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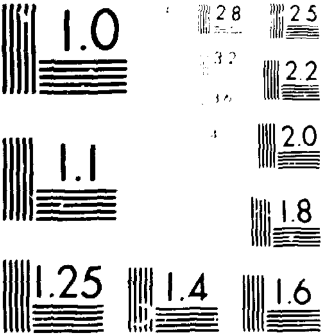

MICROCOPY RESOLUTION TEST CHART

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INTRODUCTION

In market-economy countries, technology maintains, modifies or wholly changes production systems in response to the business needs of competing corporate organizations. In mature industries, as that of petrochemicals, significant developments in technology also arise from real or perceived threats from competing industries and competing nations and groups of nations.

In the industrialised market-economy countries, the business corporation is commonly the instrument through which the relevance of diverse technological approaches is tested. Bad technology is eliminated - does not endure - if a product does not perform to its user's expectations. Realised financial benefit is usually the sole measure which both the producer and the user employ to discover relevance.

In its 70 years of existence, the 'petrochemicals' industry has successfully innovated relevant technologies to use a wide span of industrial raw materials, some associated with petroleum, such as naphtha, and others wholly unassociated with and independent of petroleum, such as calcium carbide, coaltar, biomass-based ethanol and ethane. These raw materials have been in competition with each other over various periods of time until resource limitations, technological inefficiencies or other factors gave particular raw materials or technologies an advantage.

Looking at the current scene, with the industry almost totally dependent on petroleum, one is tempted to conclude that petroleum represents the last in a succession of relevant feedstocks.

It is possible that the future might show such a conclusion to be in error. Traditionally, the chemical industry has employed feedstocks based on national and regional accessibilities rather than international availability.

Petroleum is the major feedstock, but not the only one in effective use as a petrochemical feedstock, ethane and propane are also used as feedstocks.

Petrochemicals being hydrocarbons or hydrocarbon-based have frequently benefited from technological developments related to the application of hydrocarbons as fuel - gasoline, diesel, heating oils, etc - and from other technology-related scale factors arising from such usage. Because of the great strategic significance of fuels, governments of industrialized countries have also systematically encouraged the 'stocking' of technology for emergency situations. Such technology has scope in the production of petrochemicals. Thus, perhaps more than any other industry, the hydrocarbon industry has ready options in terms of alternate technology concepts.

Three countries - the United Kingdom, the Federal Republic of Germany and the United States of America - have invented or developed most of the world's present stock of hydrocarbon technologies. Because of their traditional market economies, this technology is invested in private corporations, basically in the 'oil', 'chemical' and in some cases, 'chemical-engineering' corporations.

Till recently, a very recognizable structural feature of the hydrocarbon industry was that chemical and oil companies could be clearly distinguished by their product lines. There was also little intercorporate investment between them. Even though the industries could be using the same primary resource, natural gas or crude oil, or raw materials derived from them (as ethane), they were procured and contracted for independently. While chemical companies competed with each other for markets, there was little or no competition between chemical and oil companies. Areas of influence were delineated.

The changes that occurred in the ownership, price and supply of oil in the 1970s through the actions of OPEC has affected the stature, composure and the viability of the oil and chemical companies and confused their lines of operation. These companies who were the architects of strategies to internationalize hydrocarbon resources need now to resort to proximate resources.

If chemical companies wished to sustain their existing market positions, dramatic changes were required in technologies for utilizing resources other than petroleum. Stocked technologies were commercially untested; it might not be competitive in the international market-place where petroleum-based products could be supplied by oil-producing countries. Oil majors with national concessions, or with links to non-OPEC oil producers, could also be expected to enter petrochemicals markets which, for 20 years, had shown better profitability than those of energy. Indeed, oil companies with 'chemical arms' could readily do so. In the altered situation, survival in the period prior to new technology development meant linkage with oil firms. For the chemical companies, particularly the giants of Europe - ICI, **Hoechst,** Bayer, BASF, Rhone Poulenc - alliance meant the sharing of assiduously developed domestic and international markets.

The capability to develop dramatically new technologies has been exhibited by the petrochemicals industry. Naphtha, which is a source material for practically every organic chemical and polymer today, became subservient to wholly new technologies which were developed within a short 10-year span, **1955-1965.**Ethylene in 10 years totally replaced the role that acetylene had played for 25 years. A revolution of this type could occur again.

United States oil majors can certainly be expected to play a large role in new chemicals technology. Since 1964, they have been acquiring coal, shale and other hydrocarbon resources and redefining their business objectives. Indeed, to win high values from a barrel of oil, they invented technologies, like catalytic cracking, which were 'chemical technologies'; these technologies were put into practice long before naphtha came to be a prime chemical feedstock. They can be expected to develop similar technologies for the utilization of coal, particularly the low-cost of **United States** coal.

However, the prospect of being able to develop proficient technologies is an insufficient condition for success if coal, natural gas, shale, biomass, etc. are not accessible at the national or regional levels.

Many countries of Europe, and most certainly Japan, are poorly placed for most of these resources. It would thus be worth enquiring into the possible directions that these countries, more particularly the corporations of these countries, would follow.

While resource-short industrialized countries had certain options open to them, such as specializing in service functions, diversifying into non-chemical industries, developing specialities and **proprietary** products with high value-addition, redeploying investment in countries with feedstock security, etc., oil-deficient developing countries, with otherwise viable resources like coal, natural gas or biomass had no options unless appropriate **matched technologies were available for** their exploitation. Technologies which will become available to developing countries in the next two decades will largely be the technologies developed by industrialized countries in response to the new environment. Unless new technology was developed, or stocked technology upgraded by the industrialized countries in response to the change in resource pattern, petroleum-deficient developing countries would have to work with uncompetitive and less efficient second-class technologies. Thus, it would be in the developing countries' interest to promote technological change that will enable them to utilize their resources optically.

The objectives of this document are to identify:

(a) major developments in petrochemical technology in the advanced countries;

(b) the major factors influencing technology change;

(c) the implications of technology ownership in relation to the mobility and transferability of technology;the opportunities that new technologies could afford to developing countries;

(d) constraints, in access to such technology and the forms in which technology transfer can take place.

A particularly important objective is to examine what forms of action developing countries, individually or collectively, **may** be able to take to influence the evolution of technology so as to make it viable to their needs in both economic and strategic terms.

In order that central technologies and issues can be studied in some depth, a few key commodity petrochemicals and polymers were pre-selected as candidates for investigation. Inherent to the selection process was the realization that commodity petrochemicals, as ethylene or PVC are not about to be replaced; that new technologies relating to them would lie basically in developments or changes occurring in their feedstocks.

Brazil, India and Mexico have been identified as among the potential early users of emerging technology. Technology development is seen in relation to its acquisition by such countries.

For the preparation of this document a broad-based survey involving personal interviews with institutions in Western Europe, Japan and the United States (viewed as major sources of new technology) and with governmental industry agencies in Brazil and Mexico (seen as pivotal organizations influencing the reception of new technology) was considered a requirement and was undertaken.

The survey was planned on the basis of the following premises which were corroborated by its findings:-

(a) as a consequence of the rise in the price of oil and problems of supply, chemical corporations of the industrialized countries were seriously engaged in developing technologies that would minimize their dependence on oil as feedstock;

(b) emerging technologies will have significant relevance to developing country requirements in the present and following decades.

The survey was carried out in two phases, the first of which covered five countries of Europe - the United Kingdom, France, the Federal Republic of Germany, Belgium and Italy - in the period January to early March 1981, and the second, covering Japan, the United States, Mexico and Brazil between April and June 1981.

The institutions interviewed in the advanced countries were mainly major chemical and petroleum corporations of international stature, and operative, in some form or another in developing countries. In order to obtain technical depth and to appraise developments without a 'producer company' bias several internationally recognized engineering and technical consultancy organizations, associated with or reviewing technology development, were visited.

A list of all corporate organizations interviewed during the Survey, in the order in which they were visited, is presented in Annex II.

The document draws upon through the Survey,information from large corporations of industrialized countries as gathered from the interviews (and supported by corporate documents or published policy statements). Interviews were mostly with senior managers of corporate planning departments, arranged several weeks in advance. In the United States, practically all interviews were with corporate personnel with the rank of Vice-President and above. Only three organizations, two in Europe and one in the United States did not grant interviews. Otherwise, all requested interviews were granted. The response to the survey (which was conducted without standard questionnaires on the grounds that each interview upgrades one's level of knowledge and only new issues were needed to be taken up in subsequent interviews) was uniformly good insofar as it sought clarificatory non-confidential information. In practically no case was research information volunteered, or was adequate response given to questions leading to a corporation's basic research thrusts. The great benefit of the interviews lay in that an appreciation was obtained on what peer or competing organizations were doing, or were thought to be doing. This helped immensely in framing questions in succeeding interviews. For obvious reasons information provided in interviews, which could have been in the nature of personal opinion, is not identified by source.

Partly as a result of findings in the European phase of the survey, and partly on the basis of a mid-survey review, it was felt that a'petroleum company perspective' would be useful. Thus, most visits to oil companies were made in the United States phase. This revision, has given new dimensions to the findings.

GENERAL FEATURES

Major developments in the petrochemical industry have historically emerged from factors associated with the demand and supply of technology, in turn, responding to economic and political factors. In order to determine whether and what technology will emerge in the future, in particular situations, enquiry is essential into the nature and direction of the forces creating demand and into the patterns of response (supply). Such enquiry, for a particular country, can be expressed in three simple questions:

(a) Is there a demand for technology in that country?
(b) If so, what is its direction?
(c) Is the technological need being met?

If, in the post-OPEC era (1973-1980), new technology did not emerge it then becomes necessary to enquire into the compensation shifts that may be taking place in the demand and supply of the industry's basic goods. That is, a country may be abandoning the search for technology because it no longer wished to produce goods of a particular type.

