical industry in developing countries

As it is impossible to present all developments taking place in the petrochemical industry in developing countries, the following examples have been chosen to indicate where significant industrial complexes have come on stream since 1964 or are under construction. These examples illustrate the different ways of developing petrochemicals - from the growing industries of Mexico, Chile and Turkey, based on resources of raw material and investment fully supplied by the public sector, to the developing industries of India, Brazil, Iran etc., based on joint ventures of foreign and local firms belonging to the public or private sectors.

(a) Mexico, with Pemex plants at Ascapotzalco, Cuidad Madero, Pajaritos, Minatitlan and Posa Rica;

(b) Chile, with Empresa Nacional de Petróleo at Concepción;

(c) Turkey, with Petkim Petrokimya at Izmir;

(d) India, with National Organic Chemical Industries Limited (NOCIL) at Bombay, including Shell International Chemicals;

(e) Iran, with National Petrochemical of Iran and B.F. Goodrich at Abadan.

The adequate growth of the petrochemical industry in developing countries requires that several viewpoints be taken into consideration:

(1) The viewpoint of the foreign company, which is presumably trying to determine what opportunities exist for selling the export production from its foreign-based plants and for establishing a local manufacturing operation of some type. Foreign companies are interested in ensuring that their local and foreign-exchange expenditures are reimbursed in the currency in which they were incurred, that their investments are safeguarded, and that operations yield a reasonable profit that can be repatriated.

(2) The viewpoint of the Government or the planning organization, which is faced with a shortage of foreign exchange for the country and consequently has to limit the amount that can be allocated to the petrochemical sector. The Government needs to establish targets for consumption and determine the most economical ways of satisfying them; it also desires to help to create new industrial units and new jobs.

(3) The viewpoint of local business, which is interested in promoting profitable projects in its own interest. It usually has no independent source of foreign exchange and usually needs a competent foreign partner for technical reasons, but it takes its profit in local currency.

Unfortunately, if each of the above groups were to take the simplest and most direct means to achieve its objective, it would prevent one or both of the others from attaining theirs. The only market study that is undertaken is carried out by a foreign company at the instigation of local business. It cannot take in all three viewpoints and yet it is used by all three groups.

It is interesting to compare the foreign-currency costs of manufacturing petrochemicals on a scale appropriate to developing countries with the foreign exchange costs of imports. To avoid confusion arising from joint costs and accounting practices in petrochemical production and to be able to distinguish cost and price items clearly, it is helpful to consider a single plastic such as polyethylene (high-pressure process) and to examine its price structure and the cost of producing it in developing countries, using a simplified model first with regard to foreign-exchange costs, and then to examine the total costs.

The model is simplified and summarized in table 8, but it has been derived from a detailed study of specific cases in connexion with an industrial project now being implemented. The model may be said to present the case for local production, since it is very difficult to conceive of a set of circumtances in most developing countries that would be as favourable as those shown. The size of the model was chosen to correspond to the average demand for polyethylene in many developing countries.

The prevailing prices for polyethylene and the predicted prices for 1974/1975 and thereafter at constant money values are shown in table 9. Table 10 shows the amortizable investment and other capital requirements, and the probable foreign-exchange component (this last is somewhat high for the standards of India, Pakistan or the Philippines and somewhat low for the others - in any event it is an order of magnitude and sufficiently accurate for the purposes of this paper). It also shows a summary both in total costs and in foreign-exchange costs of the three main components of a selling price: manufacturing cost, profits and net raw material costs. The model was drawn up under a variety of favourable conditions that applied in the area for which it was designed. Considering that financing was not involved, the investment cost was taken as 120 per cent of Western European investment costs, which becomes a very low figure if one considers that plants in developing countries will probably have to be financed with credit of some type. In this way the actual cost can easily reach 135 per cent of Western European actual costs - without any allowance for import duties or inland construction (which can amount to large sums, but payable in local currency).

Table 8

Production of 15,000 tons per year of polyethylene from ethane

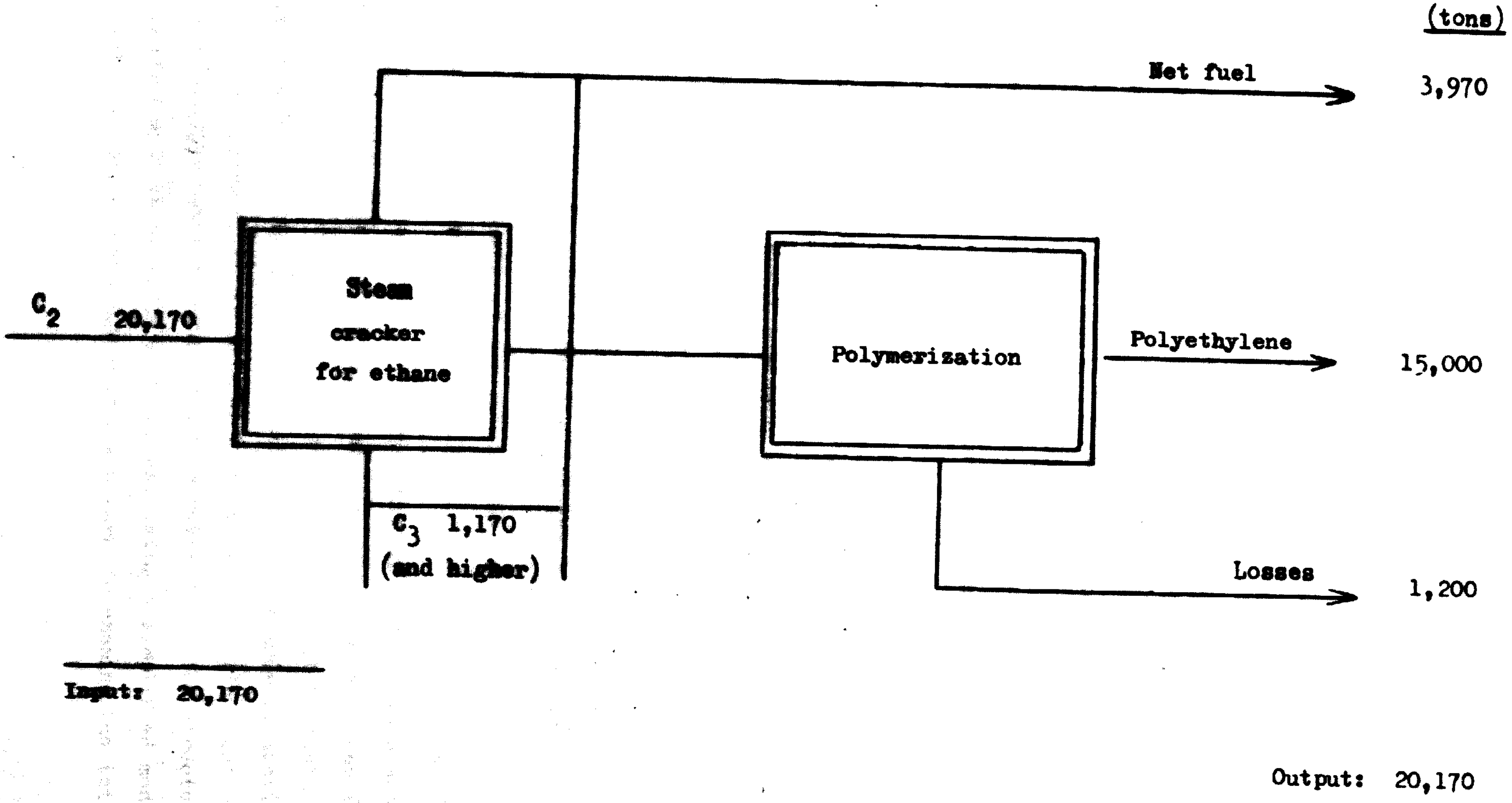

Table 9

Estimated price structure for polyethylene

Composite average prices 50% general purpose 50% film	Prices in US cents per pound 1966	 1974/1975	 Thereafter
Stable domestic long-term and export contracts	12-13	10-11	10
Spot export prices	10-11	8-9	8

Average predicted price of polyethylene in South East Asia (1970-1980)

10 ¢/lb for the plastic
0.5 to 1 ¢/lb for transport

10.5 to 11 ¢/lb Total

Table 10

Costs for manufacture of 15,000 tons per year of polyethylene from ethane

	Total costs		Foreign-exchange costs	
	million $	¢ per lb	million $	¢ per lb
Investment costs				
Amortisable investments	18.70		15.30	
Other capital requirements	0.60		0.30	
Operating costs and selling prices				
Variable costs	1.37	4.1	0.50	1.5
Fixed charges	3.58	10.8	2.90	8.8
Total operating costs		14.9		10.3
Profits (no tax)	1.87	5.7	1.87	5.7
Net ethane feed	0.40	1.2	0.40	1.2
Total selling price		21.8		17.2[a]

Note: Import price is 10.5¢ to 11¢ per pound.

[a] Entirely foreign shareholding. In case of divided shareholding (50% foreign, 50% local) this figure could be reduced to 14.4.

2. THE ESTABLISHMENT OF THE PLASTICS FABRICATION INDUSTRY IN DEVELOPING COUNTRIES

Summary of statement by Richard M. Kossoff

The consultant reviewed for the group the recent progress in the development of plastics raw materials for traditional and novel applications and discussed the potential value of several materials for use in developing countries. He reviewed particularly products that would compete, both in performance and in price, with certain traditional products in the immediate future.

New plastics processing properties that have extended the range of applications were noted by the consultant. Examples were polyphenylene oxide and poly-4-methylpentene-1, capable of resisting steam sterilization for surgical instruments; polybutene-1 for film, coatings, moulded products and pipes; silklike fibres based on materials such as polyesters; clear PVC bottles; stereospecific PVC fibres; and ethylene-propylene rubbers of good chemical resistance.

The consultant discussed the problems of establishing a plastics fabrication industry in developing countries, including the selection of plastics raw materials, fabrication equipment and moulds; the application of recent moulding techniques such as blow moulding; trade in plastics raw materials and end products; research and development; and education and training of plastics technologists. Examples of these problems were illustrated by case studies in selected developing countries.

The studies on which the consultant based his statement have been published by UNIDO in the Petrochemical Industry Series, under the title "Studies in Plastics Fabrication and Application" (Sales No.: 69.II.B.32), which includes the following articles:

"Potential plastics applications for fabricators in developing countries" by J. F. Dash and R. M. Kossoff

"Plastics fabrication and raw materials integration in developing countries" by R. M. Kossoff

"Establishing an integrated coatings and adhesives industry in developing countries" by I. Skeist

3. PETROCHEMICAL DEVELOPMENT IN BRAZIL SINCE 1964

Summary of statement by Rinaldo Schiffino

The new Government of Brazil that was installed in March 1964 introduced many changes that affected the political and economic situation in the country. Disorder had been spreading throughout the country for the two previous years, owing to acute inflation, lack of credit and lack of confidence. Brazil lost practically the entire year of 1964 trying to reorganize its public administration, and consequently very few projects progressed satisfactorily.

The petroleum industry in Brazil is a state monopoly that covers exploration activities, refining operations, oil and gas production and inland and coastal transportation of crude oil and its refined products. Petróleo Brasileiro S. A. (Petrobrás) is the state corporation that handles these petroleum operations.

The petrochemical industry is not included in the monopoly of Petrobrás, but this does not mean that Petrobrás cannot participate in the petrochemical field. For economic reasons, a refining operation or even a natural gas processing operation can be extended to a further stage of processing that may be considered to belong to the petrochemical sector. Petrobrás produces ammonia and nitrogen fertilizers, butadiene and synthetic rubber and is recovering ethylene and propylene from a refinery tail gas.

Even before 1964, foreign private companies were in operation producing polyethylene, styrene monomer, methanol, carbon black and other products. Since 1964, Brazil has shown great interest in promoting and facilitating the development of petrochemical industries either by national or foreign companies.

At present, since Petrobrás refineries have not been able with their by-products to fill satisfactorily the demand for raw material for the petrochemical plants, private enterprises have been permitted to install large naphtha crackers and to integrate themselves into the complex of industries based on such core plants.

Authorization has been given for the establishment of a subsidiary company of Petrobrás to run its petrochemical plants, to promote new projects and to participate in the petrochemical field in association with private enterprises - national or foreign - even if it is in a minority position.

Petrobrás, the holding company, is interested for the most part in keeping the market sufficiently supplied with locally refined products, including, as far as possible, naphtha for petrochemicals.

Two projects based on the use of imported naphtha were approved in 1966 by the competent authorities of GEIQUIM, an agency of the Ministry of Industry and Commerce responsible for the development of the chemical industry in Brazil. The projects have been supported by adequate incentives such as credit guarantees, financing and tariff protection.

One of the projects will produce ammonia, nitric acid and urea from imported naphtha. This project is promoted by the Phillips Chemical Company of Oklahoma (USA) in association with a local company, Ultragaz, a large distributor of LPG in cylinders to houses and apartments. The other project, promoted by Union Carbide, is based on the use of a Wulff furnace and will produce ethylene and acetylene as well as benzene from imported naphtha.

A third large project is based on the use of domestic naphtha and is being promoted by a group of Brazilian investors, with the participation of the Petrobrás subsidiary (25 per cent) and the International Finance Corporation (10 per cent). It will consist of a naphtha cracker for 185,000 tons per year of ethylene and a catalytical reformer for 7,500 barrels per day of naphtha.

The following table lists 28 petrochemical projects approved by GEIQUIN and indicates their location, capacity and status.

Petrochemical projects approved by GEIQUIM (1965-1968)

Company	Location	Product	Capacity 1,000 tons per year	Status
Rhodia Ind. Química e Texteis S. A.	São Paulo	Adipic acid Ammonia	28.3 13.0	On stream
Ciquimi - Cia. Ind. Química do Nordeste	Bahia	Phthalic anhydride	4.5	On stream
Empresa Carioca de Produtos Químicos	São Paulo	Dodecylbenzene	10.0	On stream
Union Carbide do Brazil	São Paulo	Polyethylene	19.5	On stream
Resimpla - Resinas Sintéticas e Plást. S.A.	Rio Grande do Sul	Formaldehyde	4.8	On stream
Ultrafertil (70 per cent Phillips)	São Paulo	Ammonia Nitric acid Ammonium nitrate	150.0 180.0 220.0	Under construction
Union Carbide do Brazil	São Paulo	Ethylene Acetylene Benzene Polyethylene	128.0 36.3 18.6 62.5	Under construction
Alba Ind. Química S.A.	São Paulo	Methanol	36.0	Engineering
Petrobrás - Petróleo Brasileiro S.A.	Bahia	Ammonia Urea	66.0 12.5	Under construction
Prosint S.A.	Guanabara	Methanol	16.5	Engineering
Alba Nordeste S.A.	Pernambuco	Formaldehyde	7.0	On stream
Paskin S.A.	Bahia	Methyl methacrylate	5.0	Engineering

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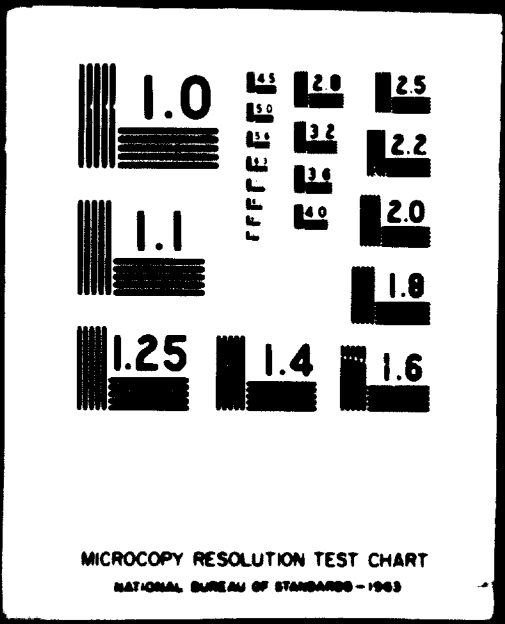

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963

[illegible]	Location	Product	Capacity 1,000 tons per year	Status
[illegible] do Brasil	São Paulo	Vinyl chloride monomer	70.0	Under construction
Petroquímica União S.A.	São Paulo	Ethylene Propylene Benzene	181.0 90.0 150.0	Engineering
[illegible]	São Paulo	Benzoic acid	1.0	Engineering
[illegible] Ind. Químicas e [illegible] S.A.	São Paulo	Nitric acid	33.0	Under construction
[illegible] Cia. Ind. [illegible] do Nordeste	Bahia	Phthalic anhydride (expansion)	4.5	Engineering
[illegible] Ind. de [illegible] S.A.	Bahia	Formaldehyde	7.5	Basic design
[illegible] da Bahia	Bahia	Formaldehyde	6.0	Basic design
[illegible] Prod. Quím. Ltda.	São Paulo	Epoxy resins	1.5	Engineering
[illegible] Prod. Quím. S.A.	São Paulo	Maleic anhydride	1.0	Basic design
[illegible] Sintéticos [illegible] S.A.	Bahia	Acrylonitrile	15.0	Basic design
[illegible] Brasileira S.A.	Guanabara	SBR latices	3.0	Basic design
[illegible]	Idem	Sulphur	10.0	Basic design
[illegible] Ind. Químicas e [illegible] S.A.	São Paulo	Phenol Acetone	50.0 30.0	Engineering
[illegible]	Bahia	Propylene glycol	12.5	Basic design
[illegible]	Bahia	Petrolatum	2.0	Basic design
[illegible]	São Paulo	Styrene	60.0	Engineering

4. PETROCHEMICAL AND PLASTICS DEVELOPMENT IN INDIA SINCE 1964

Lovraj Kumar

The demand for synthetic organic chemicals grew rapidly in the decade 1954-1964, and domestic production was particularly rapid in pharmaceuticals and dyestuffs for the textile industry. Much of this production was based on imported intermediates.