If, on the other hand, technology was forthcoming it was necessary to identify its suppliers and its quality: whether the supply was from traditional industry or a competing industry: whether the supply from national or international sources; and finally, whether t emerging technology was relevant?

Section I of this document, General Technological Structure of the Petrochemical Industry, is concerned with these questions, while providing background on the traditional suppliers of technology. The issues and events of three periods are discussed:

(a) early period;
(b) a 1965-1973 period; and
(c) post 1973 period.

Emphasis is on the latter two. This division has been selected to highlight or identify how industry has restructured itself to changes in technology and feedstock supply.

The early period is seen as a general period of settling into technological change - industrial restructuring pivoted on the use of petroleum as fuel and feestock. The pre-OPEC period (1965-73) is reviewed in relation to the process of industrial consolidation in the perspective of diminishing reserves of natural resources, particularly petroleum. The post-OPEC period (1973-1980) is discussed in terms of the findings of the survey - the response and the resilience of the industrialized economies to changes in price and supply, and the technological efforts to adjust to these changes.

Section II Feedstock Economies and Technological Implications, presents the survey's technical findings. New technologies, both breakthrough and upgraded, are discussed against a background of conventional feedstock economics. This section particularly evaluates the economic, political and technological significance of the emergent technologies for developing country needs and aspirations. Measuring the pace of change, the discussion leads to the conclusion that while there is a great economic potential in emergent technology, various factors are impeding their commercial realization in the geographical territories of the technology suppliers; and that, unless commercialization first takes place in such territories, developing countries, in electing to use them, will be risking their scant material, financial and managerial resources.

The infrastructure of the petrochemical industry inhibits the commercialization of new technologies.

In the overview, the concept of 'technological mechanisms' that developing countries can use to precipitate or accelerate impending technological change is analyzed.

This document is basically addressed to planners in the governments of developing countries, including oil-producing developing countries, who are involved in strategic assessments of technological change - in terms of advance resources planning for the chemical or hydrocarbon industries. However, it also highlights issues for collective developing country action. Thus, it seeks readership in intergovernmental agencies in developing countries associated with the management of hydrocarbons. In Annex I and the footnotes information is presented which is both in the nature of data and of technical clarification. This information is largely obtained from published technical and economic literature, but has been drawn from publications of the interviewed corporations.

Quantitative data are used in this document more to give dimension to comparisons and contrasts, rather than for analysis of technological trends. That is, the main source of information on technological change is direct corporate comment.

OVERVIEW

Structural Aspects of the Petrochemical Industry

On the basis of the field survey it is considered that the United States will become, in the post OPEC period, the largest petrochemical market and production centre. It is forecast that United States consumption of ethylene, a fundamental building block of the petrochemical industry, will reach 30 million tons by the year 2000. To produce this level a 65 per cent addition to existing capacity will be needed. The level of consumption in the United States by the year 2000 will be 40 per cent higher than that of Europe and 80 per cent higher than the developing countries as a group.

Because of a series of developments in the international energy field, there is wide recognition that petroleum companies, very largely the 'oil majors', will build the new capacity. It is also anticipated that oil companies will control much of the ethylene capacity in the United States, both through outright ownership and through participation in joint-venture with chemical companies.

United States leadership of the industry will be vastly enhanced by the large moves that the United States Corporations, mostly the petroleum corporations, are making to manage international production of ethylene, such as Shell, Exxon, Occidental and Dow Chemicals' efforts to secure access to North Sea NGL supplies for Scottish-based ethylene production plants: Shell, Exxon and Dow Chemicals ventures in Saudi Arabia, in association with Saudi Arabian agencies; the maintenance and expansion, directly and through joint-venture, of oil company investments in Europe as those of Occidental-ENI, Gulf Oil, Exxon, Marathon and Caltex: of the Mobil and Exxon ethylene venture in Australia; Exxon's proposed ethylene project in Indonesia: the joint-ventures of the type established by Dupont and Union Carbide with Polysar in Canada, etc. Since investments in these ventures are large, and will produce commodities as polyethylene and ethylene glycol far in excess of demand of the countries in which the investments are made, they will be exported on the world market.

The commodity products being based in most of these locations on raw materials (such as ethane) whose alternative value is as a fuel with high cost transport will be able to penetrate tariff barriers in most countries. Thus, American corporations, besides enjoying a large home market, can be expected to dominate world markets.

European chemical firms, through joint-ventures with oil majors and with national oil companies, presently have sufficient feedstock to maintain their commodity businesses (bulk plastics and chemicals) in their home markets; they are unlikely to expand their positions or seek greater consolidation. It is anticipated that they will preferentially move 'far downstream' into speciality and proprietary products, which have a low feedstock content and which can be advantageously marketed through their cultivated brandname-based distribution chains. At the same time, because of the high cash flows that arise in tonnage products, such as plastics, the European firms are expected to reinforce their existing manufacturing positions in the United States market area to take advantage of its fast growth.

The **Japanese** appear as the most disadvantaged of the industrialized countries in the post-1973 period in consequence of their very distant location from energy/feedstock resources and because of their near total reliance on imports for meeting energy needs. While, like the Europeans, the Japanese are not expected to cut-back in home-based petrochemical commodities, they are, however, not expected to add to capacity of anywhere near the rates achieved in the earlier post-war period. As a consequence of the changes in the supply and price of petrochemical feedstock, the Japanese petrochemical industry is being restructured. New feedstocks are being used and plants are being constructed in countries with assured supplies. As an interim measure Japanese companies are broadening their product mix and turning to fine and speciality chemicals.

A survival option being exercised by the Japanese petrochemical corporations - individual corporate decisions rather than the policy of some control planning body - is a drive to internationalize investment. This finds expression in the association of Japanese companies with multi-partner energy/feedstock enterprises in hydrocarbon-rich countries, as in Indonesia for oil, in Australia for coal, in Canada and Alaska for natural gas, in the United States for ethylene dichloride (indirect access to electric energy), in Saudi Arabia for crude entitlements, etc. While these projects give Japan access to hydrocarbons (feedstocks and energy) to service home industries, there appears to be little motivation for the Japanese companies, at the present time, to see international locations as sources of petrochemical commodity supply for home markets. Japanese overseas investments appear to relate to 'world markets', usually developing country markets.

Individual Japanese corporations, do not have the financial resources of their United States counterparts and thus engage in joint ventures with other Japanese corporations (chemical and non-chemical associates) in order to survive home market competition.

The petrochemical industry of the three industrialized regions discussed is faced with three common factors:

(a) large dependence on the Middle East countries for crude oil supplies:
(b) the need to depend on sources of petroleum which are not controlled by them:
(c) competition in home markets arising from the sharing of naphtha between the petrochemical and gasoline users in a situation of tight supply.

These give rise to problems, to the industry, in terms of the play of political forces in the case of the first situation, that of 'guaranteed access', or feedstock security, in terms of the second, and price in the case of the third. While the strategies adopted by the countries to solve these problems differ in many ways, there are two common approaches:

(a) reduce reliance on Middle East crude oil;
(b) implement inter-fuel substitution thus allowing maximum petroleum usage in markets where it enjoys a premium, namely transportation fuel and petrochemical feedstock.

One of the basic features of these strategies is stress on locating, or developing, regional access (stable access) to hydrocarbons. This has been aided by new resource developments or new resource discoveries. Thus, the United States, Alaska, Canada and Mexico are new sources of hydrocarbons, which supplement the existing domestic supplies (these are already being expanded by graduated removal of government price and supply controls on natural gas and crude). For the European petrochemical industry the discovery and development of North Sea oil and gas was an important addition of secure supplies. There are also plans for Europe to gain access to the large reserves of natural gas in the Union of Soviet Socialist Republic (USSR). The Japanese also see natural gas from "neighbourhood" sources such as Indonesia, Brunei, Thailand, Alaska and Canada as a means of reducing their dependence on OPEC oil supplies. Thus, the petrochemical industry in all three regions is strongly influenced by the nature and location of new hydrocarbon resource developments. That is, strategic **access plays a far greater role than total supply availability or the costs and convenience of use of feedstocks.**

Most of the countries of Europe obtain a degree of flexibility through accent on the use of indigenous fuels: brown coal and lignite in the Federal Republic of Germany; nuclear energy in France; natural gas, from the Groningen fields, in the case of the Netherlands; oil and gas from the North Sea for the United Kingdom,etc. These supplies are then supplemented by access to 'regional sources' - as Soviet and Algerian gas - to give the countries, the assurance, from their political viewpoint, of reduced dependence on the Middle East.

In the United States, the dominance of the automobile creates such a large demand on gasoline that, unless there were to be significant technological breakthroughs for obtaining alternate sources of gasoline, the country would not be able to reduce its dependence on the Middle East.

Interfuel substitution strategies, combined with access to regional hydrocarbon sources, have thus given the developed countries a means of temporary adjustment to the oil supply crises.

The survey shows European chemical corporations preoccupied with structural change in the industry:

(a) the penetration of oil companies, particularly oil majors, into European chemical commodity markets;

(b) the growing saturation of the European market in areas as **fibres**, synthetic rubbers, etc. which could well extend itself to the plastics if petroleum-based;

(c) feedstock prices represent a high percentage of feedstock costs;

(d) the abandonment of the European chemical market by United States chemical companies such as Union Carbide, Monsanto and Gulf: by European companies as Rhone Poulenc and Napthachimie and the collapse of companies such as S.I.R., **Liquichimica and** Rumianca, etc;

(e) the giant moves being made by oil companies, on the periphery of Europe, to produce commodity chemicals with location advantages;

(f) the difficulty of raising financial resources of the order required to commercialize European coal or imported coal as petrochemical feedstock.

Thus, for the European companies, internationalization of investment, to obtain growth markets, particularly the United States, appears as a viable solution, although it is a structural one.

In other words, the economic situation in Europe requires or permits its corporations to postpone technological change. The technological effort for the independent survival of competing units - which spurred much of post-war research in Europe - or the prompting, at the level of corporations, to undertake defensive research to maintain product or market leadership positions, appears in decline.

At the same time it needs to be recognized that such postponement of technological change can only be temporary. Europe will continue to need energy materials, such as plastics, to penetrate markets for metals, support high-technology industries as electronics and aviation, maintain employment, yield large cash flows through tonnage production, etc. Significantly, even if volumetric production of indigenous industry is to stay at present levels, recapitalization of much of existing industry would be required within the decade. It would be inconceivable for them to continue on technologies in which feedstock costs are upwards of 60 per cent of total production cost. Likewise, founded on innovation in chemicals, and with international product leadership in specific lines, it appears unlikely that prime organizations such as ICI, Bayer, Hoechst, or Solvay would dilute their **European** corporate identities by c t offshore investments and markets. In such revamping, the Europe companies can also be expected to revert to their traditional independence from international petroleum corporations.

Thus, although the survey finds that Europe does not presently have a strong demand for technology for the introduction of new feedstocks replacing technology, the need for new technology is expected to arise, at the latest, when the industry is recapitalized.

It is only in the United States that there is a definite corporate perception of technology demand. In acknowledging this, it must be recognized that the chemical industry of the United States today, is an industry shared by both chemical and oil companies in keen competition with each other (as enterprises and as industries). Hence, this perception has different bases.

To the oil companies, coal (as a source of coal liquids or syngas) has emerged as a viable alternative to petroleum (seen as a source of gasoline) solely because the price gap in real terms between it and oil is widening, favouring coal. With 70 per cent of United States coal in the hands of oil companies - as a result of acquisition policies adopted as early as 1964 - access is not a problem.

For the chemical companies coal, 30 per cent of which is with 'independents', appears an alternative not only because of its price differential with respect to petroleum but as a means of maintaining their traditional independence from the oil companies in respect of feedstocks (i.e. similar to their reliance on the natural gas-processing industry for the raw material ethane, rather than on the oil industry for the alternative naphtha).

For both the United States oil and chemical companies the forecasted size of the national incremental market for ethylene, 15 million tonnes by 2000, to be met by large net additions to **capacity - provides** further incentive to develop coal since its conversion economics - whether to liquid or gaseous hydrocarbons, is highly scale-sensitive.

Prospects for the development of coal in the United States are further reinforced by the investment interests of German companies in the United States industry, particularly with their long association with commercialized (wartime) coal technology. Even Japanese companies have waited years to participate in efforts to exploit low-cost Western United States coal if American investor interest was forthcoming.

The importance of coal as a chemical feedstock is highlighted by the following shell forecast of ethylene sources for the United States in 1990 and 2000.

Per cent of incremental ethylene demand m from	1990 - 2000	
	Scenario I	Scenario II
Petroleum	65%	25%
Coal	27%	67%
Imports	8%	8%

(Scenarios I and II differ in the degree to which syngas serves as an energy feedstock).

Directions of Technological Development

The most important development taking place in the international petrochemical industry, especially in the United States, is the attempt to switch from oil and gas to other hydrocarbons as primary feedstocks. This more has been prompted by the sharp rise in crude oil prices since 1973 and the more recent increase in the price of natural gas. In addition there is concern over the supply of crude oil in terms of reserves and oil exporting country production policies.

The non-petroleum hydrocarbons that could be considered as possible replacement petrochemical feedstocks are coal, oil shale, tar sands and biomass. Reserves of these hydrocarbons are large, in most cases very large, in relation to production and would not be a limiting factor for the future production level being considered. The price of these hydrocarbons varies greatly according to type and location but is largely determined by extraction and processing costs, and can therefore be estimated and long term supply price agreements can be agreed.

Today, coal is considered the most attractive of the alternative petrochemical feedstocks. Firstly, it has the largest known reserves of any hydrocarbons and it has a wide, geographic distribution, which is not the case for tar sands or oil shale. Secondly, coal has been produced for hundred of years and the technology and infrastructure for its exploitation, processing and transportation already exist in most parts of the world. Finally, it is produced at very low cost in certain locations, for the American petrochemical companies the low cost coals of the Western States of America are of particular interest.

The economies of large scale production are very relevant to coal production because of the large fixed investment and infrastructure needed. Therefore large scale production is required to achieve low cost coal. Petrochemical feedstock volumes are very small in relation to those used for fuel (only 8 per cent of all petroleum processed is used for chemicals), and consequently low cost coal can only be produced and processed if it is to be used largely for energy purposes.

Technical and economic efficiency is increased when coal is used jointly for energy production and petrochemicals with low-level waste heat from the energy system being used in the chemicals process.

The most important area of modern research relating to petrochemical feedstocks is the capability to convert methanol and synthesis gas to ethylene and propylene. The significance of this development is that they are linkage technologies and these can be incorporated within existing industrial structures and technologies. Figure I - Methanol as a Petrochemical Feedstock - identified the position of the linkages looking at the industry from a conceptual point of view.

The conversion of methanol and similar intermediates into ethylene and propylene has been carried out at the research level. The commercialization of the technology will depend on methanol having a sufficient price advantage over existing feedstocks (principally naphtha), to allow for the cost of a distribution system for methanol and provide an incentive for the building of "grassroots" methanol to ethylene facilities.

A finding of this survey is that the conversion of methanol to ethylene will only be economic if methanol is produced on a large scale. This means in fact that methanol would have to find a market as a fuel. Thus technical change in the petrochemical industry is dependent upon structural and technical changes in the energy sector.

The possibility of using methanol as a fuel has been greatly enhanced by the "M"gasoline process, a revolutionary but technologically simple way of obtaining conventional gasoline from methanol.
New Zealand is committed to produce "M" gasoline to fuel a third of its automobiles. Argentina also has a significant "M" gasoline programme.

In the United States any major methanol production would be based on coal. The major problem for a coal to methanol development is the scale of investment needed for an economic size unit. Cost estimates for these "coalplexes" have been made of the order of $3 to 6 billion. To obtain financing for this level of investment would generally require the formation of consortia. Such consortia whether composed of major oil or chemical companies would face difficulties of anti-trust legislation in the United States. Thus, problems of industrial structure in the United States may postpone or prevent technical change in the form of methanol from coal.

In Western Europe, the only country with a possibility for methanol from coal is the Federal Republic of Germany. It has large reserves of coal and the use of methanol as a fuel would fit well into the energy policy of reduced reliance on imported oil. There are, however, a number of negative factors for coal to methanol developments. Firstly, the hard coals in Germany are very expensive to mine and the brown coals and lignite deposits are already committed to electric power production. Secondly, as in the United States, the very high investment needed would strain the financial resources of individual corporate organizations.

The other possible feedstock for ethylene and propylene is synthesis gas. This would again normally be derived from coal. As in the case of methanol, for syngas to be a major petrochemical feedstock would require it first to be a major energy source. The role of syngas as an energy form is limited by:

(a) the cost and disturbance of a pipeline distribution system or pithead electric power generation with the problems and cost of transmission;
(b) technological problems relating to variations in the grade of coal.

At the present there is no viable technology for ethylene and prophylene production from syngas. But there is no theoretical impediment to its development. In fact the Fischer-Tropsch process, currently used in the Sasol oil from coal plants in South Africa, produces ethylene as a co-product with hydrocarbons. Optimism about the development of ethylene from syngas can be gauged by Shell Oil's forecast that by the year 2000, 8 percent of the worlds ethylene will be syngas-derived.

Implications of New Technology for Developing Countries

Although still in the research and development stage, there are strong indications that the olefins, ethylene and propylene, can be produced from methanol on a commercial scale. The reasons for such optimism are:

(a) the production of "M" gasoline from methanol in Mobil's process involves "in-process" creation of ethylene and propylene which are then transformed in-situ into gasoline molecules;
(b) Mobil has stated that the process of olefin conversion to gasoline can be arrested and diverted to the production of the olefins;
(c) other researchers have confirmed Mobil's findings;
(d) large chemical companies are undertaking investigation of the process including construction of pilot plants;
(e) energy-promoted large scale production of methanol carries the promise of reducing the cost of methanol which improve its position as a chemical feedstock;
(f) there are fully commercial processes for the production of other petrochemicals, such as acetic acid and acetic anhydride from methanol, and finally;
(g) some chemical companies are already expanding their methanol production capacities at international locations.

As seen can be seen from Figure I methanol occupies an intermediate position between the source hydrocarbon - petroleum, biomass etc. and the petrochemical building blocks of ethylene and propylene. For the developing countries the methanol to ethylene and propylene route has many advantages:

(a) methanol is internationally traded and is available from a number of competitive sources;
(b) it can be stored, transported and serviced by the existing petroleum infrastructure;
(c) it can be produced in a scale sufficient to service developing country level ethylene markets;
(d) it can be indigenously produced from a variety of hydrocarbon sources and therefore allows a non-petroleum route to petrochemicals.

The ability to obtain ethylene and propylene from methanol broadens the production pathways to the main organic chemicals, as shown in Figures II, III and IV. Figure II shows the present position with naptha as the main commercial feedstock and the narrow role of methanol. Figure III indicates the degree that methanol could substitute for naphtha and other feedstocks in chemical production. Figure IV shows non-conventional routes to petrochemicals (new applications of methanol as described in Figure III are excluded). The field survey, on the basis of the various studies presented in the body of this document projects final commercialization of emerging technologies as given in Table 1. This forecast is based on the assumption of a continuation of the historical trends in the petrochemical industry. As seen in Table 2 naphtha based technology took over from carbide-based in a time span of less than 20 years.