Thermoplastics - polyethylene, PVC and polystyrene - were first introduced in India in 1956/1957 as imports. The demand increased by 29 to 30 per cent *per annum* during the period 1957-1964.

The white sugar industry produced a substantial surplus of fermentation alcohol in the period 1954-1962. As this was considered a suitable feedstock for the manufacture of a variety of ethyl alcohol/ethylene-based products, relatively low-capacity plants were set up to manufacture acetic acid, acetic anhydride, butyl alcohol, butyl acetate, polyethylene and styrene, and polystyrene in quantities required at that time by the Indian market. With the erection of coal carbonisation plants - largely attached to steel plants - substantial quantities of benzene, toluene and naphthalene became available; this enabled the industry to produce the intermediates for dyestuffs, plastics and pharmaceutical industries. The quantity of surplus alcohol was estimated to be sufficient for the production of about 24,000 tons per year of butadiene, and a plant with a capacity of 30,000 tons per year (styrene-butadiene rubber) was erected to use this surplus of ethyl alcohol. Locally produced rubber began to replace imports of rubber. Manufacture of PVC was established on the basis of calcium carbide.

This first phase led to a substantial increase in the production of plastics, rubber, alcohol- and benzene-based chemicals and to the foundation of the synthetic organic chemical industry in India. This is turn accelerated the consumption of chemicals that might not otherwise have taken place in view of the constraints on imports of raw materials. For the first time the importance of the synthetic organic chemical industry was realised. It soon became evident that the small size of domestic plants led to high production costs (and consequently high prices) even though certain raw materials were relatively cheap and world prices of such chemicals had begun to decline. In spite of high prices, the demand continued to increase so rapidly that it overtook domestic production, and Indian consumers clearly showed that they were prepared to switch from traditional materials to synthetic organic chemicals. These factors became more urgent after the constraints on imports of raw materials became more severe in 1959. It became evident that conventional raw materials for the chemical industry - calcium carbide, fermentation alcohol and coal carbonization by-products - would no longer be sufficient or appropriate to meet the rapidly growing demand for synthetic organic chemicals. Economies of scale and the availability of suitable hydrocarbons from oil refineries (first established in 1954 and 1955) also made it expedient to manufacture petrochemicals. It was realised that this would require substantial capital investment, with a large foreign-exchange component, sophisticated technology and skilled manpower. Export studies were therefore commissioned.

The basic feature of the programme adopted between 1962 and 1964 was to develop petrochemical manufacture in order to enable plants to switch from high-cost raw materials to relatively lower-cost petrochemical feedstocks. Such plants were then to be expanded to take advantage of economies of scale and to diversify production; this would make possible the manufacture of import-substitutes for a wide variety of basic organic chemicals. Thus, in stages, the entire structure of the organic chemical industry was programmed for change.

During the past four years, India has established a production capacity of 75,000 tons per year of petrochemical ethylene, 55,000 tons per year of petrochemical benzene; and plants for the manufacture of low-pressure polyethylene, ethylene oxide, PVC, plasticising alcohols, acetone and derived chemicals, petrochemical butadiene, cumene, phenol, benzene etc. Plants have switched from high-cost raw materials to cheaper petrochemical feedstocks. During the next five years, the production capacity of ethylene is programmed to increase to 225,000 tons per year, petrochemical benzene to 100,000 tons per year. Substantial petrochemical production of ortho- and para-xylenes, alpha olefins will be established. [illegible] [illegible] and programmes worked out for the manufacture of [illegible] based on intermediates available from petrochemical plants.

Thermoplastics (low- and high-pressure polyethylene, PVC and polystyrene)

Production capacity increased from 19,000 tons in 1963 to 110,000 tons at the end of 1968; for 1973, the expected capacity is 230,000 tons. In addition to increased capacity and larger units for these three major thermoplastics, there will also be significant production of polypropylene, copolymers and polyethylene, PVC and styrene, methyl methacrylate, nylon, vinyl and acrylic dispersions, latices, urethanes, silicones and probably certain quantities of newer plastics. In spite of the steady increase in production, current imports of thermoplastics are valued at $20 million.

Synthetic fibre intermediates and fibres

India is a large fibre consumer, and current consumption requires the import of $150 million worth of cotton, wool, synthetic fibres and fibre intermediates. Consumers have shown preference for mixed fabrics and synthetic fibres such as polyester, nylon, acrylic and PVA fibre, also polypropylene. These fibres sell at almost five to ten times the price prevailing in developed countries. The manufacture of polyester and nylon, based on imported intermediates, has grown from about 4,000 tons per year in 1966 to 14,000 tons in 1968. A major area of development in the next five years will be the manufacture of these synthetic fibres and fibre intermediates. By 1973, India plans to produce 100,000 tons per year of these synthetic fibres and the related quantities of intermediates.

Synthetic rubber

The demand for all types of rubber has increased at the average annual rate of 15 per cent compounded over the last five years. End-use studies, taking into account substitution of plastics for rubber in such applications as cables, wire and footwear, indicate that India will face a deficit of over 50,000 tons of rubber in 1973. In planning the manufacture of suitable synthetic rubber to cover the deficit, India has taken into account that several neighbours are large producers of natural rubber and it is of mutual interest to increase intra-regional trade. The manufacture of synthetic rubber must be viable, and the product must be sold at a reasonable price. First priority, therefore, has been directed towards improving the viability of the existing SBR plant, which has been plagued by raw material shortages and high production costs. Although India has tentative plans to cover the deficit of over 50,000 tons by further production to the extent of about 30,000 tons, several aspects of the problem are being studied before final decisions are taken.

Synthetic detergents

Increasing rural prosperity, urbanisation and consumer behaviour have led to a rapid increase in the demand for vegetable oils for soaps and fats. Because the demand has outstripped the domestic supply, the pressure on domestic prices has been severe, and $21 million worth of vegetable oils and tallow has been imported in the last twelve months. India has three synthetic detergent plants importing dodecyl benzene. Production has increased from barely 10,000 tons per year in 1966 to over 30,000 tons in 1968, and the rate of growth is increasing. One manufacturer has introduced a composite bar soap for laundry use that sells exceedingly well. Demand for synthetic detergents is expected to increase to 100,000 or 120,000 tons per year by 1973.

India has an excellent source of slack wax at one of the refineries. Paraffin wax for coatings and other uses is being produced at another refinery, and until recently the country was a significant exporter of wax. The demand for paraffin wax has now outstripped production, but purification facilities are being expanded and new facilities are being installed. Slack wax is programmed for use in the manufacture of about 28,000 tons per year of dodecyl benzene, which will be about 90 per cent biodegradable - an important factor in the increasing consumption of synthetic detergents in the large hinterland of India. The other alpha olefins that will become available will be suitable for the manufacture of plasticising alcohols for the PVC-compounding industry.

Other organic intermediates

Production of a wide variety of petrochemical intermediates has given a tremendous impetus to the synthetic organic chemical industry, which at present imports chemicals valued at $150 million. In consultation with manufacturers of dyestuffs, pharmaceuticals and pesticides, several detailed studies have been completed and programmes worked out for the manufacture of chemicals based on intermediates available from petrochemical plants.

No manufacturing programme can be meaningful without supporting research and development, technical services, personnel training and other infrastructure facilities. These broad subjects cannot be given adequate consideration in this brief discussion. Five major chemical technological laboratories have been working in the field of organic intermediates. These laboratories have done notable work in assisting the synthetic organic chemical industry to solve its technological problems. They have developed several processes that are being exploited commercially. These research activities are being closely aligned to the programmes of the petrochemical and synthetic organic chemical industry that have been drawn up for a perspective of ten years.

Manufacturing on a fairly large scale, a recent development, has accelerated the provision of technical services by manufacturers and marketers. With the assistance of the United Nations, an institute has just been set up to train mould and die makers for the plastics industry. Training courses in this institute will start early in 1970. The Indian Institute of Petroleum runs extended courses for orientation in petrochemical technology, and other institutes of technology and certain universities have special courses in specific areas of petrochemical technology.

One of the most encouraging developments in India in the last five years is the rapid growth of engineering design and construction organizations. This has greatly helped to improve the evaluation of technology, cost estimation, design and procurement of domestic equipment. As a result, the foreign-exchange component of projects has been sharply reduced and will undoubtedly continue to be reduced so that at least one of the severe constraints to rapid development will become far less severe.

5. DEVELOPMENT OF THE PLASTICS INDUSTRY IN SOUTH EAST ASIA WITH PARTICULAR REFERENCE TO PAKISTAN

Summary of statement by Ahmad Shah Nawaz

The author, who served as a member of a recent survey mission on behalf of the Economic Commission for Asia and the Far East (ECAFE), gave a general review of the plastics industry of nine countries in South East Asia, namely - India, Indonesia, Iran, Malaysia, Pakistan, the Philippines, the Republic of Korea, Singapore and Thailand.

The figures for consumption of plastics in these nine countries are listed below:

	GNP *per capita* ($)	Yearly thermoplastic consumption *per capita* (kg)
India	105	133
Indonesia	n.a.	128
Iran	270	1,208
Malaysia	279	1,114
Pakistan (East)	84	89
(West)	107	230
Philippines	179	620
Republic of Korea	146	1,178
Singapore	603	6,288
Thailand	150	974

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n.a. = information not available.

It appears that the consumption of plastics increases with the gross national product (GNP) in each country. The true growth rate, however, appears to be faster than the projection for plastics consumption *versus* GNP in many countries, e.g. India, the Republic of Korea and Thailand.

Plastics are substituted for traditional materials and new applications are introduced increasingly rapidly as plastics raw materials, equipment and skills become more available.

In some countries the development of the plastics industry is impeded by the high prices asked for manufactured products. For example, when high-density polyethylene rose to 60-70¢ per kilogram in India and East Pakistan, the price of a plastic bucket in India was three times that of the same bucket in Singapore.

In spite of difficulties, the production and application of plastics are increasing rapidly in South East Asia. The present status of the production of polymer in some countries under survey is summarized below.

India

The demand for plastics is expected to rise sharply in the immediate future.[1]

Iran

A plant is under construction to produce 24,000 tons per year of PVC and 10,000 tons per year of dodecyl benzene based on refinery gases to yield ethylene and propylene. The plant is scheduled to operate by 1969 and is located in the vicinity of the Abadan refinery.

The huge reserve of associated gases, about 675 cubic feet per barrel, that had to be flared in the past is now being piped to the USSR; however, 500,000 tons per year of ethane are available for conversion into ethylene. Assuming the price of ethylene to be 1.5 to 2.0¢ per pound and storage and transport costs 2.5 to 3.0¢ per pound, the cost of ethylene delivered in the South East region is about 4.0 to 4.5¢ per pound. This price could be attractive to some of the countries in the region that are planning to establish polymer manufacture based on either a 60,000-ton cracker or imported ethylene. The advantages of using imported ethylene are: (a) no by-product problems such as disposal of propylene and other chemicals; and (b) the

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[1] For a detailed treatment of this subject, see L. Kumar, "Petrochemical and plastics development in India since 1964" in this publication.

production plants for PVC and polyethylene can be on a relatively small scale. Aromatics based on the C_6 and C_7 fractions, caprolactam and dimethyl terephthalate (DMT) are other products being planned.

Iran has the advantage of having little or no foreign-exchange problems, and highly trained technical and managerial personnel is available.

Pakistan

In 1964, there were only two small plants on stream and two crackers, one in East Pakistan and the other in West Pakistan. Of the two small plants, one produced polyethylene based on alcohol and the other PVC based on carbide. Fortunately, the two plants were situated not far from the site of the crackers so that the switch from non-petroleum-based raw materials to petroleum was fairly simple. Since the high tariff on plastics was lowered the consumption of plastics has doubled.

Although apparently uneconomical at present, a 65,000-tons-per-year cracker is being planned to produce nearly 20,000 tons of ethylene on the assumption that full-capacity production will be possible in a few years. With tariff protection, this operation becomes feasible in terms of a five-year payout period.

Polyethylene production enables polyethylene bags to be substituted for jute bags, and thus jute can be exported.

There is no surplus of naphtha in East Pakistan. A consultant study recommended the establishment of PVC and vinyl alcohol plants based on acetylene. A market survey on the consumption pattern is now under way. An operation for obtaining methanol from natural gas is being studied.

Iran, Pakistan and Turkey are planning to co-operate in the production of synthetic fibres. Pakistan will produce polyacrylonitrile and polyester fibres initially based on imported intermediates. Iran will produce DMT and acrylonitrile.

Republic of Korea

Action is being taken to operate some of the polymer plants more economically. At present there are three or four carbide-based acetylene plants and two vinyl chloride plants; vinyl chloride is also imported from Japan. There is a big demand for polyacrylonitrile (25,000 tons per year). The polymer is converted into finished products, such as sweaters, for export.

A 65,000-ton cracker to produce ethylene and an equal amount of propylene is being planned. The plant will also produce butadiene and aromatics as well as caprolactam. Under an agreement between the Republic of Korea and China (Taiwan), the Republic of Korea supplies China with caprolactam and in return, China (Taiwan) supplies the Republic of Korea with DMT.

Thailand

The consumption of plastics in Thailand has increased sharply, and as much as 18,000 tons of polyethylene are being consumed. To enjoy the advantages of economies of scale, a cracker operation carried out jointly by some countries appears desirable. A 65,000-ton cracker could be built jointly by Indonesia, the Philippines, Singapore and Thailand to produce ethylene and detergents, butadiene and aromatics. ECAFE is studying the relative advantage of using a cracker as against importing ethylene from Iran.

6. RECENT DEVELOPMENTS IN PETROCHEMICAL AND PLASTICS TECHNOLOGY IN THE USSR

Alexei G. Litvinenko

The supply of cheap and readily available hydrocarbon raw materials of petroleum origin, the practically unlimited demand for various types of chemical products, and the high level of national scientific and technical achievement have been responsible for the Soviet Union's great successes in the important branch of the national economy represented by petrochemicals and have won for the Soviet Union second place in the world, after the United States, in volume of manufacture of chemical products from petroleum.

The achievements of the Soviet Union in developing the petrochemical industry and its experience in assisting other countries to develop such an industry (Bulgaria, Ethiopia, India, Poland, Turkey etc.) can be of benefit to countries that have not yet established this industry. The Soviet Union is prepared to send experts to developing countries and to help in working out the complex problems involved in establishing a petrochemical industry.

Development of the raw material base and the production capacity of the petrochemical industry in the USSR

At present, natural gas is processed in many chemical plants in the Soviet Union. Over 50 per cent of the entire output of ammonia, urea and methanol is produced from natural gas. The consumption of petroleum hydrocarbon gases for chemical processing over the period 1958-1970 is shown by the following figures:

	Per cent
1958	100.0
1963	270.0
1965	480.0
1970 (planned)	900.0

In 1965, 3.7 billion cubic metres of natural gas (2.9 per cent of the entire production of such gas) was used for chemical processing, while in 1970, it is planned to use 10.3 billion cubic metres of natural gas (4.4 per cent of the total production of such gas) as chemical raw material. This amount will be 2.8 times more than in 1965. The main purpose for which natural gas will be used in the future, as at present, will be the production of ammonia and methanol, while the main processing method will be conversion to give hydrogen and synthesis gas.

Ammonia produced from natural gas is one half the price of ammonia produced from coke and coal, and the specific capital investment required for its production by this method is 20 per cent lower.

The cost of methanol produced from natural gas is 60 per cent lower than that of methanol produced by the gasification of coal, and the specific capital investment for its production is 25 to 30 per cent lower. Acetylene produced by the thermo-oxidative pyrolysis of natural gas at the place where it is extracted from the ground is approximately 40 per cent cheaper than acetylene produced from carbide, and the specific capital investment for its production is 25 per cent lower. The main raw material for the production of acetylene is natural gas and, to a small extent, benzene; methanol and ammonia are produced primarily from natural gas, and synthetic alcohol is produced from gases arising in the processing of petroleum, other by-product gases etc.