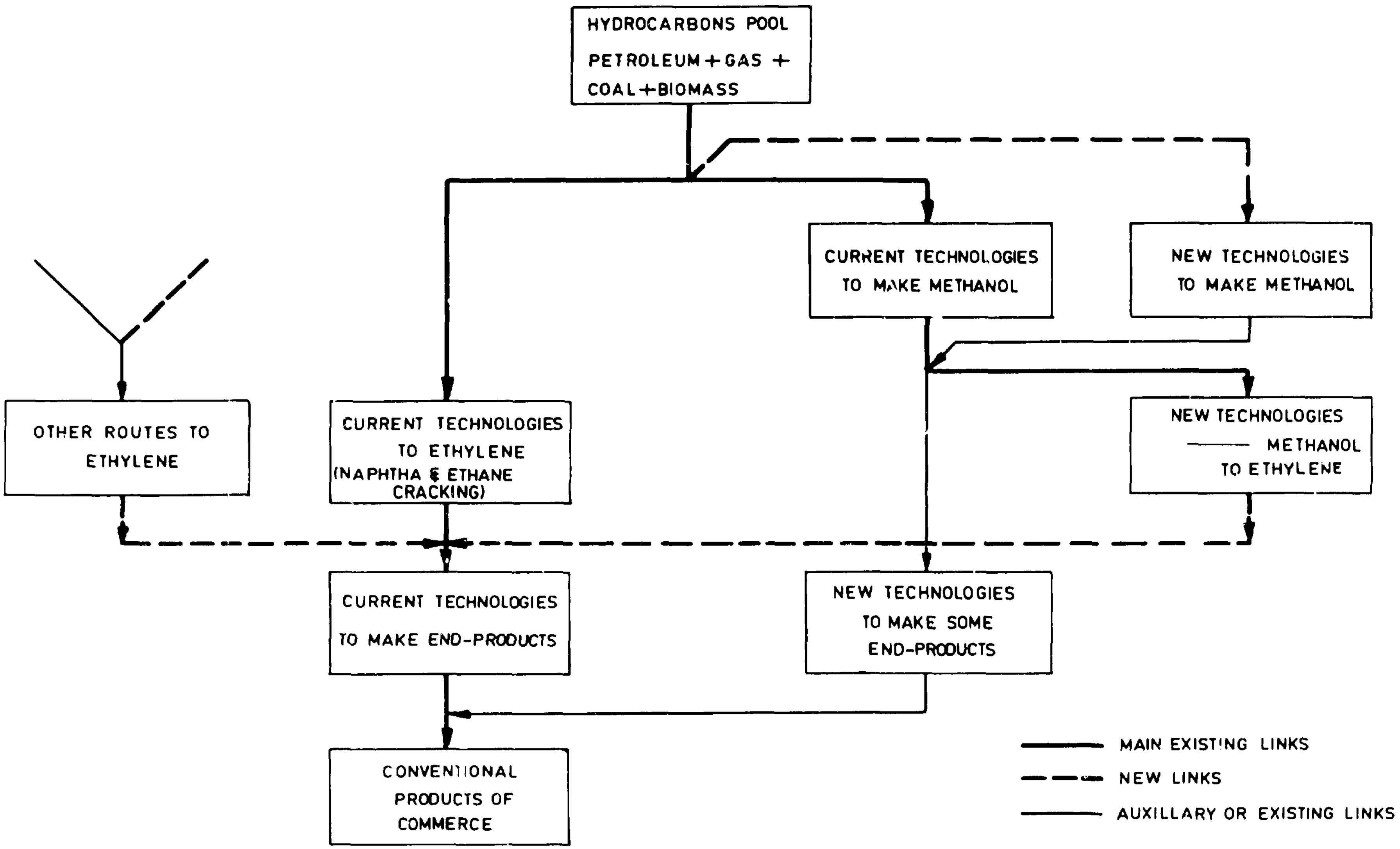
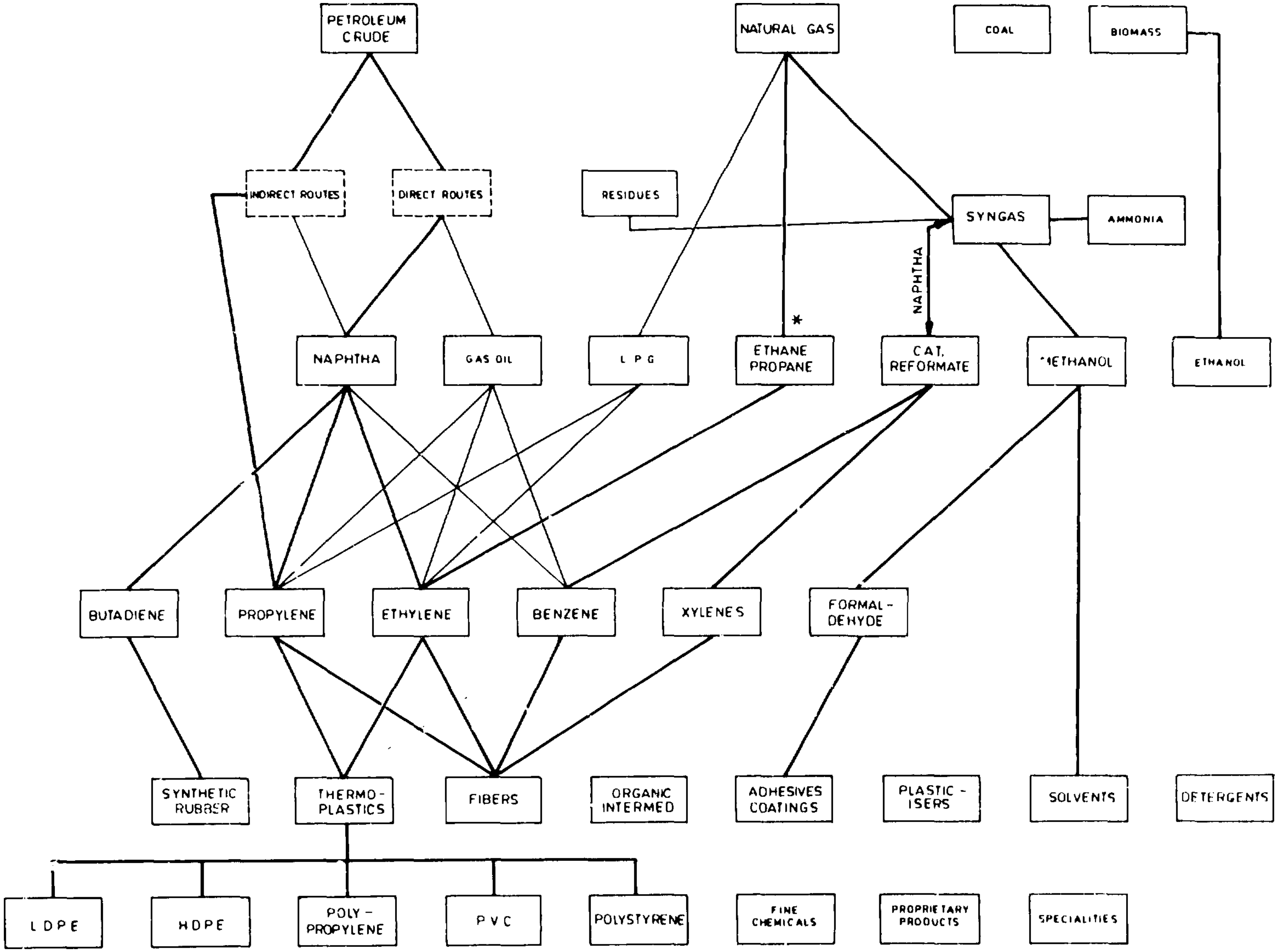


FIG. I METHANOL AS PETROCHEMICAL FEEDSTOCK



* THROUGH NATURAL GAS PROCESSING

FIG. II FEEDSTOCK LINKAGES TO MAIN ORGANIC CHEMICALS AND POLYMERS (1981)