The petrochemical industry is the main consumer of the liquefied gases produced in the processing of petroleum by-product gases and the stabilization of petroleum. The total commercial production of liquefied gases in 1965 was almost 2.8 million tons - ten times more than in 1958. In the next few years, a further considerable increase in the production of liquefied petroleum gases and gaseous benzene is planned in order to satisfy the requirements of the petrochemical industry and other branches of the national economy. In 1970, the production of liquefied gas will be three times higher than the 1965 level. Most of the output of hydrocarbon raw materials comes from the petroleum refining industry, which produced about 60 per cent of the total output of liquefied gases in 1967. Oil refineries used to produce only one type of liquefied gas, the butane-butylene fraction, but now they produce a wide range of the C_3-C_5 hydrocarbons needed by the petrochemical industry.

Oil refineries also supply the petrochemical industry with methane-hydrogen fractions for the production of ammonia, methanol and acetylene; ethane fractions and propane for the production of ethylene and propylene; butane and pentane for the production of divinyl and isoprene; narrow benzene fractions for the production of benzene, toluol and xylols; paraffins for the production of albumins of fatty acids and alcohols; and hydrogen sulphide for the production of sulphuric acid and sulphur.

The main raw materials for the production of practically all synthetic materials are olefin, aromatic and higher paraffin hydrocarbons.

The production of ethylene and propylene is growing at a particularly rapid rate. The increase in the consumption of ethylene and propylene is shown below based on '100' in 1958.

	Ethylene	Propylene
1958	100.0	100.0
1962	207.2	200.0
1963	279.0	261.7
1964	365.4	333.4
1965	390.3	416.7

The percentage breakdown of the production of ethylene from various raw materials in 1965 is as follows:

Ethylene produced by pyrolysis of hydrocarbon raw material - 96.76 per cent;

Ethylene from the coal tar chemical industry - 1.92 per cent;

Ethylene produced by the breakdown of ethyl alcohol - 1.32 per cent.

Ethylene, propylene and other monomers are the basis for the production of the most widely used types of plastics (polyethylene, polypropylene, copolymers of ethylene and propylene, polystyrene and copolymers of styrene etc.) and the most promising types of synthetic rubber and latex (polyisoprene, polybutadiene, butyl rubber etc.)

Extensive production capacity for the output of polyethylene has been established in Soviet oil refineries and petrochemical plants. Capacity has also been installed for the production of polypropylene, another important plastic material based on low molecular weight olefins that surpasses polyethylene in a number of properties. The production of styrol has been developed extensively and the output of this product has been considerably increased over the last seven years.

It is planned in the next year or two to begin quantity production of copolymers of ethylene and propylene, which have high resistance to attack by chemical media, good resistance to heat and cold, and high mechanical and dielectric properties.

Isopropyl alcohol, which is taking the place of ethyl alcohol to an increasing extent in the paint industry and other fields, is now produced in quantity from propylene, phenol and acetone. The financial saving from the use of isopropyl alcohol instead of ethyl alcohol amounts to 250,000 to 300,000 roubles per thousand tons of alcohol. A more sophisticated method for the production of isopropyl alcohol by the direct hydration of propylene is being worked out. The production of acrylonitrile and butyl alcohols is also being developed.

In the last few years, processes for the production of oxygen-containing compounds from hydrocarbon olefins (alcohols, aldehydes and acids) have assumed considerable importance. It has become possible to manufacture these products thanks to the development of processes for oxosynthesis and alumino-organic synthesis, and also methods for the direct oxidation of ethylene to acetaldehyde, with subsequent condensation of the latter into butyraldehyde and 2-ethylhexanol.

Large-capacity plants have been set up in the USSR for the production of butyl and higher alcohols by the oxosynthesis method. This has made it possible to abandon the use of edible raw materials in the production of butyl alcohols. Plants now producing these materials permit an annual saving of about 200,000 tons of edible raw materials to be made, and alcohols produced by oxosynthesis are in no way inferior in quality to those produced from edible raw materials. The higher alcohols can be used successfully as flotation agents in the enrichment of non-ferrous metallic ores, and after suitable purification they can also be used as a plastifying component for PVC resins.

Great progress has been made in the development of the production of aromatic hydrocarbons, which are one of the first chemical products to be obtained from hydrocarbon raw material. The coal-tar chemicals industry now plays a drastically reduced role in the production of aromatic hydrocarbons, and toluol and xylols are now produced mainly from petroleum raw material:

	Percentage of aromatic hydrocarbons obtained from petroleum raw material		
Product	**1963**	**1966**	**1970**
Benzene	1.0	9.0	36.8
Toluol	48.7	62.1	76.5
Xylols	74.2	84.2	93.6

Benzene is of the greatest importance in the manufacture of synthetic products from the lower aromatic hydrocarbons. Among the products manufactured from benzene are isopropyl benzene and phenol, ethylbenzene and styrene, caprolactam, chlorbenzene, nitrobenzene, dodecyl benzene and other materials produced from these compounds, such as synthetic resins, plastics, fibres, rubber, wetting agents and dyes. By 1970, the petrochemical industry will supply about half the total national production of benzene, which is the basic raw material for the production of caprolactam used in the manufacture of synthetic fibres.

In the near future, toluol may be used in the production of phenol, divinyltoluol (to replace styrene in the production of plastics), caprolactam and DMT. In addition, toluol may be widely used in demethylization processes for the production of benzene and hence in the production of a whole range of products manufactured from benzene. Toluol can now be considered a replacement for benzene in the synthesis of basic organic intermediate materials or an additional source of raw material for the production of benzene itself.

Xylols have been used in the manufacture of synthetic materials for only a relatively short time. For a long time, they were used only as solvents. Para-xylol is of great importance, as it is now used in the production of the fibre "Lavsan".

The petrochemical industry will be mainly responsible for a further extensive reduction in the use of vegetable oil in the production of paints and varnishes.

Petroleum paraffins have assumed great importance in the manufacture of many petrochemical products in the last few years. They serve as the raw material for the production of synthetic fatty acids and higher fatty alcohols by the direct oxidation method.

The sharp increase in demand for wetting agents and surface-active products and the need for the greatest possible reduction in the use of natural fats for technical purposes have been important factors in the development of a new branch of the petrochemical industry: the manufacture of synthetic fat substitutes and of surface-active agents and wetting agents based on such substitutes.

The use of synthetic fat substitutes in industry made it possible over the period 1964-1967 to free for their more normal and proper use as foodstuffs over 800,000 tons of edible products of vegetable and animal origin. Furthermore, synthetic fatty acids can be produced more cheaply in terms of labour and operating costs than acids made from natural fats.

	Acids from natural fats	Synthetic fatty acids from solid paraffins	Synthetic fatty acids from liquid paraffins
Cost per ton of acid (per cent)	100.0	50.7	89.3
Labour costs for production of one ton of acid (per cent)	100.0	15.5	20.0

Synthetic fatty acids and products manufactured from them are widely used in industry and agriculture, in daily life and in medicine. In the production of toilet soaps and commercial soaps, these synthetic fatty acids replace edible fats and imported coconut oil, while in the petroleum industry they are used in the manufacture of high-quality lubricants. Synthetic fatty acids are now widely used in the production of softeners and plasticizers for the leather industry and the plastics industry. The residual high-molecular-weight acids are used in the manufacture of finishing materials for the construction industry and high-quality bitumen.

In the last few years, a large-scale industry for the production of primary higher fatty alcohols by the hydrogenation of synthetic fatty acids has been built up. These alcohols in turn have become widely used in many branches of the national economy: in the production of plasticisers, in the flotation processing of non-ferrous metallic ores and in light industry.

Large production capacity has been established in oil refineries and petrochemical plants for the production of synthetic wetting agents in powdered and liquid form.

To satisfy even the basic requirements of the economy of the country, the output of petrochemical products in 1970 will have to be 2 to 2.5 times greater than the 1965 level, with the output of individual products being increased by the following factors: methanol and ethyl alcohol - over 1.3; butyl alcohols - 3.6; phenol - 1.7; ammonia - 1.6; carbamide - 3.5; and sulphuric acid - 3.3. To ensure the further rapid growth of the manufacture of synthetic products, it is planned to increase the output of ethylene and acetylene not less than 2.5 times by 1971.

At present, the main types of raw material for the production of monomers for use in the manufacture of synthetic rubber are:

(a) Petroleum hydrocarbon raw material: n-butane, isobutane, pyrolyzed butylene-butadiene fractions, pentane etc;

(b) Synthetic ethyl alcohol;

(c) Hydrolyzed ethyl alcohol;

(d) Acetylene produced either from calcium carbide or by pyrolysis of natural gas (methane).

The use of petroleum raw material for the production of synthetic rubber on an industrial scale is now developing very extensively in the following directions:

(a) The production of butadiene from ethyl alcohol synthesised from ethylene by the sulphuric acid process or by direct hydration;

(b) The production of butadiene from butane by two-stage catalytic dehydrogenation over a powdered catalyst in a fluidized bed;

(c) The production of isobutylene by the catalytic dehydrogenation of isobutane;

(d) The extraction of isobutylene from the C_4 fraction of cracking gases and the pyrolysis of petroleum with sulphuric acid;

(e) The production of styrene by the dehydrogenation of ethylbenzene;

(f) The production of isoprene from isobutylene and formaldehyde by the two-stage method;

(g) The production of isoprene by the dehydrogenation of isopentane;

(h) The production of butadiene from pyrolysed butylene-butadiene and cracking butane-butylene fractions.

The use of petroleum raw material in the production of synthetic rubbers has great economic advantages. The cost of one ton of ethyl alcohol produced from petroleum is three times less than the cost of one ton of ethyl alcohol obtained from edible raw materials. Since 1967, the synthetic rubber industry has used practically nothing but petroleum hydrocarbons as raw material.

The transition to the massive use of hydrocarbon raw material will permit the expansion of the raw material base for the production of synthetic materials, plastics, synthetic rubbers and fibres and will greatly benefit the economy of the country.

The production of plastics, synthetic fibres and synthetic rubbers

At the present stage of science and technology, the solution of many important technical problems is impossible without the use of plastic materials. The production of plastics in the USSR has increased rapidly. Whereas about 300,000 tons of plastics of all kinds were produced in 1960, 950,000 tons were produced in 1965, and about 1.2 million tons in 1967; in 1970, the production of plastics and synthetic resins will reach between 2.1 and 2.3 million tons, or 2.7 times the quantity produced in 1965.

Besides this increase in the volume of production, there has also been a steady change in the types of plastics produced and the relative output of the various types. The share accounted for by plastics produced by polymerization in 1960 was only 18 per cent, while in 1965 it was 30 per cent.

The production of the various types of plastics in 1970 will be increased over the 1965 production by the following factors: polyolefins, 5.5; PVC, 3.0; phenol-formaldehyde resins, 1.4; phenol-formaldehyde moulding powders, 1.6; amino resins, 2.3; moulding powders based on amino resins, 1.3; polyester resins for glass-like plastics, 3.8; polystyrene and its copolymers, 4.1; ion-exchange resins, 2.1.

In the Soviet Union, some 35 to 40 per cent of the plastics and synthetic resins produced are used by the engineering industries. Plastic materials are used not only as substitutes for metal, wood, glass and leather but also in steadily increasing quantities as independent, non-substitute materials. The use of plastics and synthetic resins in this way will result in a significant rise in productivity, a sharp decrease in operating costs and a substantial saving in capital investment. The production of plastics requires from one half to one third of the capital investment required for the production of non-ferrous metals. The cost of producing one ton of plastics is from one half to one third of the cost of producing one ton of non-ferrous metal, and in terms of one cubic metre the cost is less than one tenth.

In 1970, the consumption of plastics in engineering will be about three to four times the 1965 level. Moreover, as a result of the replacement of metals by plastics, more than one million tons of valuable types of steel and over 600,000 tons of scarce non-ferrous metals will be released; the saving in direct labour costs will be more than two hundred million man-hours, and the saving on production costs will be over 170 million roubles.

Of all the engineering industries, the largest consumer of polymerized materials, particularly plastics and synthetic resins, in the current five-year period and in the next period will continue to be the electrical engineering industry. For example, every ton of epoxy resins used in the production of transformers will save about 1.5 tons of copper and 9 tons of rolled ferrous metal. Polymerized materials are already being widely used as electrical insulation materials and construction materials.

Plastics are being used increasingly in the manufacture of chemical equipment such as vessels and pipelines, valves, filters, pumps and sealing components, which must be resistant to corrosive liquids. The replacement of the lead lining of chemical apparatus by plastics will permit a saving of three to five tons of lead for every ton of plastics.

It is hardly possible to imagine the further development of the cable industry without polymerized materials, mainly PVC and polyethylene. One ton of these polymers takes the place of two to five tons of lead, while one ton of lavsan takes the place of about three tons of cotton yarn and natural silk. Over the period 1959-1965, the amount of lead used per ton of electrical cable produced fell on the average by 27 per cent; the amount of cotton yarn used fell by over 40 per cent; whereas the amount of PVC used increased almost twice and the amount of polyethylene used increased ten times.

Soviet production of resins produced by polycondensation and of plastics based on them is increasing constantly, and new types of such resins and plastics are being developed. Thus:

(a) More than 200 different types of phenol-formaldehyde resins and moulding materials based on them are being produced.

(b) A great deal of work is being done on the replacement of the batch process for the production of urea-formaldehyde resin by continuous production processes, and on the development of a new method for the continuous synthesis of amino resins by means of high-temperature polycondensation and the subsequent concentration of the product.

(c) Polyester resins are being produced industrially on a large scale for general use, for uses requiring high heat-resistance, high elasticity and specific impact strength, and for uses requiring high water- and acid-resistance.

(d) In 1967, more than fifteen types of epoxy resins and more than ten types of compound based on them were produced, and new methods were developed for the epoxidation of unsaturated compounds, while new techniques were also developed for the continuous production of several types of epoxy resins.

(e) Among the polyamides produced by industry, the commonest are: nylon 6, produced from caprolactam; nylon 6,6, produced from hexamethylenediamine and adipic acid; nylon 6,10, produced from hexamethylenediamine and sebacic acid; and a new anti-friction construction material, caprolon.

1/ The [illegible] metric weight in grams per 1,000 metres of yarn.

(f) A technique has been mastered for the manufacture of a new thermoplastic material, polycarbonate diflon, and preparations are being made to build a plant for its production.

(g) A new thermoplastic material, polyformaldehyde, is being developed; efforts are being made to raise the polymer's resistance to heat and light and plans are being made for large-scale production.

(h) Experimental installations are being planned for the synthesis of polyarylates - a new type of heat-resistant polyesters - and of dichloranhydrides of aromatic dicarboxylic acids.

The production of synthetic polymerized resins and plastics based on them is increasing at a rapid rate even though production on an industrial scale began much later than in the case of condensation polymerized products.

PVC is an important industrial polymer because of its low cost, the ease with which it can be processed, its durability and its excellent physico-mechanical properties. The technique for the production of PVC has been steadily improved, and the volume of production has increased.

While vinyl chloride was originally produced by dehydrogenation of dichloroethane in alcoholic alkali, a system was subsequently devised for producing it by hydrochlorination of acetylene in the gaseous phase over a solid mercury catalyst. As a result there was a distinct improvement in the quality of the original monomer.

The industry produces six varieties of suspensions of polyvinyl chloride (PVC-S) and nine varieties of polyvinyl chloride latex (PVC-L) differing in molecular weight and application. Suspension PVC is used mostly for the preparation of high-quality cable, electro-insulating and hose rubber, vinyl sheeting, film and sheet materials, phonograph records, chlorinated PVC etc; latex PVC is used for the preparation of artificial leather, hard and soft films etc.

Glues and varnishes are made from chlorinated PVC. Chlorinated PVC resin is used to make varnishes and paints that are highly corrosion-resistant and weather-resistant.

Production of chemical fibres in the USSR amounted to 407,300 tons in 1965, 450,000 tons in 1966, and will reach between 780,000 and 830,000 tons in 1970. The output of synthetic fibres in 1970 will be 276,000 tons.

The proportion of viscose fibres in the total output of chemical fibres dropped to 72.3 per cent in 1965, while that of synthetic fibres rose to 19 per cent (including 16.1 per cent polyamide, 1.8 per cent polyester (dacron), 0.7 per cent polyacrylonitrile (nitron), and 0.4 per cent chlorinated PVC. In 1970, synthetic fibres will account for about 35 per cent of the total volume of chemical fibres produced.

There is also a greater variety of fibres. In addition to capron and PVC, the synthetic fibre group now includes polyester (dacron) and polyacrylonitrile (nitron). Over the last few years techniques have been developed for producing polynose, polyvinyl alcohol and polypropylene fibres, which have been manufactured on an experimental scale.

The increased output of chemical fibres has been accompanied by improvements in their technical and economic characteristics. This has been facilitated to a considerable degree by the combining of enterprises into larger units. For example, the daily output of a modern cord plant is between 50,000 and 100,000 square metres of capron cord fabric, while the output of a textile thread plant is between 10,000 and 15,000 tons a year, and for an industrial fibre plant between 30,000 and 35,000 tons a year.