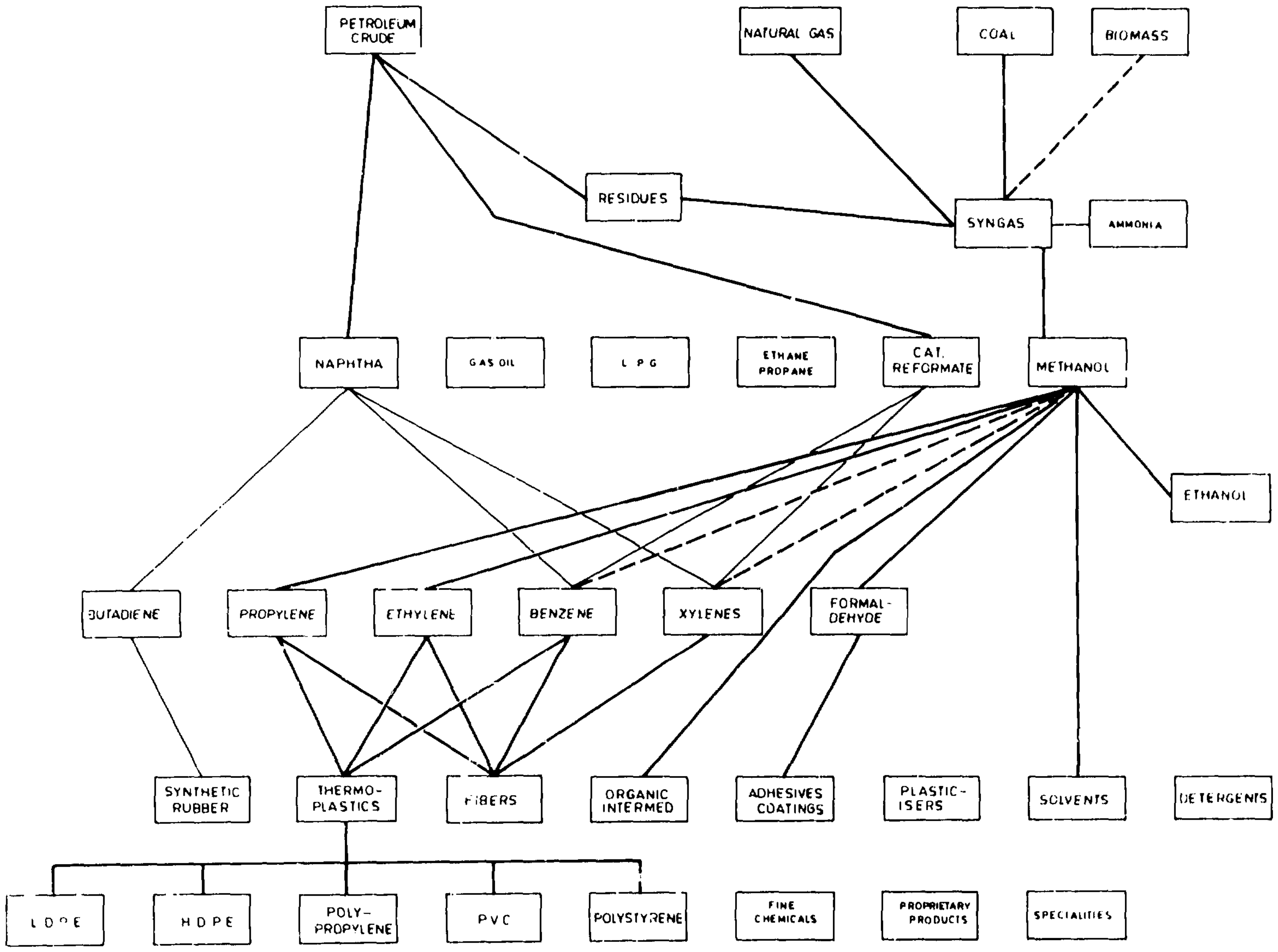
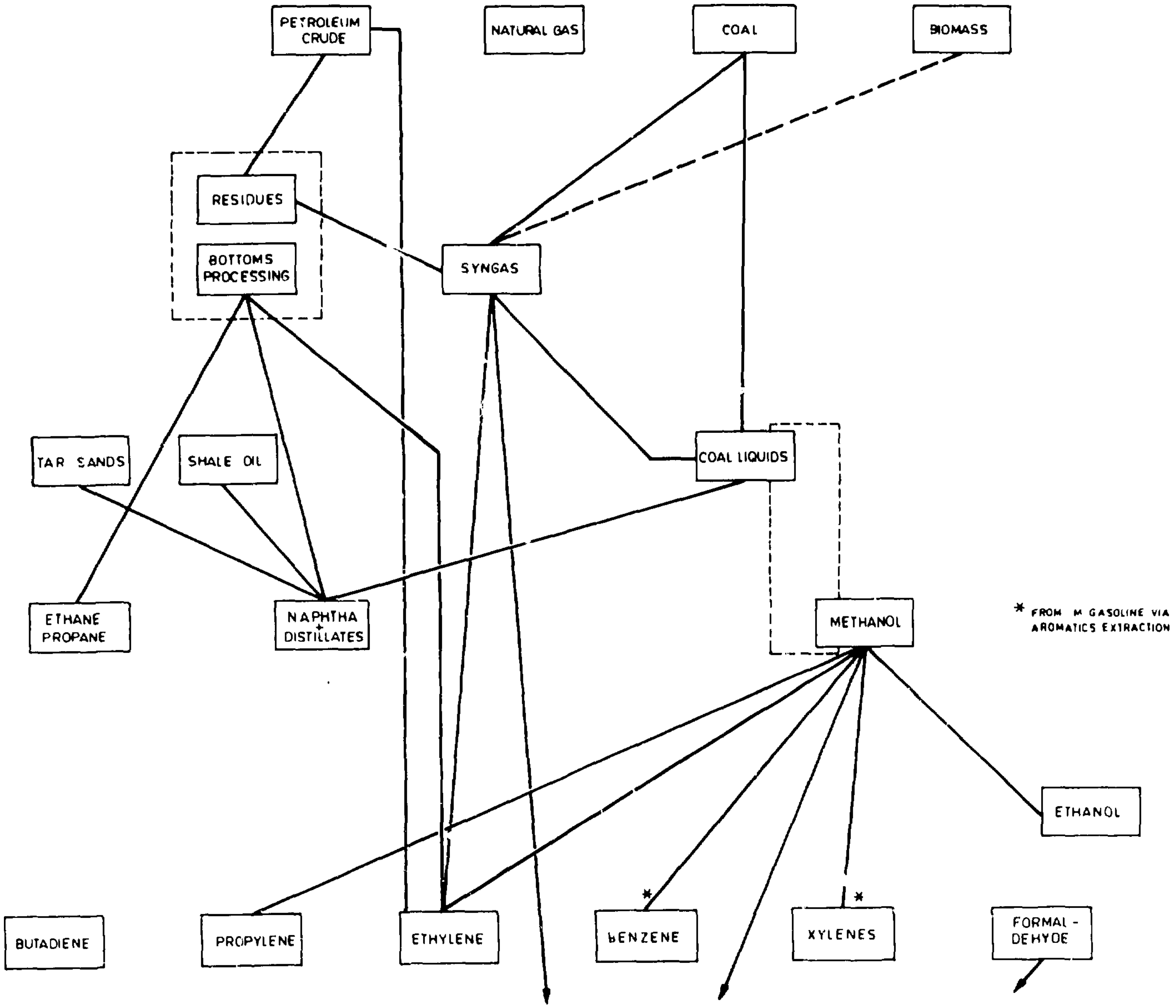


FIG. III METHANOL AS A MAJOR FEEDSTOCK SUBSTITUTE TO NAPHTHA



* FROM M GASOLINE VIA AROMATICS EXTRACTION

FIG. IV NON-CONVENTIONAL ROUTES TO PETROCHEMICALS

Table 1

TIME-FRAME FOR EARLIEST COMMERCIAL UTILISATION OF EMERGENT TECHNOLOGIES

Legend: O= Industrialised countries
X= LDCs

	1980–85	1985–90	1990–2000
I. SYNGAS			
1. From conventional resources			
A. Natural gas to syngas (for organic chemicals other than methanol)	O	X	
B. Petroleum residues to syngas for chemicals	O	X	
C. Direct routes to products			
(i) acetic acid(HA) acetic anhydride (AA) vinyl acetate (VA) MMA, ethylene glycol (EG)		O(HA) O(AA) O(EG)	X(HA) O(VA) O(MMA) X(EG)
(ii) ethylene/propylene (thus to virtually all thermoplastics and chemicals)			O X
2. From non-conventional resources			
A. Coal to syngas (for chemicals)*		O	X
B. Biomass to syngas		X	O

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*Excluding South Africa

Table 1 (cont'd)

	1980-85	1985-90	1990-2000
II. METHANOL			
1. Direct routes to products			
(i) acetic acid(HA)	O(HA)	X(HA)	
vinyl acetate(VAM)		O(VAM)	x X(VAM)
ethylene glycol(EG)		O(EG)	X(EG)
styrene (S)			O(S)
ethanol(E)			O(E)
(ii) ethylene/propylene (thus to virtually all thermoplastics and chemicals)			O X
2. Methanol to gasoline (G)/Aromatics(A)		O(G) x (G)	X(A)
III. PETROLEUM & FRACTIONS			
1. Fluid Catalytic Cracking (FCC) to chemicals	O	X	
2. Naphthas from hydrocrackers - for use in conventional steam-cracking (ethylene and propylene)	O	X	
3. Direct cracking of crude to ethylene			O
IV. NON-CONVENTIONAL FEEDSTOCKS			
1. Coal liquids(used for chemicals)			O
2. Shale (SH) and tarsand (TS) distillates (used for chemicals)	O(TS)		X(SH) O(SH)

Table 2

Evolution of Typical Sizes of Production Units from 1955 to 1976 for Some Significant Products (Thousands/Tonnes/Year)

	1955	1960	1965	1970	1976
Basic products					
Ethylene	20	50	150	300	450
Ammonia	50	85	150	350	350
Intermediate products					
Acetaldehyde	10	20	30	100	135
Acrylonitrile	10	15	30	60	180
Caprolactam	10	20	40	60	70
Phenol	10	25	45	70	90
Styrene	10	30	50	150	450
Vinyl chloride	30	50	100	150	270
Ethylene oxide	5	10	20	70	135
Final products					
Low density polyethylene	10	30	50	100	100
High density polyethylene	5	10	20	60	90

Source: ECMRA Conference "European Chemicals in the problems and possibilities". Venice, 1978.

Options for Developing Countries

As indicated earlier there are many advantages for developing countries in having the ability to produce petrochemicals from non-petroleum sources. Natural gas, coal biomass etc. are all possible feedstocks for the production of the basic petrochemicals ethylene and propylene through the medium of syngas or methanol. For the development and commercialization of these new petrochemical technologies the developing countries have the following options:

(a) carry out the research and development at the national level:

(b) obtain the necessary technology from the developed countries;

(c) joint research and development on bilateral, regional or international basis.

The first option of national action is obviously limited to a very few developing countries as it requires an existing research organization with the capability to undertake developments in petrochemical technology. Most of the research and development in petrochemical technology has been carried out by transnational oil and chemical companies. National research in the developing countries would obviously be starting from a very low base.

Obtaining technology from the industrialized countries of the North has, no doubt, been the normal route for many developing countries in several fields. This method has all the well known problems of "the wrong technology on the wrong terms" for developing countries. In the particular case of new petrochemical technology there is another major problem in that the industrialized countries have little demand for non-oil based petrochemicals and therefore have little or no incentive to develop such technologies for coal or natural gas to methanol, or methanol to ethylene.

The final option of joint research and development can take many forms. It could be sponsorship of research and development in developed countries with an option for the use of any technology developed. At the other end of the spectrum is Technical Co-operation Among Developing Countries (TCDC). This has many advantages for developing countries and the possibility for such co-operation in the field of petrochemical technology should be closely studied. It is important to note that many of the oil-rich developing countries are entering the field of petrochemicals and are therefore acquiring technology and know-how in this field. Another possibility for joint research for developing countries in the area of new petrochemicals, is the setting up one or more "centres of excellence" where technologists from developing and developed countries could work together.