Continuous production processes are being introduced successfully into the synthetic fibre industry. For example, polycaprolactam is now manufactured and converted into fibre as a continuous operation. The production of nitron now includes combined polymerisation and dissolution of the polymer. A continuous process has been developed and high-efficiency equipment constructed for the manufacture of industrial capron thread with a thickness of 93.46 tex[1/] (Nos. 10 and 7) and 186.91 tex (Nos. 5 and 35). Over the last few years a method has been developed for forming capron cord without intermediate separation and pulverisation of the polymer.

Large quantities of capron thread are also used for the manufacture of V-shaped belting and conveyor belts, for sheathing sleeves and rubber hosing, and so on. As a result, the service life of conveyor belts is doubled or tripled; the parts are lighter; and the permissible loads are increased.

Because of the high-quality performance of polyester fibre (dacron), the production of this fibre is being accelerated. It is of great importance in

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1/ One tex equals weight in grams per 1,000 metres of yarn.

the rubber industry. Compared with capron, dacron exhibits lower thermoplasticity and a higher elastic modulus. The manufacture of heavy-duty, dacron-base conveyor belts for the mining industry has been introduced.

New plants for the production of polyvinyl alcohol and polypropylene fibre are under construction. In addition to its good physical and mechanical properties, polyvinyl alcohol is also very resistant to light and atmospheric effects. It is therefore being extensively used for manufacturing canvas, upholstering materials, cables and netting.

Polypropylene will become one of the cheapest synthetic fibres available and will likewise be widely used for making cable, upholstering materials and netting. Carpets made of polypropylene, just like those of polyamide, are highly resistant to wear and can be cleaned and washed.

Polyacrylonitrile (nitron) is similar in properties to wool and is used to make a similar variety of fabrics. Considerable savings have been obtained by using nitron to filter exhaust gases in the non-ferrous metallurgical industry. Nitron is a valuable material for manufacturing parts that operate at low temperatures, in high vacuum and under conditions where they are subject to radiation from radioactive substances.

The use of certain synthetic fibres, for example, dacron, polyphene etc., has also proved effective in medicine.

Research into the production of heat-resistant fibres is progressing favourably; studies are near completion on the production of phenylon, which is heat-resistant at temperatures up to 250°C; technology is under development for polypyromellitimide fibres, which are heat-resistant at high temperatures; materials of this kind have also been produced from polyacrylates, which are new polymers; exceptionally high resistance to aggressive media (acids, alkalis and oxidants) is shown by the fluorine derivatives of ethylene, which also exhibit a low friction coefficient, thereby suiting them for extensive use in gasket linings for different kinds of machinery.

Until 1970, the principle industrial fibres will be the viscose and capron varieties. In that year the ratio between viscose and synthetic industrial fibres will be 58.42.

The prospects for the synthetic fibre industry are very good. Its high rate of development is due to the fact that the fibres can be used with great economic advantage in engineering, and it is planned to use dacron, amide, and polypropylene fibre in this context. An increase in the production of PVC by a factor of 4.5 is envisaged for the period 1966-1970. Research is under way to obtain new types of PVC and polymers derived from it that possess higher shock-, heat- and frost-resistance.

Owing to the low cost and abundant raw material, polyolefins occupy the lead among polymers; before long they will become the most commonly used types of plastic. Whereas the production of polyethylene was only tens of thousands of tons in 1964, the figure for 1970 will be hundreds of thousands of tons.

The most important type is low-density polyethylene (high-pressure polyethylene), possessing excellent dielectric properties, pliability and elasticity. It is widely used in cable production, in electrical engineering and in the manufacture of all kinds of hardware. The first major plant for its production began operations in 1962. Industrial production of high-density (low-pressure) polyethylene has also begun. This type is more durable and heat-resistant than the low-density variety, but not so good in dielectric characteristics, and is mainly used as a construction material for prefabricated parts, ventilation units, piping and corrosion-resistant equipment.

Soviet scientists have worked out a unique and highly productive technological process for obtaining polypropylene at low pressure. The method has been used since 1967 for large-scale production of this valuable, high-grade plastic. By 1970, its production will have risen from 10,000 tons a year to a considerably higher figure. Polypropylene, which can be much more easily synthesized at low pressure than polyethylene, is also more durable and heat-resistant (up to 150°-160°C). It has the disadvantage that it acquires a certain brittleness at temperatures below 0°C. Polypropylene is used for fibres, fabrics, floating cables etc.

Once the method of continuous block polymerization in columns and the suspension method had been introduced, the USSR began producing pure, high-grade polystyrene. This plastic has excellent dielectric characteristics and is highly water-repellent and is one of the main materials used for making electric insulators and various consumer goods. A technique has been developed for producing a variety of styrene derivatives, but only the copolymers of alpha-methylstyrene and styrene have acquired practical importance. The combining of polystyrene plastics and rubber by the graft polymerization technique makes it possible to produce a wide variety of materials with good chemical, mechanical and dielectric properties. It has been possible to manufacture a shock-resistant material, SNP, based on styrene, nitrile rubber and acrylonitrile.

In addition, several large plants for the production of vinyl acetate and products made from it are either in operation in the USSR or under construction; a large number of materials and parts based on polymethyl methacrylate containing styrene (styracryl) and other monomer and polymer additives are now being manufactured; the ever-increasing consumption of fluoroplast-4 (polytetrafluorethylene) and fluoroplast-3 (polychlorotrifluoroethylene) has acted as an incentive for a great increase in their output.

The following figures show the dynamic growth of synthetic rubber production in the USSR:

	Growth in synthetic rubber production based on 100 units in 1961
1961	100.0
1964	134.0
1967	192.0
1968	211.0
1969	269.0 (estimate)
1970	338.0 (estimate)

From the above figures it will be seen that the average annual increase in the production of synthetic rubber during the period 1961-1967 was 15 per cent; the rate of growth will be considerably higher during the years 1968-1970.

At present, the basic monomers in the synthetic rubber industry are butadiene, isoprene, isobutylene, ethylene and propylene. The following approximate increase in production capacity (in percentages, compared with 1966) are planned for 1970:

Butadiene	-	162
Isoprene	-	270
Isobutylene	-	180
Ethylene	-	250
Propylene	-	320

The new industrial process of obtaining butadiene by two-stage catalytic dehydrogenation of n-butane presents greater technical and economic advantages than the production method based on ethyl alcohol.

The new methods of producing butadiene are based not only on the dehydrogenation of n-butane but also on butylene-butadiene pyrolysis. The figures (in percentages) for the production of butadiene from alcohol and by the method of n-butane dehydrogenation and butylene-butadiene pyrolysis, respectively, are as follows: 1965, 67 and 33; 1970, 43 and 57. Extensive research is being successfully carried out to devise still more effective methods for the production of butadiene: one-stage dehydrogenation of n-butane in a fluidized bed of a powdered catalyst and one-stage oxydizing dehydrogenation of n-butane in the presence of iodine and an acceptor.

Isoprene has become very important as an industrial monomer for the synthesis of rubber as a substitute for the natural product. At present, only two methods are used on an industrial scale in the USSR to produce isoprene: synthesis from isobutylene and formaldehyde and catalytic dehydrogenation of isopentane. Major effort in the future will be concentrated on the second method.

Production of isoprene rubber was begun in 1964 at synthetic rubber plants in the towns of Togliatti and Volzhsk, while in the same year the factory at Efremovo began to produce rubber from divinyl. These plants have the highest production capacity in the world.

The main trend in the development of the Soviet synthetic rubber industry is to build up the capacity to produce high-quality rubbers from isoprene, divinyl and other substances. The changes planned in the pattern of production and in the types of synthetic rubbers and latices produced are listed below. The figures show that by 1970 the specific gravity of special-purpose rubbers and synthetic latices will have increased considerably; and the specific gravity of isoprene and divinyl rubber will be almost 30 per cent as against 3.5 per cent in 1965. It is anticipated that by 1970, production of synthetic rubber and latices will be 2.2 times greater than in 1965, and the production figures for isoprene and divinyl will be 15 and 42 times higher, respectively.

Changes planned in pattern of production of synthetic rubbers and latices

(per cent of production)

	1960	1965	1970
Rubbers for general purposes, total	88	88.1	74.2
Sodium-butadiene rubber	51	18.8	4.1
Butadiene-styrene and butadiene-methylstyrene rubber	37	65.8	40.0
Stereospecific butadiene rubber	-	0.7	11.8
Isoprene rubber	-	2.8	18.3
Rubbers for special purposes, total	9.4	8.5	20.3
Butyl rubber	-	0.1	3.5
Chloroprene rubber	8.0	6.2	12.3
Nitrile rubber	0.7	1.5	3.1
Other special rubbers	0.7	0.7	1.4
Synthetic latices, total	2.6	3.4	5.5

Increasing use of rubbers of the stereoregular type (isoprene and butadiene) in the tire industry will make it possible to reduce imports of natural rubber and will result in considerable savings by increasing the life of tires by 20 to 30 per cent. It is estimated that expenditure on the construction of isoprene-3 and butadiene synthetic rubber plants can be recovered in two to three years. The synthesis of stereoregular rubbers from isoprene and butadiene thus provides a means of solving one technical problem - how to make elastomers that are not only not inferior to natural rubber but even surpass it in certain characteristics.

The introduction of special-purpose synthetic rubbers such as butadiene-nitrile, chloroprene, siloxane and fluorine-containing rubber has made it possible to create a number of fundamentally new technical rubber articles for modern engineering uses. By 1970, it is estimated that there will be as many as 28 different types of synthetic rubber and as many as 200 different varieties (brands). Extensive scientific research and experimental work will be necessary to create synthetic rubbers with fundamentally new technical properties ("the ideal elastomers of the future").

7. TRENDS IN PRODUCTION AND CONSUMPTION OF PLASTICS IN THE WORLD

Eric G. Hancock

World production capacity

The present world production capacity for plastics is about 20 million tons made up as follows:

	Million tons
United States	7.0
EEC countries	4.5
Japan	3.0
USSR	1.5
United Kingdom	1.3
Developing countries	0.8
Other developed countries	1.9

New plants are announced constantly, but not all come on stream on time or function at 100 per cent capacity immediately. Older plants go out of production with little or no announcement; hence, actual capacity is often appreciably less than it appears. In spite of this, world capacity will probably be well over 100 million tons by 1980 and approaching 1,500 million tons by the year 2000.

It is not easy to predict the percentages of production for various products, but as a first approximation, by 1980, polyolefin plants should reach a combined capacity of about 30 to 35 million tons; PVC plants, including copolymers, about 20 to 25 million tons; and polystyrene plants including ABS, perhaps 10 to 15 million tons.

The production of polyolefins and PVC is capital-intensive largely because the raw materials used are gases and also because continuous processes in large establishments are necessary for economic production. Polystyrene is intermediate, but most of the thermosetting resins have been made using relatively simple equipment; only recently have continuous processes been developed. Traditionally, production has been labour-intensive, but the position is slowly changing.

Much capacity will probably be devoted to new plastics. Many of these will be new copolymers of existing monomers; thus the polyolefin figures given above are assumed to include copolymers of olefins with modest proportions of other monomers. By 1980, there will also be a limited production of entirely new products with special properties such as heat-resistance or greater stiffness.

World production

Figure 1 shows the world production of plastics to 1966 and projected production to 1980 giving upper and lower limits. The mean figure is slightly over 100 million tons. Below is a similar projection for the developing countries, with figures up to 1966 collected from various countries. It seems likely that production will rise at a slightly greater rate than that of developed countries merely because of the enormous potential consumption. The two curves show an average increase in the period 1965-1980 of 17 per cent for the developing countries and 14.4 per cent per year for the world.

World consumption

Plastics consumption will be increased by:

(a) An increase in population, meaning more consumers;

(b) An increase in the standard of living, meaning greater consumption per person;

(c) The replacement of traditional materials - wood, metal, cement etc. - by plastics;

(d) The creation of new applications for plastics.

World population, according to a forecast published in Modern Plastics, August 1966, is expected to increase from 3.5 billion to 7 billion by 1980, which would by itself account for a twofold increase in consumption.

National incomes and standards of living are difficult to forecast, since they are related to the increase in population and affected by political activity. Some recent figures for national income are given later in this paper.

Figure 2 shows world production of steel. Actual consumption in any year will be a little less than the figure indicates, owing to material in transit, in stock or scrap. The same chart gives production figures in the developing countries; but owing to imports and exports, the consumption of developing countries cannot be calculated directly from the chart. Both curves are projected to 1980, and comparison with figure 1 will show the slow rate of growth of steel compared with that of plastics, steel growth averaging 4.7 per cent per year compared with plastics growth of 14.4 per cent per year taken between the years 1965 and 1980.

For many applications, volume is more significant than weight, and if the world volumes are plotted on one chart (see figure 3) it becomes clear that the volume of plastics produced in the world is likely to exceed the volume of steel by the early 1980s. The average density of plastics has been taken as 1.0 in the necessary calculations involved.

Another approach is to compare a key property with the price of traditional construction materials and plastics. The figures of table 1 have been extracted from a paper by W. O. Alexander published in Contemporary Physics Volume 8, 1967, and are based on United Kingdom prices but converted to dollars at £ = $2.40.

Table 1

Basic data of structural materials

	Tensile strength (ton/in^2)	Density	Cost ($/ton)	Average cost (¢/in^3)	Cost per ton (¢ per unit of tensile strength)
Steel	40	7.8	216	2.7	0.067
Reinforced concrete	1	2.4	19.20	0.07	0.070
Timber	0.5	0.5	121	0.065	0.013
Copper castings	15	8.9	1,560	22.9	1.53
Aluminium sheet	16	2.7	1,032	4.5	0.28
Polyethylene	1	0.9	360	0.55	0.55
PVC (rigid)	4	1.4	240	0.57	0.14
Nylon plastic	5	1.15	1,680	2.7	0.54
Glass-weave polyester laminates	50	1.87	2,768	8.0	0.16