The advantages and disadvantages of new petrochemical feedstocks are summarized in the following pages.

Methanol

Advantages

Already a well-established commercial raw material; easily transportable and storable; existing petroleum infrastructure can handle product; developing countries very favourable placed with respect to raw materials and can be self-sufficient with existing resources; very standard specifications and very simple chemical structure; investment and operating costs comparable to routine investments in petrochemical industry; no unknown environmental problems; no unknown safety aspects; introduction, expansion or multiplication of production facilities can be readily accommodated without appreciable change in petrochemical industry structure; substantial scope still exists for methanol production costs to be lowered; has large alternate uses; is rapidly growing in consumption because of usage in non-chemical sectors; faces little tariff barrier in exports to industrialised countries; no producer/consumer cartels; except possibly transportation, no implied requirement for direct linkages with petroleum industry; technology mobile and readily transferable; would not have broad-based interface with national government and statutory agencies.

Disadvantages

In conversion process from primary energies sources there is considerable loss of energy utilization; ethylene from methanol exceptionally awkward, as it can be alternatively derived from syngas, the basic intermediate for methanol production; **presence** of oxygen in molecule requires its deprivation in the manufacture of most petrochemical products; its growing uses as an energy material (gasoline additive, M gasoline, peak-shaving fuel) implies energy-related pricing structures will carry over to chemical industry; has disadvantages of the 'one feedstock one product' production system; thus, not readily amenable to a **multi-product** production facility.

Synthesis gas

Advantages

Highly developed technology because of its wide usage in ammonia, methanol oxo synthesis and refinery hydrogen production systems; high energy efficiencies possible if chemical production integrated to energy-production schemes; possibility of it becoming available as saleable by-product of other industries, as the 'energy industry'; technologies of production and usage open to economies of scale; derivable from practically any hydrocarbon; conceptually more acceptable than methanol (as source) because no theoretical limits prevent direct derivation of ethylene from syngas; has large alternate use as energy which may aid in reducing impact of infrastructural costs on costs of production or utilization; no necessary or implied linkage to petroleum industry; oligopolies not significant; no unknown environmental problems; multi-product production structure viable and intersupportive; technology mobile and readily transferable.

Disadvantages

Cannot be stored; pipeline transmission limited to 200 miles or so with present technology; new infrastructure development necessary for wide-scale use; carbon monoxide/hydrogen ratio adjustments and impurity levels require monitoring problems; safety in gas transmission involved; presence of oxygen implies removal costs for most petrochemicals and plastics; large scales of investment necessary for viable production; in most cases economic considerations will require integration to energy usages; international linkages through ort/export not possible; 'export market' cannot contribute to scale advantages; requires some interface with national Government agencies.

Non-conventional Feedstocks
(coal liquids: oil/shale and tar/sand naphthas)

Advantages

Ability to use abundant raw materials (international perspective), particularly coal for which infrastructure presently exists (or requires revitalisation): countries with indigenous coal resources, or with regional access, can utilize hydro-carbon resources whose price differential to crude is steadily widening with time (real price gap): resource exploitation costs scale-responding: scale-sensitive and responsive to volume production and product-mix diversification; with coal or coal liquids no unknown environment problems; very responsive to multi-product strategies; where required can exist without integration to petroleum refineries or 'the business of petroleum': at same time, integration possible with advantage of materials balance; i.e. useful disposal of by-product streams; import-export trade viable and scale-responding: technology mobile (coal liquids), but not readily transferable.

Disadvantages

Resources, particularly oil-shale and tar-sands, not widely distributed: 'coal liquids' (other than methanol) are yet to be commercialized; raw material **specifications variable; viable production costs** require very large levels of fixed investment; because of issues of integration as infrastructure, environment permits, transportation by rail, etc. considerable interface with government bodies may be involved; complex production-mix essential; use of oil-shale and tar-sand naphthas may involve unknown environment problems; **transferable** technology will take considerable time to develop; logistics may require involvement with the 'business of petroleum'; sources of technology most probably producer-companies with competing product interest.

Fuel-oriented refinery streams (i.e. refinery operations as FCC, 'bottom of the barrel' processing, yielding VGO, residues, etc.)

Advantages

Chemical plants integrated to refinery operations as FCC, hydrocracking, etc. can obtain scale-advantages; infrastructure of oil refining and oil distribution industries can be advantageously used; import/export possibilities good, with candidate material already in international commerce; very good potential for obtaining low-priced feedstocks relative to hydrocarbon valves (i.e. prices will be in between that of heavy distillates, as fuel oils, and coal); no known environment or safety problems: institutionally built-in feedstock flexibility if integrated to refinery operations; technology mobile and transferable; production technology for 'raw materials' as FCC stocks, VGO or residues well developed.

Disadvantages

Unless operable on 'arms length' purchases of raw materials, interface with petroleum industry introduces operational inflexibilities; in most cases, difficult to obtain raw materials of consistent specifications; in most developing countries, private chemical companies will mostly have to work with public sector oil companies which may effect business flexibility; raw material prices associated with energy pricing and open to swings;'single product' or 'main product lines' business difficult.

Naphtha

Advantages

Highly developed infrastructure in most countries; excellent international infrastructure; technologies of production highly developed and extensively employed; single or multiple product business strategies viable; raw materials easily stored and transported; fixed investment costs not extremely high and, in most countries will pre-exist production; no unknown environment or safety problems; standard specifications apply to procurement; sources of technology are engineering companies; naphtha-users can exist without close application to petroleum industry or petroleum plants (but affiliation certainly helps); huge international infrastructure build pre-1973 subsidises production costs of industrialised countries.

Disadvantages

Strong competition from gasoline which increases prices and sets limits on availability; cartelisation of prime crude sources gives strong 'political coloration' to prices and availability; production costs now no longer sensitive to production scale; multiproduct strategy enforced on naphtha user.

GENERAL TECHNOLOGICAL STRUCTURE OF THE PETROCHEMICAL INDUSTRY

Introduction

In order to perceive major technological changes and shifts that are taking place today in the world's organic chemical industry, it is useful to obtain an appreciation of some of the forces that are compelling such changes. Since the chemical industry is energy-intensive, consuming worldwide about 15 per cent [1/] of total industrial energy use, it is quite obvious that the rising real cost of energy, is a substantial factor. However, it is a finding of the present survey that chemical corporations believe equally important factors are logistics in the availability of, and in the supply of, energy to the industry. It is also a finding that a remarkable redefinition is taking place in the business purposes of many major international chemical organizations. To put these factors in perspective, and to relate them to situations in developing countries, this **document takes note of the changing structure of the** organic chemicals industry in the three regions of the world where most of the technology is concentrated, and from where the bulk of the world's production originates, namely, Europe, Japan and the United States.

The perusual of corporate literature and discussion with major corporations reveals that the industry - which it **may** be noted plays a vital role in the development of energy resources - is not so much concerned with the present or long-term scope of global energy supplies (see Annex I) as much as it is with access to them - in terms of national geography, the forms of energy supply (fuels and feedstocks) and the distribution of the energy forms between it and those of its competitors (transportation, commercial/residential heating and electrical power generation). Consequently, it can be expected that the attitudes of chemical producers will vary with national resource endowments.

[1/] ECOSOC Report Chem/A.C.4/R.2/Add.1 12th Aug 1976

As will be expanded upon later, almost the entire chemical industry of the advanced countries is now based on petroleum fractions, essentially for feedstocks, and on natural gas, substantially for fuel requirements, but also serving as feedstock to a degree. However, the more crucial need of the industry is for naphtha, which as gasoline is the predominant source of energy for the transportation industry. Since almost all advanced countries of the above three regional groups, with the exception of Canada, Great Britain and Norway, are net importers of energy [2] - basically of petroleum crude and distillates - the extent to which petroleumliquids are available to the chemical industry (of a region) is determined, in substantial measure, by competing consumption of gasoline. While undoubtedly there is intechangeability among the fossil fuels (coal, natural gas, petroleum), and they can compensate for petroleum, meaningful change can take place only in the long-term - because the infrastructure requirement for each of the energy forms is substantially different from that of the others. Inter-energy flexibility, of course, is at the heart of national strategies. Technological change arises thus.

However, the intensity of technological change, and its pervasiveness in industry differs significantly in the three regions. It is important to recognize that because of the market economies of the countries involved,

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[2] Energy self-sufficiency of certain countries (The Petroleum Economist, Nov. 1975):

	per cent	
USA	- 86	(This position has deteriorated since 1975)
FRG	- 50	
France	- 23	
Italy	- 15	
Japan	- 10	

the perceptions, attitudes and actions of individual corporations - attitudes and actions of individual corporations - national and transnational - would be as significant as any anticipation based on generalised resource imbalances, national or regional, although such would certainly influence decisions. Thus, as will be discussed later, corporate strategies do envisage the relocation or expansion of production facilities in countries or regions where there may be a higher assurance of feedstock/energy security, stability of costs, prices, markets etc. Where indeed such is the view of corporations, their individual emphasis on technological development (R+D), to adjust to shifts in a particular geographical area, may well be absent. Equally, the abandonment of business in certain product lines, on the basis of resource limitations - as is the case of methanol production in Japan - would reduce the impetus for technological innovation in that product line.

Before analysing structural changes that are presently taking place in particular regions, it is useful to review briefly the historical evolution of organic chemicals in the three regions of the world and assess its status at the time of the major oil price rise (1973). It provides, first, a framework for understanding the present virtual shift of technological superiority and leadership from Europe to the United States (even though corporate identities do not appear to change in equal measure), and second, the growing role of petroleum companies in the world chemicals economy.