Figure 1

Plastics production, 1958-1980

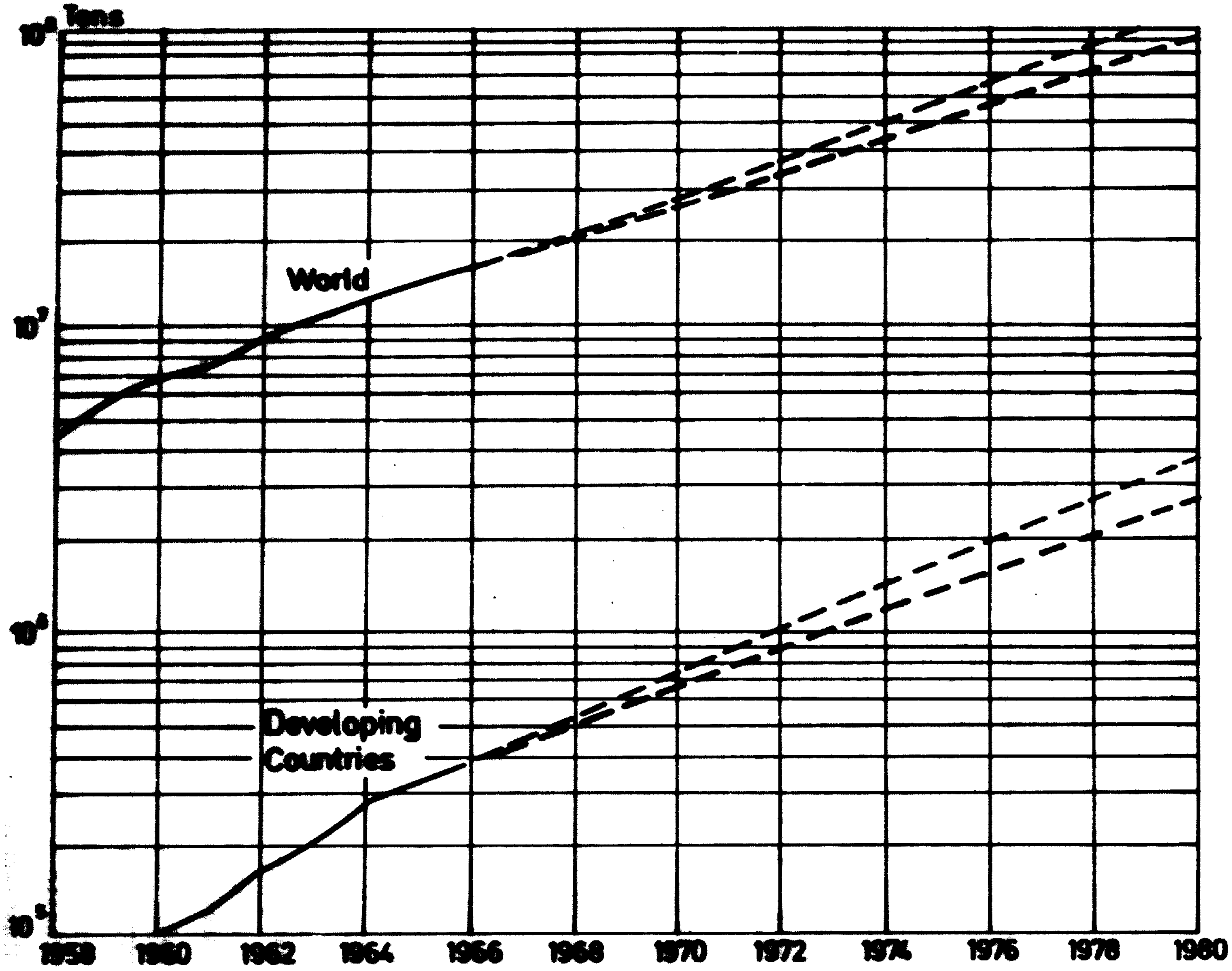


Figure 2

Steel production, 1953-1980

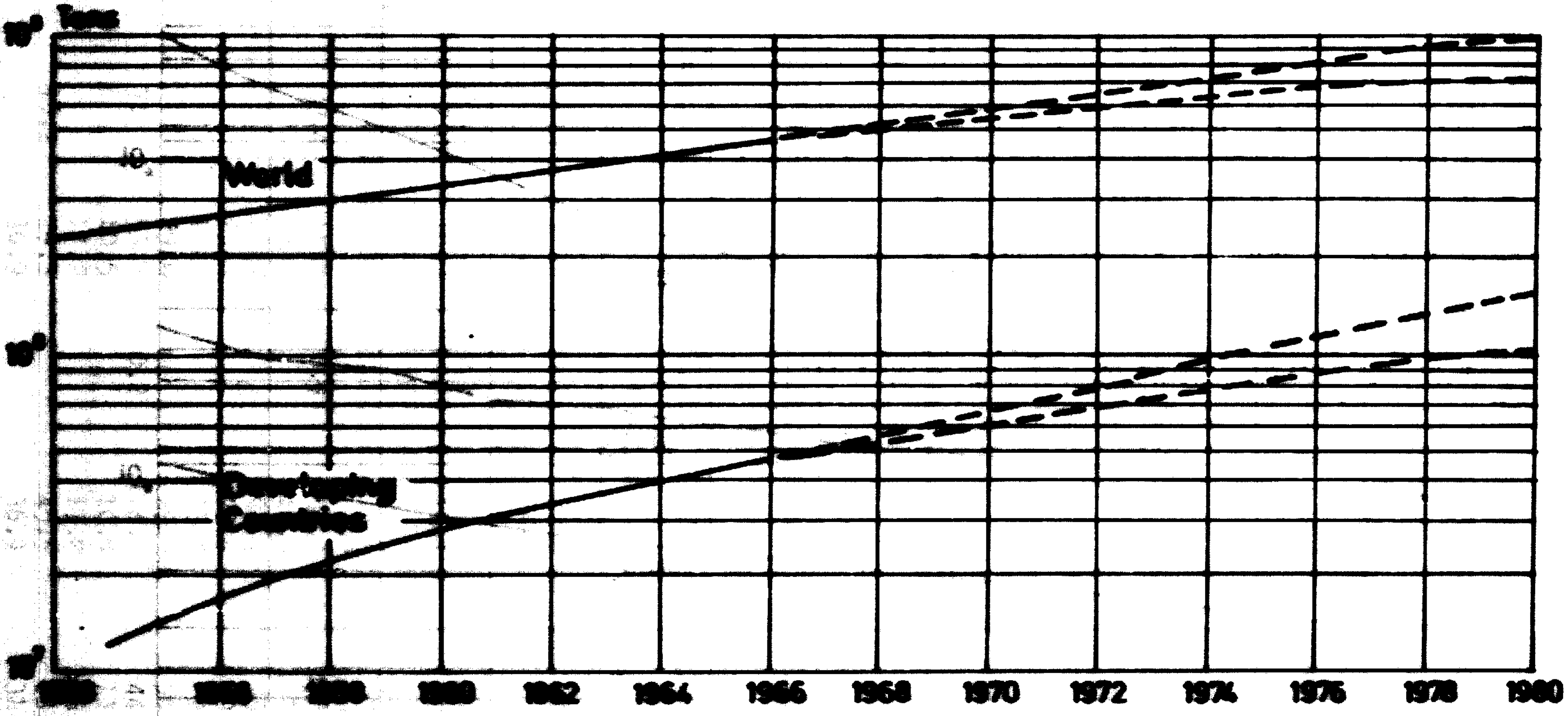
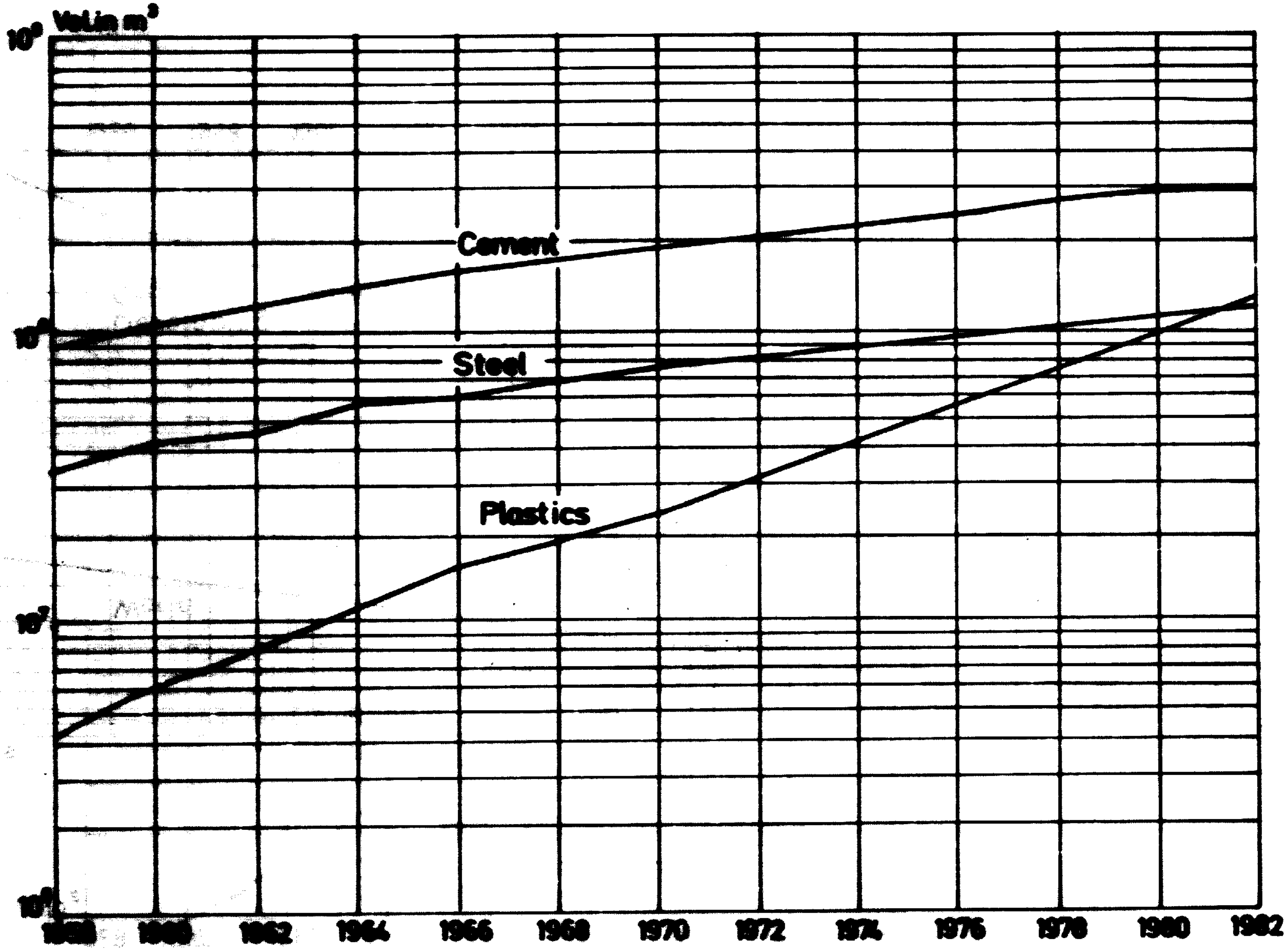


Figure 3

Steel, cement and plastics world production on a volume basis, 1953-1980



For purely structural applications it is clear that plastics cannot yet compete with steel, reinforced concrete or timber in price. They have, however, certain advantages such as being: (a) easier to manipulate than conventional materials; (b) resistant to water and many corrosive chemicals; (c) attractive in their colour range; (d) excellent for electrical insulation; and (e) much more resistant to bacteria than wood.

The price of plastics is falling owing to improved techniques of manufacture and the increased scale of production, while that of traditional materials is rising in most industrial countries.

The consumption of plastics in individual developing countries, shown in table 2, has been calculated by assuming that imports are equivalent to consumption after allowing for production and, in a few cases, export. The consumption of plastics for 1966 in the developing countries listed below is based on figures taken mostly from United Nations sources. Population figures are used to calculate consumption in pounds per person.

Table 2

Plastics consumption in 20 developing countries, 1966

	Production	Import	Export	Consumption	Population (millions)	Consumption (lb/person)
	— thousand	tons —				
Algeria		8.5		8.5	12.1	1.57
Argentina	58.9	14.6	0.7	72.8	22.7	7.18
Brasil	53.4	17.3		70.7	83.1	1.90
China (Taiwan)	45.6	26.2	0.7	71.1	12.8	1.25
Columbia	2.0	18.3		18.3	20.3	1.98
Congo (Dem. Rep. of)		3.7		3.7	16.0	0.52
Gambia		1.8		1.8	3.8	1.06
India	39.4	16.8	0.9	55.3	498	0.248
Indonesia		14.0		14.0	107.8	0.294
Iran		23.4		23.4	25.8	2.03
Kenya		29.4		29.4	9.6	6.85
Lebanon		13.7		13.7	2.5	12.4
Malaysia		29.0		29.0	96	0.679
Mexico	71	53.3	0.2	124.1	44.1	6.3
Morocco		10.5		10.5	13.7	1.72
Pakistan		17.2		17.2	105	0.366
Philippines	16.2	29.3		45.5	33.4	3.3
Thailand		36.9		36.9	31.5	2.62
United Arab Republic		12.9	0.2	12.7	30.1	0.94
Venezuela		35.5		35.5	8.9	8.9

The corresponding figures for the United States are 59 pounds per person; the EEC countries, 47 pounds per person; and the United Kingdom and Japan about 40 pounds per person. These figures for 1966 appeared in an article by the author in the Financial Times of London, 19 June 1967, page 15.

Table 3 compares plastics consumption with national income; plastics are valued at $500 per ton on the average. The final column of the table gives the ratio of the value of plastics consumption (x 1,000) to national income. Only certain countries have been included because of the difficulty of getting reliable statistics.

Table 3

Relation of plastics consumption to national income

	National income in 1966 (billion dollars) (a)	Value of plastics consumed (million dollars) (b)	Ratio b to a $\frac{b \times 1{,}000}{a}$
Argentina	16.3	36.4	2.22
Brasil	42.4	35.3	0.84
China (Taiwan)	2.53	35.8	14.2
India	32.1	27.65	0.87
Iran	5.42	11.7	2.16
Japan	53	882	16.6
Lebanon	0.87	6.85	7.85
Mexico	19.7	62.05	3.15
Morocco	2.37	5.25	2.22
Pakistan	11.7	8.6	0.73
Philippines	4.91	22.7	4.7
Thailand	3.78	18.4	4.9
United Kingdom	76	488	6.41
United States	621	2,590	4.16
Zambia	0.78	0.9	1.15

Table 3 suggests that countries less well endowed with natural resources, whether they have a large national income or not tend to use a larger proportion of plastics.

Distribution of consumption among products

Forecasts of production of the major thermoplastics are difficult to make. For a rapidly growing product, consumption tends to lag behind production owing to the need to increase stocks. However, it is probably reasonable to assume a world consumption of 95 million tons by 1980 (table 4).

Table 4

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
Miscellaneous and new materials	3

Production in developing countries

Table 5 shows the raw materials required for the principal plastics and sources from which they are obtained.

Table 5

Raw materials for the principal resins and plastic polymers

Resin or plastic polymer	Secondary raw material	Basic raw material
Polyethylene	-	Ethylene
Polypropylene	-	Propylene
Polyvinyl chloride	Vinyl chloride	Ethylene
		Chlorine
Polystyrene	Styrene	Ethylene
		Benzene
Nylon 6	Caprolactam	Benzene
		Propylene
		Ammonia
Nylon 66	Adipic acid	Benzene
	Hexamethylene diamine	Ammonia
Polymethyl methacrylate	Acetone	Propylene
	Hydrogen cyanide	Methane
		Ammonia
Saturated polyesters	Terephthalic acid	Para-xylene
	Ethylene glycol	Ethylene
Unsaturated polyesters	Phthalic anhydride	Ortho-xylene
	Maleic anhydride	Benzene
	Propylene glycol	Propylene
	Styrene	Ethylene
		Benzene
Polyvinyl acetate	Vinyl acetate	Ethylene
		Acetic acid
Polyacrylates	Alkyl acrylate	Propylene
		Appropriate alcohol
ABS	Styrene	Benzene
		Ethylene
	Butadiene	-
	Acrylonitrile	Propylene
		Ammonia
Cellulose acetate	-	Cotton linters
		Acetic acid
Phenol-formaldehyde resins	Phenol	Benzene
		Propylene
	Formaldehyde	Methyl alcohol
Urea-formaldehyde resins	Urea	Ammonia
	Formaldehyde	Methyl alcohol
Melamine-formaldehyde resins	Melamine	Ammonia
	Formaldehyde	Methyl alcohol
Polyurethanes	Polyols	Propylene
	Isocyanates	Toluene
		Ammonia
		Carbon monoxide
		Chlorine

It is remarkable how the whole range of plastics can be prepared from so few base materials. Table 6 lists these materials with their methods of production.

Table 6

Production methods for the base materials of plastics

Plastics base material	Method of production
Ethylene Propylene Butadiene	Steam cracking of naphtha or natural gas containing substantial proportions of C_2 and above
Benzene Toluene Ortho-xylene Para-xylene	Catalytic reforming of special naphtha fraction, followed by solvent extraction and, if necessary, dealkylation
Methane	Natural gas
Ammonia Methyl alcohol	Steam reforming of oil fraction, particularly naphtha, to give synthesis gas followed by the appropriate catalytic reaction.
Carbon monoxide	By-product in many processes
Chlorine	Electrolysis of brine
Acetic acid	Oxidation of naphtha

To be viable, these base materials, except methane and carbon monoxide, must be produced on a very substantial scale. Further, the co-products of the first two reactions require a planned disposal of all of them, unco-ordinated demand again greatly raising the price. For example, the carbonisation of coal for the production of metallurgical coke produces limited quantities of by-products such as benzene, toluene, xylenes, phenol and ammonia.

In countries where electricity is cheap and brine is available, chlorine and caustic soda would probably be produced for other chemical purposes. If coal is available, the cheap electricity may be used to make calcium carbide and hence acetylene, which will react with hydrogen chloride to produce vinyl chloride, the monomer of PVC.

A certain amount of aromatics, e.g. benzene, toluene and xylenes, can be extracted from the liquid phase in the steam cracking of naphtha, depending on the condition of the operation.

There are four stages in the production of plastics:

(1) The production of the primary chemicals from the oil feedstock;

(2) The production of the secondary chemical or chemical that is to be the subject of polymerization or condensation process;

(3) The polymerization or condensation stage to give the primary polymer;

(4) The compounding or colouration of the polymer, in some cases the product of bulk sheet or tubing, to give the raw material from which the plastic product or article is made.

As indicated in table 5, not all stages are necessarily present in every plastic material.

Normally a developing country wishing to start plastics production should not attempt stage one unless a major petrochemical industry producing a wide range of chemicals is proposed. It would be unwise to envisage an ethylene cracker or any ammonia plant with a capacity of less than 100,000 tons per year. Ammonia is far more likely to be viable because of home-produced nitrogen fertiliser.

Stage two usually requires heavy capital investment, and only in special circumstances can it be recommended. Some countries, notably Australia, have gone ahead with major chemical projects and protected the output by high tariffs. Presumably this protection is intended to be only temporary, but a developing country adopting this course might find the need for protection anything but temporary and would as a result invite retaliation. The mere admission of the necessity for such protection implies that home production cannot compete with world prices and the country's population pays more than the world market price for the products.

Stage three is more controversial. The production of polyolefins (there is no stage two here) would never be recommended, since the raw material is a gas and relatively expensive to transport, although great progress is being made in this field. As mentioned earlier, the process is capital-intensive.