Early Development of the Petrochemical Industry

The major beginnings of industrial organic chemistry can be traced to Germany previous to the First World War period when tonnage production of synthetic coal-tar based indigo started: this was hitherto imported from India [3]. Over 15000 dyestuffs, obtained from derivatives of coal-tar, a byproduct of the coke-oven industry, gave Germany, and Europe, a dominant economic position, supported by trusts as the I.G. Farben cartel (in which Bayer, BASF and Hoechst of that period were major shareholders). Later, between the wars, Germany developed 'calcium carbide chemistry' which played a major role in the production of organic chemicals till even the mid-1960s. German industry also discovered the Haber route to ammonia (in the 1920s) exploited by BASF to produce nitric acid, explosives and nitrogen fertilisers.

This exploitation subsequently manifested itself in a 'nitrogen trust', in which ICI and DuPont were to become participants. These developments led to the replacement of 'chilean nitrate' (saltpetre) which, in the early years of this century, was exported by Chile (a monopoly supplier) in the magnitude of several million tonnes. Germany, also developed 'coal chemistry' - coal hydrogenation and Fischer-Tropsch syntheses - in the 1930s which were employed during the Second World War period. The processes, while holding potential for the production of chemicals, were then wholly oriented to military fuels.

3/ India's exports of plant-derived indigo which was at the level of 187,000 tonnes per annum at the turn of the century dropped to 11000 tonnes by 1913 (Source: A Century of Chemistry, Ernst Baumler, ECON, Verlag Dusseldorf (1968).

Although after the end of the First World War the organic chemicals industry made substantial headway in Britain, France, Russia and the United States, leadership in innovation and commerce remained with Germany till the beginning of 1940. The discovery of the Texan oil fields in the United States in the 1920s while it gave the country a technology base in oil-processing technology - the development of the very important 'cracking processes' - the petroleum industry was essentially fuels and auto-industry oriented.

Yet the basic fillip for the petrochemicals industry, as we know it today, can be traced to the commercial effort made in the early 1950s by American chemical corporations for developing large consumer markets for low-density polyethylene (LDPE), a product invented in England during the war for coaxial and radar cables and manufactured, for that purpose, in the United States (by DuPont and Union Carbide). It was indeed the rapid public acceptance of LDPE that spurred the usage of other plastics as polystyrene and PVC, even though the latter materials were commercially produced in Europe in the pre-war period.

While in the post-war period the petrochemical industry developed, in quantitative terms, most rapidly in the United States, and its engineering firms, based on their experience in petroleum processing, made major contributions to the field of petrochemical engineering, the essential technology base for present day industry continues to be European. This can be illustrated by the processes as that of HDPE developed by Hoechest; polypropylene by Montedison; methanol, polyester fibre intermediates and LDPE by ICI; ethylene-based acetaldehyde, vinyl acetate monomer, polyvinyl alcohol and the suspension grade of PVC by Wacker-Chemie; the ethanol (hydration) and ethylene oxide technologies of Shell N.V.; cumene by National Distillers UK (now BP Chemicals) etc.

FEEDSTOCK BASES IN THE DEVELOPMENT PERIOD OF INDUSTRY

Essentially, the present raw material base of the European industry is naphtha, like that of its counterpart in Japan. The situation in United States is different in that the predominant part of the industry is based on by-products of the oil/energy industry, namely, natural gas liquids (NGL) and refinery off-gases.

Strangely, while naphtha cannot be seen as a 'byproduct' in the European context of the present time, it was indeed so in the early 1950s. This resulted from decisions of the European nations to build refineries on the continent, rather than purchase distillate requirements from refineries in the United States, the Carribbean or from the Middle East, which were otherwise accessible to them (thus taking advantage of freight advantages offered by large crude tankers over the import of distillates shipped in oil drums). These refineries were slated to the maximised production of middle distillates (diesel oils) and fuel oils (for power generation). This configuration yielded large volumes of naphtha for which there was inadequate demand (unlike in the United States) since the passenger car industry was yet to become significant. With little prospect of export, and alternative use only as boiler fuel, naphtha presented itself as a potential feedstock for the chemical industry if only it could be cracked to ethylene on an economic footing.

Firms such as Hoechst and BASF were already operating inefficient and size-limited 'whole-crude' crackers ('cokers') for obtaining ethylene, they were attracted to naphtha which was selling at a low price. Although initial levels of ethylene production in the newly developed naphtha crackers were small (20000 tonnes per year), the size of crackers developed rapidly. One of the major benefits (to Europe) of this shift to naphtha-cracking came from the co-products of ethylene manufacture - propylene, **butadiene** and the aromatics - for which there were few alternative sources, other than import. As some of the co-products commanded substantial price premiums in the international and **European** markets, the net cost of ethylene dropped, thus spurring its greater adoption as a basic industrial raw material 4/

4/ Between 1955 to 1970, the price of European ethylene dropped two and a half fold in real terms (in the **United States, it dropped by a factor of 2**).

However, for many products, and particularly in the European situation, ethylene had to compete with acetylene as a rival feedstock. From the early 1940s to about 1967, acetylene was the major feedstock for volume chemicals as PVC, vinyl acetate, acrylonitrile, polychloroprene, acrylics, trichloroethylene, etc. and remained a viable contender till the early 1970s. It then wholly gave way to ethylene chemistry because the price of ethylene dropped to half that of acetylene (even though shifts had concurrenlty occurred in the raw material base for acetylene, from electricity-dependent calcium carbide to the petromaterials, LPG, naphtha and methane). It is important to realise, in this context, that not only did the real price of petroleum drop in the 1960-1973 period, enhancing naphtha usage, but vast economies were achieved in the production of the basic, or 'first-generation', petrochemical raw materials. This was as a result of fast escalation in the size of naphtha-crackers. These factors, together with keen competition in petrochemical end-products - downstream petrochemicals - resulted in growth of chemicals production at a rate of about three times that of aggregate industry 5/.

The development of the refining and petrochemical industries in Japan, from the 1950s to the early 1970s, more closely follows that of Europe than of the United States because, like Europe, Japan was wholly dependent on imported crude for its industry. Like the European evolution, strong emphasis on calcium carbide chemistry gave way to developments on the products of the naphtha cracker. However, unlike Europe, and without its deep technological background or the organizational sophistication for individual corporate entities to rival the industrial empires of an ICI, Hoechst or Shell, Japan's contributions to chemical technology, while not without significance, were (and have been) more peripheral than fundamental. This is especially so for the commodity petrochemicals, the basic concern in this document.

In the United States, however, while practically the same technologies have been at work as within Europe and Japan, more specifically for downstream petrochemicals, a sharp difference occurs in the 'mix' of petroleum raw materials that the industry employs.

5/ In the period 1967-1974, ethylene consumption grew at the rate of 20 per cent per annum, and that of propylene 16 per cent per annum. (ECMRA/CMRA Conference, London, 1975).

The traditional United States chemical industry developed around two sources - natural gas liquids (NGL) - materials obtained by physically processing natural gas - and refinery 'off-gases', mainly propylene by-product from catalytic cracking processes. NGL were substantially cheaper than naphtha, not only because naphtha had a competing use as gasoline but also because the United States Government depressed the inter-state prices of natural gas (for purposes discussed later).

Whereas the chemicals industry's requirement of propane and refinery propylene had to be met in competition with the energy-industry's use of them as bottled propane gas (LPG) and octane-upgrading 'alkylate', there was no such competition for ethane, and it was available at almost its fuel price plus extraction cost. With rich reserves of natural gas in the United States, and its heavy exploitation, the United States ethylene-based industry developed rapidly, increasing ethylene consumption from about 115,000 tonnes in 1940 to around 4-5 million tonnes in 1967.

While United States chemical engineering firms, because of their experience in building large refineries and thermal cracking processes made substantial contributions to steam-cracking of ethane, and the Unites States chemical firms, DuPont and Union Carbide in the tubular processes for LDPE production, the technology-base for the exploitation of ethylene in the United States was largely European.

In the case of propane/propylene-utilising technologies (and those of butanes/butenes), however, we find very major, and certainly unique, contributions from the American industry. Without such development it would indeed have been hard for the industry to compete with its energy counterparts for its raw materials. Illustrative of American contributions to petrochemical technology are Sohio's ammonoxidation of propylene to acrylonitrile, the Halcon-ARCO Oxirane route to the simultaneous production of propylene oxide and styrene, Goodyear's route to isoprene, large-scale exploitation of oxo-technology using heptenes derived from refinery alkylation processes, detergent raw materials based on propylene trimers and tetramers, etc.

INDUSTRY STATUS PRIOR TO 1973

OPEC's price-raising decision in 1973 reinforced changes that were already taking place in the chemical industry of the advanced countries. These were not occurring in anticipation of sharp price revisions in energy materials (the eventual fourfold rise in petroleum taking the industry in total surprise) but because the availability of the industry's raw materials was being threatened by competing demands of the energy sector.

Western Europe

In Western Europe, rising living standards, and a growing automobile population, although of small cars, began to change the balance which, in the post-war period, had favoured the sector chemical industry with surplus naphtha at a cost well below its price based on calorific value. The growth of the industry, because of its replacement of traditional materials, was very high compared to the general indicators of economic growth [6] - as indeed was the characteristic situation of other developed regions. In Europe increasing import and fractionation of crude did not yield domestic naphtha sufficient to cover the needs of the auto industry considered together with that of the chemical industry. Direct import of naphtha was not only necessary but the chemical industry had to live with the fact that it would increase as the automobile industry consumed 70 per cent of all naphtha. Import meant higher prices, but more importantly, problems of guaranteed access. The situation was heightened by the large integrated complexes that had been established all across Europe in response to the growing market situation and because of the scale economics achieved thereby. Steadfastness in the supply of raw materials meant high capacity operation which was essential to cover the high capital charges in production cost.