On the other hand, the production of phenol formaldehyde or urea-formaldehyde resins can be effected using relatively simple equipment and is far more labour-intensive. Nevertheless, production requires knowledge of the correct formulations and considerable skill, and such operations should never be attempted with untrained staff.

A developing country wishing to start a plastics industry might reasonably begin with stage four. Importing the uncoloured polymer, colouring it, plasticizing it or adding the filler are not by any means simple processes; they need considerable knowledge and skill but they can be carried out with relatively simple equipment using a batch process. Extruded sheet or tube or blow moulded lay flat tubing are processes that can be carried out on unit equipment of modest capacity, and, if the technical skills are available, at a competitive cost. In the United Kingdom, there are hundreds of small moulders carrying out these and similar operations at a profit.

The following appendix lists petrochemical plants in some developing countries. Many of these plants were planned some years ago when the importance of bulk production was not fully appreciated, and they are now too small to compete with the production of the major industrial countries. Developing countries must decide whether to build major plants or to import and concentrate on plasticizing, tinting and working up as mentioned in stage four.

Appendix

The most recent information available on the production of ethylene and the principal thermoplastics in certain developing countries is listed below. However, many of the sources of information contradict each other, as it is difficult to determine whether some of the plants are actually under construction or are awaiting financing or approval from the Government.

Poland

An ethylene cracker is in operation at Blachownia with a capacity of 65,000 tons per year and another plant at Plock is due on stream in 1969 with a similar capacity.

There is substantial production of thermosetting resins in Poland: 25,000-30,000 tons per year of phenolic, 30,000-40,000 tons per year of amino resins; alkyds and unsaturated polyesters are made in substantial quantities. A 24,000 tons-per-year high-pressure polyethylene plant is in operation at Blachownia (Polymex); a small 5,000 tons-per-year polystyrene plant is in operation at Oswiecim and is being expanded. There is considerable production of PVC: a major plant with a capacity of 30,000-40,000 tons per year at Oswiecim and a 40,000-tons-per-year plant at Tarnow based on acetylene from natural gas.

There are reports of a large plant at Pulawy (Lublin) making vinyl chloride from acetylene produced from natural gas, but there is some doubt whether this plant is actually on stream.

Romania

One ethylene plant with a capacity of 35,000 tons per year is now being enlarged. A 24,000 tons-per-year polyethylene plant is on stream at Ploesti, and another large plant with a capacity of 60,000 tons per year is under construction at Piteşti and is due on stream shortly. A small polystyrene plant with a capacity of 3,000 tons per year is on stream at Gheorghe-Gheorghui Dej; other plants are planned or under construction. A 40,000 tons-per-year PVC plant on stream at Rimnicu Vilcea appears to get ethylene from Pitesti; small plants are also located at Turda and Tirnaveni.

Yugoslavia

Organsko Kemijska Ind. produces 50,000 tons per year of ethylene by naphtha cracking at Zagreb; polyethylene and polystyrene are also produced.

Argentina

Petroquímica Argentina S.A. (PASA), Ipako and Duperial all have small ethylene plants with a combined annual capacity of about 40,000-45,000 tons; substantial expansion of the last two is planned. In plastics, Koppers has a plant producing some 11,000 tons per year of polyethylene, while Industries Químicas Argentinas Duperial S.A. (IQAD) (ICI's subsidiary) is constructing a 14,000 tons-per-year plant. Duperial produces 15,000 tons per year and is expanding; PASA is building a 20,000 tons-per-year plant. Monsanto's Argentine subsidiary has been producing PVC at a 4,500 tons-per-year plant but plans to sell to private interests; it also produces 6,500 tons of polystyrene yearly and a similar quantity is produced by Ipako. There are many plants producing thermosetting resins from locally produced phenol, urea and formaldehyde.

Brazil

There is a naphtha cracker at Cubatao with a capacity of 35,000 tons per year of ethylene. Petrobrás, the state-owned refinery, produces streams that are converted to chemicals. Union Carbide and Petrochlor have a joint venture making polyethylene (30,000 tons per year with a large expansion in view). Polystyrene is produced by Koppers, with a capacity of 8,500 tons per year, and by Bakol S.A. (Hüls), with a capacity of 7,000 tons per year. PVC is made by Eletrochloro, with a capacity of 25,000 tons and by Geon do Brasil, with a yearly capacity of 20,000 tons. Some ethylene and other chemicals are still produced from the fermentation of cane sugar; in fact, a small amount of polyethylene is produced from such raw material.

Chile

ENAP has a 30,000 tons-per-year ethylene plant under construction at Concepción. A small quantity of polyvinyl acetate is made; numerous thermosetting resins are made from coke-oven chemicals in modest quantities. It is understood that plants for producing polyethylene and PVC with foreign aid are under consideration.

Colombia

Numerous plants have been announced, but it is doubtful whether very many are on stream other than ammonia and urea plants. Ecopetrol has a 20,000 tons-per-year ethylene plant based on crude oil. There is appreciable production of phenol-, urea- and melamine-formaldehyde resins. Dow has a small polystyrene plant with a capacity of 3,000-4,000 tons per year, and there are two small plants making PVC each with a capacity of about 3,000 tons per year.

Mexico

Pemex, owned by the Government of Mexico, has a capacity of some 50,000 tons per year of ethylene, with major expansion under construction and possibly on stream. The Government also owns a 24,000 tons-per-year polyethylene plant, and another major expansion is planned. BASF Mexicana S.A. produces up to 10,000 tons per year of polystyrene; Prodesa (40 per cent Sinclair-Koppers) is planning to set up a plant. About 20,000 tons per year of PVC are produced by several small producers: Geon de México, 7,500; Henkel, 2,500; Monsanto, 10,000; Plásticos Omega, 3,500; and Promociones Industriales Mexicana S.A., 10,000.

Venezuela

Instituto Venezolano de Petroquímica (IVP) has an ethylene cracker (from propane) under construction, but it is unlikely this will be on stream for some time. Many plants, e.g. PVC, polyethylene, polystyrene, are in the planning stage.

The other South American countries produce negligible quantities of petrochemical or plastics raw materials.

China (mainland)

Information from China is scanty and somewhat confusing. There seems to be little if any real petrochemical production; most chemicals and plastics are based on coke-oven gas, coal tar or are from acetylene via carbide; capacity for the latter is 300,000 tons per year. Benzene is made by trimerising acetylene; there is also production of chemicals using fermentation processes.

Ammonia is produced by several plants with a combined capacity of some 200,000 tons per year; other plants are under construction. Chlorine production in 1967 was said to be 500,000 tons per year, while plastics production is 1966 was given as 60,000-70,000 tons per year.

A Simon Carves plant based on ICI know-how at Lanchu is capable of producing polyethylene and a little polypropylene. There are 10,000 tons per year of unsaturated polyesters made on the basis of know-how supplied by Scott Bader. About 100,000 tons per year of PVC are produced.

China (Taiwan)

The Chinese Petroleum Corporation has a 35,000 tons-per-year naphtha cracking plant for producing ethylene. Fertilisers are produced by several companies. The Taiwan Polymer Corporation (National Distillers USA) has a 35,000 tons-per-year polyethylene plant on stream. PVC is made by Cathay Plastics (10,000 tons per year), Chinese Plastics Corporation (several thousand tons) and Formosa Plastics (30,000 tons per year). Tai Ta Chemical Company (Mobil interest) produces polystyrene on a small scale.

India

India has many chemical complexes that make plastics. The following information, although incomplete, mentions some of the most important operations.

PVC is made by the Delhi Cloth Mills, with a capacity of 12,000 tons per year; Calico Mills, with a capacity of 4,000 tons per year; and Chemicals and Plastics Limited, (India) with a capacity of 6,000 tons per year. Allied Resins and Chemical PVT Limited makes phenol-formaldehyde resins etc. at Calcutta. Indian Plastics Limited and the Indian Resins Manufacturing Company both make synthetic resins at Bombay. Rajasthan Vinyl and Chemical Industries makes calcium carbide, caustic soda and apparently also PVC (from acetylene). Synthetic Chemicals Limited of Bombay (Firestone participation) produces synthetic rubbers, styrene monomer, ethylbenzene, toluene, acetaldehyde and butadiene. Union Carbide India Limited at Calcutta produces ethylene from naphtha cracking, while it is understood that the Government of India has a similar plant but it is not yet on stream. National Organic Chemical Industries Limited (NOCIL) has a 60,000 tons-per-year ethylene cracker on stream from which various chemicals are made, and a PVC plant is under construction. Ethylene is also supplied to an associated company, Polyolefin Productions Limited, which makes polyethylene. Polychem (Dow participation) produces some 10,000 tons per year of polystyrene.

Indonesia

Although there is ample refinery capacity, the only petrochemical production is ammonia and urea at Paelenbang, Sumatra.

Iran

The State Authority National Petrochemical Company has a 25,000 tons-per-year ethylene plant on stream and major increases are planned. A new petrochemical complex is being set up at Abadan, where propane will be cracked to give ethylene for vinyl chloride; a 20,000 tons-per-year PVC plant is expected on stream this year.

Iraq

No petrochemical plants exist at present even though substantial raw materials are available.

Israel

Electrochemical Industries Limited produces PVC resins. Israel Petrochemical Enterprises Limited produces ethylene and polyethylene. Mayer Enterprises Limited produces polyvinyl acetate, polyethylene and polyurethane foam.

Kuwait

Petrochemical Industries Company is constructing a plant to make fertilisers.

Lebanon

Esso is understood to be building a fertiliser plant.

Malaysia

The Chemical Company of Malaysia Limited (ICI participation) is building chlorine and fertiliser plants at Port Swettenham, while Esso Standard Malaya Limited is building an ammonia plant at Port Dickson.

Pakistan

Ammonia and urea based on synthesis gas from natural gas are in operation at Multan, West Pakistan, and Fenchuganj, East Pakistan. The combined capacity is 110,000 tons of nitrogen per year. Any plans for producing ethylene appear to be based on the dehydration of ethyl alcohol obtained through fermentation processes. Valika Chemical Industries has a 5,000 tons-per-year polystyrene plant.

Philippines

No petrochemical plants exist, although Esso is planning to construct a 10,000 tons-per-year ammonia plant near its refinery, and Mardinuque Iron Mines is planning a 33,000-tons-per-year ammonia plant at Mindanao based on partial oxidation of fuel oil.

Thailand

No petrochemical industry exists.

Algeria

No petrochemical industry exists.

Kenya

No petrochemical industry exists.

Morocco

No petrochemical industry exists.

Tunisia

It is believed that the Government has approved plans for an ammonia plant.

Uganda

No petrochemical industry exists.

United Arab Republic

Fertilizers and chlorine are produced but petrochemical interests are negligible.

8. RADIATION PROCESSING IN THE PLASTICS INDUSTRY

Hong-Chien Yuan

Introduction

Radiation processing has been emerging as a production tool in the plastics industry. Its applications involve polymerization, graft copolymerisation, curing and modifications of polymers. New products such as wood-plastic combinations (WPC) have been manufactured commercially. This paper reviews the current status of radiation processing and its impact on plastics manufacture.

The radiation sources refer to both radioisotopes and particle accelerators. In the former category, cobalt-60, which emits electromagnetic radiation known as gamma rays, is the most commonly used source because of its availability and reliability. Caesium-137, which is obtained from the fission products in nuclear power generation, may also be considered a suitable gamma source.

	Cobalt-60	Caesium-137
Half-life (yr)	4.6	30 ± 3
Energy (MeV)	1.33,1.17	0.548
Price/Ci (dollars)	0.50	0.20[1]

The radiation from gamma sources possesses deep penetrating power and therefore is suitable for the treatment of thick objects as well as for chemical synthesis. The merits of cobalt-60 and caesium-137 are: (a) low maintenance; (b) low cost for replenishment; and (c) dependable and reproducible energy output. Their performances have been proved in the sterilisation of medical products, the irradiation of grain and synthesis of ethyl bromide. For the time being, all WPC manufacturers use cobalt-60 as the radiation source.

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[1] Price structure not firm at present.

Accelerators are mainly electron-beam accelerators of 0.5-3 MeV. They can provide high dose rate and sufficient scanning speed of electron beams and are particularly suitable for the continuous treatment of thin sheets of plastics, textiles and surface coatings.

The radiation source provides the energy necessary to initiate chemical reaction in a given system, but its selection depends very much on the purpose and materials to be treated. The geometry of the source and the objects should be arranged so as to permit uniformity of dose and to suit the characteristic feature in the polymerization.

In comparison with conventional catalyst-initiated polymerization systems, radiation-induced polymerization takes place without the fear of catalyst residues in the polymer. The products may show superior electrical properties and thermal stability. Some polymerization reactions can be initiated with the aid of radiation, while with ordinary catalysts they fail to take place owing to the presence of inhibitors. For this reason, radiation processing opens a new horizon for the plastics industry.

To determine the economic feasibility of a radiation process the following points should be considered: (a) cost of source and its installation; (b) source replacement; (c) amortization; (d) installation maintenance; (e) load factor; and (f) production rate from a given input of power.

The last factor is directly related to the process. It is known that for one watt of power the number of kg/h of material produced is equivalent to 0.373×10^{-6} (G) (M), where M refers to the molecular weight of the product, and G is the number of radicals produced by 100 eV of energy. For the production of polymers through chain reactions, a G-value around 10 will be promising. Fortunately, most monomer systems have G-values high enough to warrant their exploitation in radiation processing.

It should be emphasised that the total dose requirement has a direct bearing on plant capacity - the higher the required dosage, the lower the plant output and the higher the cost of production. The selection of an optimal dose rate requires therefore that both engineering and economic factors be considered.

Wood-plastic combinations

There are three WPC manufacturers in the United States and one in France; all use methyl methacrylate. In England, Joseph Rodgers & Sons has recently planned the marketing of WPC using a mixture of styrene and acrylonitrile.

WPC manufacturers in the United States and England

Company	Year operations began	Product	Use
American Novawood Co.	1966	Gammapar	Flooring
Lockheed-Georgia Co.	1966	Lockwood	Product evaluation
Nuclear Materials and Equipment Corporation	1968	Perma Grain	Flooring
Joseph Rodgers & Sons	1968	Manhattan-99	Cutlery handles

Treated wood is superior to natural wood in the following aspects: static bending, shear hardness, dimensional stability, compressive strength, weatherability, decay resistance and abrasion resistance. Flame retardency of WPC is possible if a proper monomer is used. The machinability and nailability of WPC is no better than that of natural wood, but compared with plastics, WPC excels in most mechanical properties and has a better thermal resistance. Potential applications can be exploited in construction, furniture and special products. As evaluated by Vitro Engineering Company, the selling price of WPC using methyl methacrylate (MMA) is \$1.50 per board foot,[2] which is much higher than the price of ordinary wood (\$0.35 per board foot).

Cost reduction could be effected by the use of lower-unit-cost monomers and reduced monomer content and dosage. Product improvement should be sought through uniformity of treatment and the relationship between physical properties and end use. Since both homopolymerisation and graft polymerisation are involved in WPC manufacture, the effects of grafting on the physical properties should also be investigated.

The improvement of the quality of wood through impregnation has led to the development of a broad class of impregnated fibrous materials. Bagasse board, bamboo and jute have been treated successfully by radiation-induced polymerisation with vinyl monomers. The finished products possess good

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[2] 1 board foot = $\frac{1}{12}$ ft^3

dimensional stability, insect and fungus resistance and reinforced mechanical strength. Such treatment converts abundant low-cost fibrous stock into useful construction materials, as those for prefabricated housing. With the choice of a low-cost monomer system, the product can compete in price with natural wood. The success of such an attempt will mean a new market for monomers and, for tropical countries, inexpensive and readily assembled building materials that resist deformation and decay.

The following table shows the operating costs and the plant investment for WPC manufacture:

Estimated plant investment and operating costs for wood-plastic combinations

(Production: 2,500 lb/month, 8,000 hr/year operation or 9,000 t/yr)

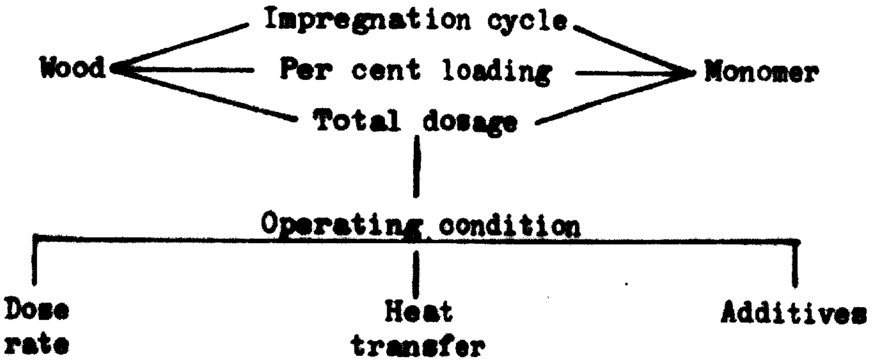
Plant investment	Dollars
Impregnator and accessories	146,000
Cobalt-60 source, 1 MCi at $0.50/Ci	500,000
Irradiator	127,000
Building and land	285,000
Plant utilities	105,000
Engineering and construction fees	244,000
Total fixed capital	1,407,000
Annual operating cost	
Depreciation	140,000
Replacement of source, 12.5% per year	63,000
Direct labour	110,000
Maintenance, operating supplies and utilities	42,000
Factory overhead	110,000
General expenses	140,000
Total cost	605,000
Cost per ton of product:	67.00

Source: A. D. Little Inc. and Vitro Engineering Company

E. Rotkirch in the Scandinavian Symposium on WPC (Helsinki, May 1968) gave the following estimates:

Plant capacity (t/yr)	Capital investment ($)	Operating cost ($/ton)
10,000	1,310,000	50.2
100,000	5,000,000	18.7

In practice, the manufacturing cost is influenced by the selection of wood species, monomer system and operating conditions. The interaction of factors can be sketched as below:



Even under the same conditions, the variation of throughput with the type of monomer and the related total dosage will effect the production cost significantly as shown in the following table based on a polymer content of 25 per cent in the product:

			Cost per kg of product ($)			
Monomer	Dosage, (Mrad)	Relative throughput	Impregnation	Irradiation	Monomer	Total
Vinyl acetate	0.5	1	0.03	0.03	0.08	0.14
Vinyl chloride	0.6	0.83	0.02	0.03	0.05	0.10
Methyl methacrylate	1.5	0.33	0.03	0.07	0.16	0.26

Graft copolymerisation

WPC is an example of monomer molecules linked to cellulose. The grafting technique has been used to improve the properties of textiles and plastic films. Recently, the Brookhaven National Laboratory has reported the research on plastic-impregnated concrete that has improved compression strength by a factor of 2.4 and reduced permeability by 98 per cent. In general, the grafting can be done by one of the following methods: (a) irradiation of polymer in the presence of a monomer; (b) pre-irradiation of polymer alone followed by grafting with a monomer; or (c) irradiation of swollen polymer-monomer systems.

A number of research activities have been reported in the use of monomer vapours. Vapour-phase copolymerisation should ease the control of the extent of grafting, and should be a successful combination with method (b) from the viewpoint of material handling. The technique, however, has not reached the stage of practical application.

There are many reports on the radiation grafting of different kinds of plastics with every conceivable monomer. The major effort is to alter the characteristics of the polymer in desired directions. Polyethylene films can be modified to improve scuff resistance, printability, adhesion and permeability. In textiles, grafting improves the soil release and crease resistance of polyester-cotton blends. Using accelerators, both Deering Milliken Inc. and Burlington Industries commercialize the treatment of fabrics with suitable vinyl monomers. Other improvements have been sought including better washability, dye retention, and antistatic properties.

Curing of unsaturated polyesters

Electron-beam curing of styrene-polyester resins has been on the threshold of commercial success. The advantages over conventional practice are: (a) instantaneous curing in air at ambient temperature; (b) simplification of handling and storage of polyester because no catalyst is required; (c) less floor space required for continuous processing; and (d) continuous coating of polyester on heat-sensitive substrates without damage to the base materials.

Coating equipment is available to treat boards 4 feet wide at speeds of up to 100 linear feet per minute. Several major paint companies have produced paint formulations that cure to an excellent finish using a small dose of radiation. The new curing method will open up new fields of polyester paints that do not require a solvent in application. Up to now the main objections to the use of polyester paints have been their difficulty in curing, their limited shelf-life and the lack of assurance of obtaining tack-free surfaces. Radiation curing will eliminate these problems. Another group of coatings based on acrylics has also been developed successfully for marketing.

With powerful accelerators in the range of 1.5-3 MeV, it is possible to cure fibre-glass reinforced wet-lay-up laminates, prepregs and even moulding compounds. The radiation-cured materials can compete with hot-press cured materials in mechanical properties as well as cost. With a total dose of 5 Mrad, the cost based on semi-commercial production is about four cents per kilogram of the product. More engineering effort in the development of accelerators is necessary to permit the curing of objects with complicated geometrical shapes.

Modification of polymer structures

The direct modification of the structure of polymers should be regarded as the earliest commercial application of radiation. The General Electric Company introduced irradiated polyethylene tape more than a decade ago. Cryovac L, a food-wrapping material from the W. R. Grace Company, is produced by irradiation of polyethylene film. Several companies have irradiated polyethylene insulations used in wire and cable coverings. Both the Toyo Rayon Company and the Sekisui Chemical Company in Japan have succeeded in manufacturing foamed polyethylene through radiation-induced cross-linking of the polymer in the presence of a blowing agent. Some heat-shrinkable polyethylene tubing, bags and films are also being produced by the Sumitomo Company. Irradiated polyethylene shows a higher tensile strength, better resistance to solvents, heat and aging. As an insulating material it is almost immune to stress cracking, which has been a major defect of ordinary polyethylene in wire and cable covering.

It has been revealed recently that the Union Carbide Corporation plans to install 100,000 curies of cobalt-60 to alter the molecular weight and the viscosity of polyethylene oxide. Another interesting application is shown in the cross-linking of natural rubber latex irradiated with 13 Mrad to form films with excellent mechanical properties.

Even though excessive irradiation causes the breakdown or deterioration of polymeric materials, it is safe to assert on the basis of the success of irradiated polyethylene that a suitable dosage, in the range of 4-40 Mrad, will favourably modify the properties of polymers. The modification is usually achieved by the post-irradiation of manufactured goods. Radiation energy emitted from accelerators initiates the formation of free radicals, and these radicals on recombination lead to cross-linking. Such treatment may introduce some special applications in the plastics industry, particularly in improving the thermal and solvent resistance of thermoplastics.

Conclusions

In the search for a new technology for the plastics industry, radiation processing has a promising future. From their initial successes in the chemical industry, plastics processing and the sterilisation of medical products, radiation processing plants are safe and easy to operate. More engineering and technological development programmes are underway in advanced countries to refine the scale-up of processes and to lower the investment cost of new plants.

In the promotion of a sophisticated technology, the situation in developing countries is in general somewhat different from that of advanced countries; some factors are common to both but more pronounced in developing countries. There is an unavoidable lapse of time from concept to full-scale production, and much time and effort are usually needed to adapt technology to the local environment in developing countries. The situation is more critical because of the lack of well-trained engineers and technical people to carry on a programme. To be successful, a project always calls for a broad spectrum of activities from process development to product evaluation. Radiation processing is not an exception and requires more effort to remove fears and doubts. Even in the United States it took four years to end the controversy over WPC and to open the way for its commercial use.

The contributions of radiation processing in cross-linking of polyethylene, in curing of polyester resins and in impregnated fibrous materials are within the reach of developing countries. The success of the attempt will depend on the enthusiasm of the countries concerned and on a sound development scheme that includes training and demonstration. In view of the limited resources in these countries, the endeavour of international organisations may provide the necessary technical assistance and promote regional co-operation to facilitate the implementation. A suggested outline for the development of radiation processing of impregnated fibreboard in developing countries is given below.

1. <u>Training programme</u>
   - (a) Radiation chemistry - polymerisation and dosimetry;
   - (b) Radiation engineering - design, systems control and project evaluation;
   - (c) Materials testing of panel boards;
   - (d) Product evaluations - prefabricated housing.

2. <u>Demonstration project - pilot-plant studies</u>
   - (a) To provide data for future engineering scale-up;
   - (b) To demonstrate the feasibility and economics of impregnated fibreboard as commercial product;
   - (c) To develop and to test prefabricated houses from irradiated boards.

It is hoped that the demonstration project will present enough evidence to clarify the concepts of potential entrepreneurs and to convince the end users of the value of the product.

9. PROBLEMS AND EXPERIENCES IN TECHNICAL ASSISTANCE IN PETROCHEMICALS AND PLASTICS IN DEVELOPING COUNTRIES

Jaromir Skarka

The development of the chemical and petrochemical industry in Czechoslovakia

Before the Second World War, the chemical industry occupied an important place in the economy of Czechoslovakia. After the war, the industry rapidly expanded, and in the last twenty years production has increased sevenfold.

The greatest expansion has taken place in crude oil refining and in petrochemistry. Czechoslovakia had only five small refineries before the war, but a large chemical factory was built during the war at Záluži in northern Bohemia, to produce fuels by carbonisation of lignite and hydrogenation of tars. In the second decade after the war, Slovnaft, a large-capacity refinery, was built in Slovakia when crude oil began to be imported on a large scale. These two refineries produce fuels and lubricants.

The older factory at Záluži has gradually reduced fuel production from lignite and is being converted to a high-capacity refinery to produce fuels from crude oil. These refineries have recently increased their capacities for producing various petrochemicals; both factories produce ethylene from refinery gases and straight-run naphtha. The petrochemical complex at Záluži produces synthetic alcohol by direct hydration of ethylene, and ethylbenzene by alkylation of benzene. These intermediates are used to produce synthetic rubber in a new factory in middle Bohemia. From propylene, higher alcohols for plasticisers will be produced by oxosynthesis.

The Slovnaft refinery produces mostly plastics such as high-pressure polyethylene, polypropylene and the intermediates for phenol, glycols, dimethyl terephthalate (DMT), and other fibres. Soon after the war, units were built to produce caprolactam, PVC and polyvinyl acetate, acetylene and methanol, formaldehyde, ammonia and several nitrogen fertilizers. Some of these were based initially on sources other than petroleum. In later stages of development they were converted to a petrochemical basis. Future projects will continue in typical petrochemical units based on ethylene and propylene. Both factories mentioned above use petrochemical processes based on ethylene and propylene, but new ethylene units are being designed. They will produce mostly plastics and intermediates for fibres and rubber production and other chemicals.

The chemical industry in Czechoslovakia was built mainly by Czechoslovak know-how and engineering and with processes, machinery and equipment originating in the country. This applies to all branches of chemistry, including nuclear chemistry, crude oil refining, organic and inorganic technologies, fertilizers, synthetic rubber and plastics, coal-tar refining and pharmaceuticals. In the petrochemical industry the pyrolysis of hydrocarbons was developed, as were gas separation, the extraction of aromatics, synthetic alcohol, ethylbenzene, phenol, formaldehyde, methanol, caprolactam, PVC, ammonia and nitrogen fertilizers. Some new technologies were brought from abroad. For example, one complex has been established that includes the following processes: gas separation, extraction of aromatics, para-xylene, high-pressure polyethylene, ethylene oxide and oxosynthesis.

The engineering for most of the new plants built after the war was done by Chemoprojekt, an engineering organization founded in 1950. The engineering activity of Chemoprojekt is based on the results of research and development, on experience and evaluation of existing commercial units, on licensed processes from abroad, and on direct co-operation with foreign engineering companies.

The main advantage of Chemoprojekt is that it concerns itself with all fields of the chemical industry. Complete engineering service is provided for its customers. Elaboration of feasibility studies, surveys, preparation of tenders, consulting and designing services, field engineering and supervision of start-up operations, technical assessment of existing processes by testing and measuring methods, designs of individual chemical processes and auxiliary facilities are carried out by Chemoprojekt engineers and technical staff.

The machinery and equipment are produced by the leading Czechoslovak manufacturers: chemical equipment, by Škoda or Královopolská - united as CHEPOS, or by Vitkovice steel; turbo and reciprocating compressors and blowers, by Českomoravská Kolben Danék (ČKD); pumps, by Sigma; steam turbines and boilers, by I. Brnó; instrumentation, by Závody Průmyslové Automatisace (ZPA); and

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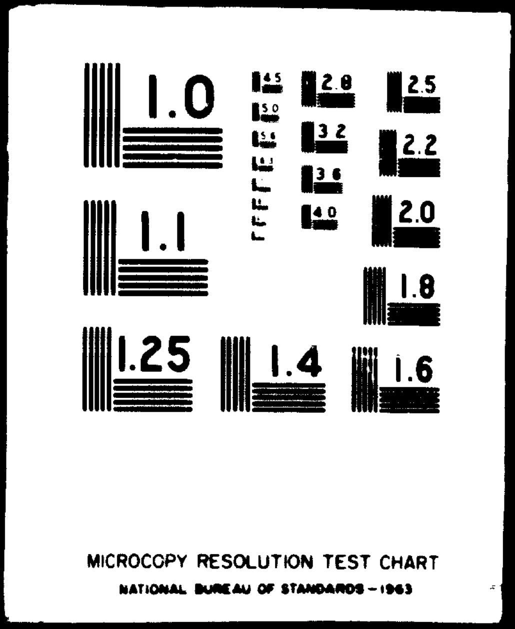
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963

electric motors and equipment, by ČKD, Elektrotechnické Závody (EZ) and other companies.

The petrochemical industry in developing countries

In some developing countries conditions are exceptionally favourable for the growth of the petrochemical and plastics industries. The following table shows the amount of natural gas produced from crude oil in Arab countries in 1965, the amount of gas used and the percentage flared. The data are given in billions of cubic feet per year.

Natural gas produced in Arab countries, 1965

	Billion ft^3 per year			Per cent
Country	Produced	Used	Flared	Flared
Abu Dhabi (Trucial Oman)	50	n.a.	50	100
Algeria	140	66	74	53
Bahrain	10	n.a.	n.a.	n.a.
Iraq	187	19	168	90
Kuwait	398	68	330	83
Libya	304	0	304	100
Neutral Zone	65	n.a	n.a.	n.a
Qatar	90	27	63	70
Saudi Arabia	379	109	270	71
United Arab Republic	n.a	n.a	n.a	n.a
	1,623	289	1,259	81

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n.a. = information not available.

Of the 1,623 billion cubic feet of natural gas produced in 1965, it will be seen that the amount of gas destroyed by flaring represents 81 per cent of the total. These burnt hydrocarbon gases represent an ideal petrochemical raw material; however, it is difficult to find use for refinery products such as straight-run naphtha or LPG. In the refineries of Iraq surpluses of approximately 150,000 to 200,000 tons per year of straight-run naphtha and from 50,000 to 75,000 tons per year of LPG are expected. have been operating uneconomically for a long time.

In Iran, the export of refinery products in 1964 and 1965 amounted to an average of 69.5 per cent of annual production. The export of gasoline was 78 per cent and fuel oils as much as 82 per cent. These figures illustrate the existence of a very large petrochemical raw material basis in the Middle East.

Sixty per cent of the cultivated land of the world is located in the developing countries of Asia, Africa and South America, yet these countries consume only 20 per cent of the world production of fertilizers. In view of the great need for fertilizers, plastics and other products, considerable pressure exists for the establishment of petrochemical industries in countries that have a favourable raw material basis.

There are many obstacles to the establishment of petrochemical industries in these countries, the major obstacle being their low level of economic development. The meagre financial reserves of developing countries must be shared among all sectors of the economy. Marketing of products is a problem in many developing countries because of their sparse populations. Difficulties arise in obtaining process know-how and licences owned by chemical and engineering companies in developed countries. The shortage of experienced technicians and skilled personnel is a common problem.

United Nations assistance to developing countries

With the help of experts provided by United Nations organizations, regions with favourable conditions should be encouraged to establish a petrochemical industry. In petrochemistry, feasibility studies are relatively difficult because the problems involved, such as co-ordination of marketing, are complex. Such studies are necessary, however, if economic capacities capable of competition with large units in developed countries are to be attained. For example, in developed countries units producing ethylene have capacities that reach 500,000 tons per year, while in developing countries capacities of 50,000-100,000 tons per year of ethylene are an acceptable maximum. Feasibility studies should be prepared in several stages, since the task is complicated and investment costs are very high.

United Nations assistance to developing countries should also be directed towards the establishment of research and development centres for petroleum, petrochemistry and plastics. Such centres do not exist in most developing countries. Instruction at the university level in these fields is also lacking.

Technical assistance from Czechoslovakia to developing countries

The manufacture of chemical equipment and machinery has a long tradition in Czechoslovakia, and the engineering corporation Chemoprojekt has gained broad experience since its founding. It was logical, then, that Czech engineering activities should expand into the international sphere. The first Czechoslovak international undertaking in the field of engineering was a large one - the construction of a petroleum refinery at Homs, Syria, based on crude oil from Iraq. This was the first turn-key job that included know-how engineering, delivery of equipment, construction, commissioning and technical help.

In spite of strong competition from other engineering companies, Chemoprojekt was awarded the contract in March 1957. Complete delivery time was set at 27 months; work started in September 1957.

Inevitably, many difficulties arose in carrying out the first turn-key job for a foreign country. Some were due to different standards and lack of experience in construction in a country with a totally different climate. When the contract was signed, the building site had not been definitely selected. This meant that no precise data on soil conditions could be given to the civil engineers on time; climatic data were also not complete. It was discovered that the water from the Oronto river that had been analysed was not representative, so that the demineralization process for the power station had to be changed during the design period. Other difficulties were encountered in choosing a civil engineering subcontractor capable of finishing the work on schedule and with the prescribed quality of workmanship. On the Czech side, certain problems arose in connexion with the delivery of equipment.

In spite of all these difficulties the Homs refinery was completed successfully, and the success of this first endeavour led to another contract for Czechoslovakia for carrying out the second stage of the project, which will more than double the capacity of the refinery.

While the Homs refinery was being constructed, two contracts were signed under the terms of which Czechoslovakia was to provide engineering know-how and to deliver equipment for the construction of distillation units in the refineries at Suez and Alexandria. Both units have been operating successfully for a long time.

Construction of a new crude oil refinery in Iraq began to be a pressing matter in 1961. Several groups worked in Iraq and in Czechoslovakia on a feasibility study that took into account local conditions and marketing prospects. Sites in the neighbourhood of Basrah were considered. At the same time, the possibilities for establishing a petrochemical complex based on the unlimited raw material sources in Basrah, Daura and the Kirkuk area were studied. Construction of the refinery at Basrah was postponed because of the enlargement of the Daura refinery, but the tendering procedure for the new Basrah refinery is now under way again.

On the basis of a recent agreement, Chemoprojekt prepared a feasibility study for a tire plant and carbon black production in Iraq. The study considered various locations for the tire plant. Marketing studies revealed several special problems relating to capacity. It was found that many countries were planning tire plants too small to achieve economies of scale. Another problem was to determine the optimal capacity of a carbon black plant. Domestic use of carbon black would not exceed 20 per cent of the capacity considered economic; exports would have to account for 70 to 80 per cent of capacity.

Czechoslovakia has been requested to send experts to assist other countries to establish petrochemical industries. In 1965, Czech experts examined possibilities for setting up petrochemical plants at Alexandria, United Arab Republic. The feasibility of participation in a new petrochemical complex by delivering individual process plants, utilities and other units was studied.

Further expansion of the chemical and petrochemical industry in Syria has also been studied. Chemoprojekt is in contact with other engineering companies with a view to pooling experience and capacity so that they could offer to third parties joint assistance in building individual petrochemical plants or whole complexes. This is the method of co-operative participation practiced in Yugoslavia. Co-operation on the part of engineering, manufacturing and financing companies is now a common practice when large projects are undertaken.

10. RECENT DEVELOPMENTS IN PETROCHEMICALS AND PLASTICS IN JAPAN

Hideo Adachi

The establishment of Japan's petrochemical industry

Japan was several years behind most of the other industrial countries in establishing its petrochemical industry. In 1954, a plan for developing the petrochemical industry began to take shape, and in 1955, the Ministry of International Trade and Industry (MITI) announced the plan.

Japanese industry had developed under the control and protection of the Government for more than 30 years. All petrochemical projects were subject to MITI's approval, and only 15 projects in all were approved. Four naphtha cracking centres were established and went into operation during the period 1957 to 1959.

The petrochemical plan provided for synthetic rubber manufacture. For the production of styrene-butadiene rubber (SBR), a new company, Japan Synthetic Rubber Company, was formed on the basis of joint investment of petrochemical and rubber companies and 40 per cent government participation.

The plan completed during the 1955-1959 period is called the first-stage plan. Under it Japan aimed to: (a) shift to economic petrochemical processes from conventional coal chemical, calcium carbide and fermentation processes; (b) produce petrochemical products that it had hitherto imported from Europe and the United States.

The goals of the second-stage plan (1959-1962) were to: (a) lower the production cost of petrochemicals to the international level; (b) lower prices of products from conventional processes without confusion by regulating competition between old and new products; and (c) scrap old plants based on the conventional processes. To carry out these goals, efforts were concentrated on enlarging the capacities of the four naphtha centres and making full use of their primary products. At the same time three more centres were added, with the result that by 1962, prices of major products had been cut by approximately 40 per cent.

During the two to three years following the second stage (called the third-stage plan) the three additional centres were completed; two more were added; the ethylene production unit was expanded to the limit of its capacity; and general use was made of olefins. Production increased and became economic. By 1963, the nine centres were in full operation. During the three stages ethylene production capacity increased as follows:

	Tons per year	No. of centres
1957 - 1959	80,000	4
1960 - 1961	300,000	4
1962	340,000	5
1963 - 1964	920,000	9

During a ten-year period, the petrochemical industry made remarkable strides and overcame rapidly its technical immaturity. Growth was due to favourable conditions such as the direct control and protection of the Government. Once a petrochemical project had been approved by the Government, it was given a long-term loan from the Japan Development Bank, tax exemption (corporation tax, import tax etc.) and granted special short-term amortization on the plant and equipment. Until 1962, the industry had grown within a completely closed economy and was thus protected from severe competition from Europe or America. Although the industry had no petrochemical technology, the Government introduced foreign techniques for short periods on a royalty basis, and Japanese industry rapidly mastered the imported advanced technology.

Developments since 1964

In 1962, trade was liberalized followed by liberalization of capital transactions in 1968. Japan entered the open economy lagging considerably behind American and European countries and thus found itself in a rather weak position with respect to international competition.

Consequently, since 1964, major efforts have been concentrated on increasing the scale of production to bring costs down, fully utilizing co-products to make production more economic, and attempting to improve imported technology. Aware that giant ethylene production units had begun to be installed in overseas countries a few years earlier, the Government set the ethylene production capacity for a unit at a minimum of 300,000 tons per year. MITI decided not to approve a production plan if the capacity were less than this scale, and directed that all existing plants increase their capacity to this size; smaller and less effective plants are being gradually scrapped.

Six units each with a capacity of 300,000 tons per year of ethylene are now under construction, and one unit of this size is pending; all units are scheduled for completion during 1969-1971. These, together with the other existing units, will give Japan a total ethylene capacity of at least 4.1 million tons per year by 1970.

If the eleven existing production centres each built a new 300,000-tons-per-year ethylene plant, Japan would face serious over-capacity. For new ethylene projects, investors are asked to form a group of two or three companies to co-operate in joint investment or investment by turns. This type of co-operation may be peculiar to Japan. Plant expansion is now carefully controlled parallel with demand increase, with Government and industry co-operating closely to prevent over-capacity. The ultimate objective of the plan is to make the Japanese petrochemical industry competitive internationally.

Ethylene production capacity for 1968 was 1.9 million tons, and the potential capacity for 1970 is 4.1 million tons; according to these figures Japan is second to the United States in production capacity.

The petrochemical industry of Japan faces an important problem of technology. Even if production capacity is increased so that economies of scale are attained, an imbalance between demand and actual production may result. To prevent this, manufacturing techniques should be developed for derivatives and the export of these derivatives promoted.

Another potential problem is to secure an adequate supply of naphtha to meet future demands. If 4 million tons of ethylene capacity go on stream during 1970-1971, about 20 million kilolitres of naphtha will be required. This problem is more acute in Japan than in other countries. A new technology is needed to produce ethylene from crude oil or heavy oil, or a technology that allows a petrochemical plant to process crude oil and make full use of all distillates. Such developments take time, but MITI has provided a subsidy for research and development. An ethylene production process based on crude oil is being developed, and a large pilot plant is under construction.

Developments in plastics, including synthetic rubbers and synthetic fibres

The production of thermosetting plastics has been a commercial operation for many years, and thermoplastics have made rapid strides as a result of the progress of the petrochemical industry. From 1960, when petrochemical production went on stream for the first time, to 1964, the average annual growth rate of total plastics production was 24 per cent; from 1964 to 1968, the rate increased to 35 per cent. Production in tons was: 697,000 in 1960; 1,377,000 in 1964; and 3,280,000 in 1968.

Plastics that have shown a growth rate of 50 to 60 per cent per year include low-density polyethylene, rigid polyurethane foam, polystyrene and polyamide. Polypropylene, a newcomer, is growing at the remarkable rate of 140 per cent annually; PVC has maintained a steady growth rate of 21 to 22 per cent per year for the past eight years and is expected to continue.

In world production of plastics, Japan stands second to the United States, but is ranked only fifth after the United States, the Federal Republic of Germany, the United Kingdom and France in terms of production per capita.

In the synthetic rubber field, SBR production was started by a joint venture of rubber and petrochemical companies with 40 per cent capital participation by the Government. Later, nine companies entered the production of nitrile-butadiene rubber, three entered chloroprene production and recently four entered polybutadiene rubber production. The total synthetic rubber production capacity of the twelve companies has reached 460,000 tons per year. The production in tons from these plants is: SBR, 250,000; NBR, 140,000; and polybutadiene 64,000.

Plans are under way for the production of polyisoprene rubber, epichlorohydrin rubber, ethylene-propylene rubber (EPR) and butyl rubber. For 1968, the total production of synthetic rubber was expected to be about 368,000 tons, an average annual growth rate of 50 per cent since 1964. Production capacity by 1970 is expected to reach 765,000 tons per year, with the breakdown as follows:

	Thousand tons
SBR, NBR	362
Chloroprene	54
Polybutadiene	140
Polyisoprene	50
EPR	99
Butyl	60
Total	765

In 1966, the ratio of natural rubber to synthetic rubber in the total consumption of Japan was reversed; consumption of synthetic rubber exceeded that of natural rubber by 50 per cent.

As for synthetic fibres, polyvinyl alcohol (vinylon) was developed early on the basis of carbide-acetylene as raw material. Production of nylon 6, which starts from coal-based phenol, also began early. Production of other man-made fibres started after the petrochemical industry went into operation and now almost all major synthetic fibres are produced.

The average annual growth rate for synthetic fibres has been 22 per cent since 1964, with production capacity expected to reach 720,000 tons per year by 1970. This does not include cellulose fibres such as viscose and acetate. Japan should soon be able to rank second in world synthetic fibre production after the United States. By 1967, the production of Japan had doubled that of the Federal Republic of Germany and the United Kingdom and quadrupled that of Italy and France. Production in 1967 by fibre was:

	Thousand tons
Nylon	188
Vinylon	61
Vinylidene	5
PVC	9
Acrylonitrile	126
Polyester	152
Polyethylene	12
Polypropylene	26
Total	578

Recent technological development in Japan

The acetylene industry developed early owing to an abundance of calcium carbide. Before the petrochemical industry was established, Japan produced almost all petrochemicals that are available from acetylene, including vinyl-based plastics, synthetic rubbers based on butadiene and chloroprene and vinylon synthetic fibre (created by the Japanese). Japan had no petrochemical technology in 1955 when the industry was first established but relied completely on import from overseas industrial countries. Japan is still completely dependent on foreign technology for production of ethylene, acetone, styrene, acrylonitrile, higher alcohol, and polymers such as polyethylene, polyacetal, polycarbonate, polyurethane, polybutadiene and isoprene, EPR, polyester etc. The balance of trade in technological import and export for all Japanese industry in 1967 was a ratio of ten to one.

Improvements and developments in Japan are constantly being reported. Japan, which had lagged behind the industrial countries of the world because of its long-closed economy and the Second World War, actively introduced foreign petrochemical technology and expanded production capacity rapidly to reach the world level. This means that Japan completely digested foreign technology within a very short period. And since 1964, when the petrochemical industry began to expand, improvements and development of new techniques have been reported one after another. For example, Japanese licensees are in turn offering their improved technology to their original licensors, or they are developing more effective processes than the conventional processes for which the patents have expired or are going to expire.

Technology recently exported from Japan in petrochemicals, plastics and elastomers and synthetic fibres (including materials) is summarized below.

(a) For petrochemical processes, improvement of conventional processes and to a lesser extent new techniques are being licensed to developed countries. Sponsored by the Government of Japan, research and development is under way in an attempt to discover a new ethylene production technology from crude oil.

(b) In export of technology, plastic production and fabrication techniques are the most frequent, especially the VCM processes (oxychlorination etc.) and PVC fabrication techniques. Licences have been granted to the Federal Republic of Germany, Italy, the United States and many developing countries. Recently, new processes for the production of completely modified polyethylene, polypropylene, polyester and the intermediates for polyester are under development. Some of them are licensed to the Federal Republic of Germany, Italy, the United Kingdom, the United States and countries of South East Asia.

(c) There has been some export of Japanese synthetic rubber technology. A new technique for butyl rubber production, formerly held exclusively by Esso, is now under development. Techniques for the production of EPR and epichlorohydrin rubber are also under development.

(d) Domestic technology for the production of synthetic fibres and their materials has attracted the interest of world producers. Processes for the production of caprolactam and nylon 6 are licensed most frequently; vinylon is next. Apart from the special photosynthesis of nylon, a new process for nylon is being exported to developing countries and the vinylon process to advanced countries. Industrialized countries are watching with great interest production processes such as that for high-purity terephthalic acid (TPA), the polyester fibre material; the new Bhet process[1] for polyester fibre production not *via* DMT; or direct, continuous polymer chip production.

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[1] Polyester manufacturing process, which starts from terephthalic acid and ethylene oxide *via* bishydroxy - ethyl - terephthalate. The process operates continuously and is developed by Nippon Soda Co.

(e) The production of plastics by the use of radiation is in an advanced stage of development.

In summary, technological developments in Japan have reached the level of other industrial countries, and since 1964 Japan has seen substantial results of its work in aiding the industrial growth of developing countries.

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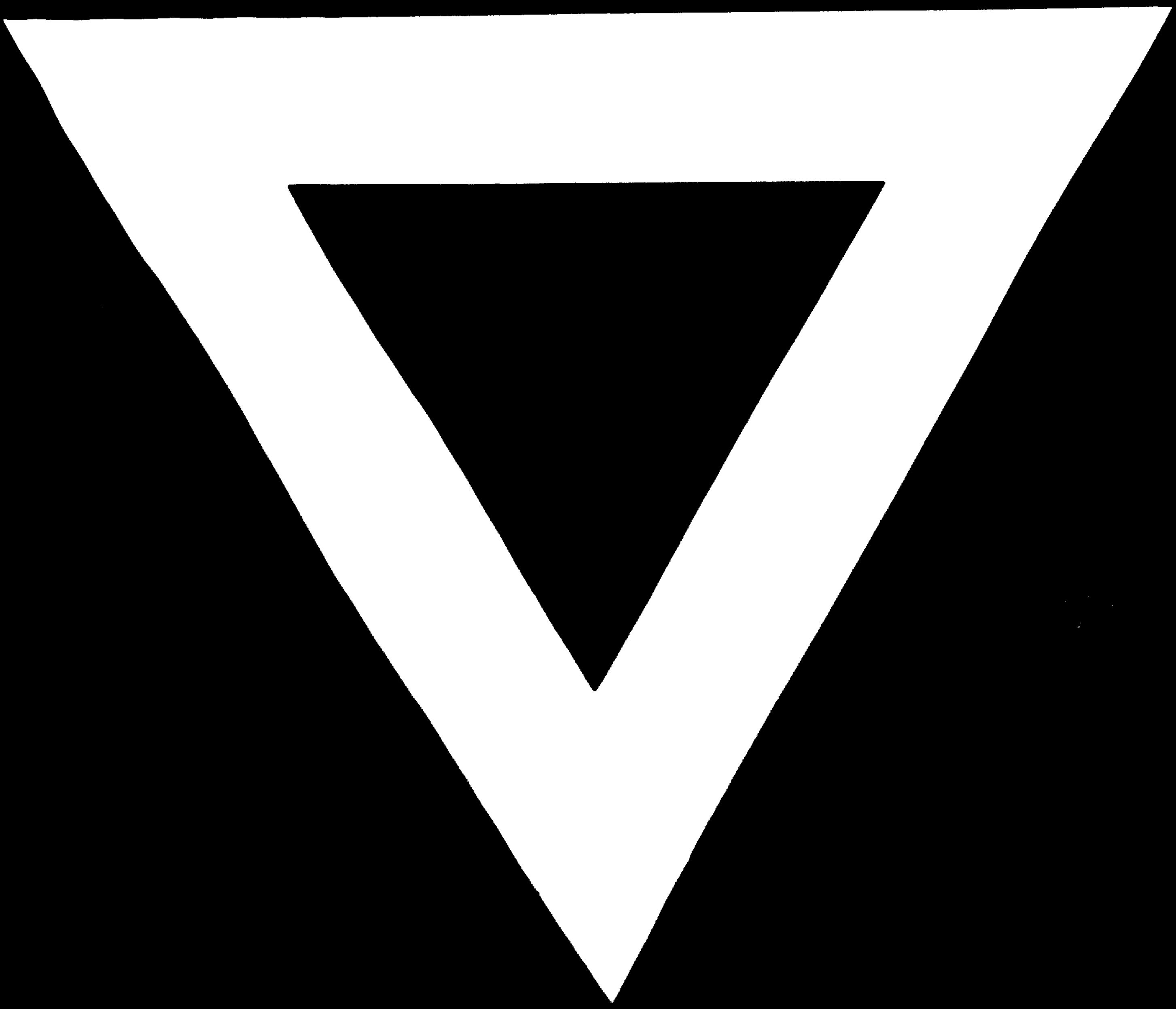

17. 9. 71