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[6] Growth rates 1965-1973

Unit per cent

	Economy	Total Energy	Oil Products	Ethylene	Plastics (note A)
Europe	4.4	5.3	7.1	21.0	12.6
Japan	10.1	10.5	14.3	23.3	17.0
USA	3.7	4.6	5.7	11.1	10.1

Note A: 1960-1975

While chemical corporations, as separate entities, reacted differently to the emerging situation, in general they had to shed their hitherto highly individualistic postures and develop closer linkages with the oil companies. It was an irksome task since companies as Exxon, the Shell Groups in the United Kingdom and Europe, Marathon Oil,Gulf, Caltex and British Petroleum, to name the predominant, had already penetrated the European chemicals market and had established production facilities. To the chemical companies, association largely meant a greater degree of market sharing.

At the same time, association with oil companies was particularly important to those chemical firms whose main competitors were already linked, in some way, and for other reasons, to oil. Thus Bayer in the Federal Republic of Germany felt disadvantaged with respect to Huls and BASF as the former was a subsidiary of **Veba Oel**, the German public sector oil company, and the latter had its own subsidiary, Wintersholl, a refining firm with concessions in the Middle East. Similarly, ICI was at a disadvantage to BP Chemicals, the chemical subsidiary of British Petroleum. American firms in Europe (to whom more attention will be given later) such as Monsanto, Union Carbide and others, were in similar positions.

In this situation, Bayer joined with British Petroleum to form Erdolchemie (a 50/50 joint-venture), and BASF, despite its refining subsidiary, linked with Shell to form ROW. Of the major firms, only Hoechst opted to remain non-integrated, preferring to buy its olefins (it is the largest purchaser of ethylene in Europe) from its four traditional suppliers, Veba Oil, Caltex, Marathon and Union Kraftstoffe Wessling [7], UKW, (in which Hoechst has a 25 per cent interest).

7/ UKW and ROW, with current ethylene capacities of 900,000 tonnes each, are Europe's largest producers of ethylene. Together with Exxon, these three units in Wessling (in the Cologne area) account for about 70 per cent German consumption.

In the case of the United Kingdom, the oil majors were traditionally in a controlling position in terms of ethylene supply (Shell, BP Chemicals, Exxon), although ICI was the largest chemical firm in the country. However, and despite the discovery of North Sea oil, ICI still bid to join up with BP (45 per cent owned by Government) to establish a joint-cracker at Teeside for supporting a part of its operations.

In the case of France and Italy, the move towards feedstock security was not as important as in the Federal Republic of Germany because of the large role that their Governments played in oil management. In the two major oil companies of France, Total and Elf-Aquitane, the Government had 67 per cent ownership and thus it could be expected to be sensitive to the needs of the chemical industry. In Italy, ENI was a wholly Government-owned public sector oil and gas company and hence chemical companies could expect, again, some security from this position. Further, and unlike the situation in France, oil majors did not have large chemical investments in Italy.

However, because of the intense competitive environment in Europe, public and private companies vied with each other in the market place. Privately-controlled French firms as Rhone Poulenc, Produits Chimiques Ugine Kuhlman (PCUK) and Napthachimie, together with subsidiaries of oil companies and of major European corporations, - Shell, BP and Solvay - competed with firms with Government majority interests as CdF Chimie (subsidiary of Charbonnages de France) and ATO Chimie (controlled by Elf Aquitaine and Total). In Italy, too, essentially private companies as SIR Consorzio, the Montedison Group of companies and Rumianca were in fierce competition with each other, and with ANIC, a petrochemical company, and a near wholly-owned subsidiary of ENI.

Consequently, despite the involvement of Government oil companies, several of the private companies in France and Italy began to develop associations with those having significant access to oil. Thus, in France, Solvay and PCUK veered to ATO to operate a joint-cracker (Feyzin, France) to obtain part of their olefin supplies. Similarly CdF Chimie moved to establish its own refinery and obtained access to oil through its participation (via Copenor, its 60 per cent subsidiary) with the Qatar Government, in reciprocity, obtained a 16 per cent share in CdF Chimie's LDPE plant at Dunkirk). Also Rhone Poulenc and Napthachimie, as will be shown later, started to approach oil companies.

In Italy, Montedison and SIR established their own refineries to meet a part of their requirements of naphtha (competing for crude in the international market) but at the same time joined with ANIC and ENI for the establishment of joint-crackers. In the Italian case, it is important to note, that the country is Europe's largest petroleum refiner (because of its proximity to the Middle East). Most of the refining is done by ENI and not by the oil majors. Thus, feedstock security, as corporate strategy, was not so important a consideration in this country as it was in the rest of Europe.

In appraising these developments it is important to note that mergers between chemical companies, to withstand competitive onslaught, was not feasible because they would attract anti-trust provisions of the EEC Charter.

Japan

Like the situation in Europe, in the period under review, there was mounting concern in the chemical industry because naphtha had to be imported in the face of rising gasoline consumption. The Japanese situation was more serious because it had virtually no energy resources (unlike Germany or the United Kingdom which had coal), and had converted its economy to total dependence on oil and natural gas and had an economic growth rate far higher than that of Europe.

However, because of the business ethos in Japan, and the role of MITI (Ministry of Trade and Industry) in distributing commercial opportunities among the companies, the importance of the growing naphtha shortage did not impact so much on the ability of individual companies to survive domestic competition (as the situation appeared in Europe) as the ability of the Japanese commodity chemicals industry, as a whole, to survive international competition.

The United States

Because the war did very little physical damage to the United States industrial structure, it was able to develop very rapidly in the post-war period. Like other industry, the chemical industry was focused on promoting domestic markets, however, being dependent for its raw materials on the natural gas processing industry, its fortunes were tied to that of the latter. During the mid 1960s, chemical corporations, as Union Carbide, began to see ominous signs that United States natural gas reserves, because of heavy exploitation (in turn aided by very low prices set by the United States Government for inter-state trade) were being rapidly depleted. In the 1960-1970 period, the reserves/production (R/P) ratio had dropped from 21 to 13 with hardly any addition to reserves[8]. At the same time, United States ethylene production, 80 per cent or so based on ethane derived from natural gas, was growing at a very healthy rate of 11 per cent per annum.

It was becoming quite clear to the chemical industry that diversification of feedstocks would become necessary and that naphtha was economically attractive. The industry felt that this would be necessary despite improvements that were taking place in ethane recovery rates from natural gas (which had doubled to 0.031 liters/1000 cubic meters between 1967-1973). However, it was equally clear that locally produced naphtha, because, of competing auto industry demand, would be too highly priced [9], even though supplies from the oil companies could be assured.

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[8] United States Proved reserves

Unit: 10^{12} cu.ft.

1960	1968	1970
262.3	287.3	290.7

Source: United States Petrochemicals. Brownstein, Arthur, M., The Petroleum Publishing Company, USA (1972).

[9] European naphtha prices were about 5.5 ¢ per United States gallon compared to the 8.5 ¢ /gallon price which a naphtha-reformer unit in the United States would be willing to pay. (The octane number of naphtha, as a 'straight-cut' from the refinery, was too low for the United States auto industry) (70 or so, when the requirement was at the level of 100). Hence to become gasoline it had to be reformed or upgraded in some other manner).

While the chemical industry did manage to get import quotas, which were necessary under the Mandatory Oil Import Program [10/], chemical majors began to come into increasing conflict with the petroleum companies. This conflict was present both in the market place and in access to foreign naphtha. Oil companies by 1970 had about 50 per cent of the market in basic chemicals as ethylene, propylene and the aromatics (30 per cent in ethylene), about 20 per cent of the intermediates market and 12 per cent of polymers and elastomers[11/]. In styrene, for example, while there was only one oil company in 1955 and five chemical companies, by 1970 five oil companies had entered the business (Cosden, El Paso, Sinclair, Suntide and Amoco) but only one new chemical company, Mobay. Also, Oil companies, as Standard Oil of New Jersey (now Exxon), Shell, Standard Oil of California (Chevron) and Phillips Petroleum had integrated forward and increased their chemical sales 100-250 per cent between 1960-1968, while sales of chemical companies as DuPont, UCC, Hercules and Wyandotte increased only from 50 to 100 per cent.

In regard to naphtha quotas, to which oil companies with 'chemical arms' would also be entitled to, the oil companies lobbied the Government for restricted imports on the grounds that it would upset domestic pricing of oil fractions - while not affecting the favourable balance of payments on chemicals trade, which was the argument of the chemical companies in favour of imported naphtha.

[10/] A United States programme designed to protect United States crude reserves.

[11/] 'Oil's Stake in Petrochemicals to Grow' Stobaugh, J.B., Oil and Gas Journal, Sept. 1, 1969.

The chemical companies finally won their quotas on arguments of privileged trade position of the European firms because of low cost Middle East naphtha and the alternative before the chemical companies of moving to Europe to stay competitive.Chemical firms also moved into Foreign Trade Zones, as Puerto Rico, to avail themselves of duty-free naphtha (but the oil firms followed).

In the period under review, the chemical industry displayed little tendency to "back-integrate" into refining operations[12]. This was in the face of the aforesaid "forward-integration" of the oil companies into chemicals. Firms as Monsanto, Allied Chemicals, Celanese and Diamond Alkali, however, did move to obtain a degree of feedstock security by the acquisition of small oil firms -as Lion Oil by Monsanto, Union Texas Petroleum by Allied Chemicals, Champlin Refinery and Pontiac Refining by Celanese, Shamrock Oil by Diamond Alkali (Diamond Shamrock of today), etc. But they were quickly disillusioned. For instance, Monsanto, Union Carbide and Celanese sold out their oil (or gas) acquisitions by 1972. Between 1967 and 1973, the United States chemical industry grew at 8.3 per cent per annum compared to the general economy at around 3.7 per cent. It attracted European companies who were hitherto, with perhaps the exception of Shell, not deeply involved in the United States. Thus Akzona (controlled by Akzo of the Netherlands) merged its three subsidiaries in the United States and acquired the chemicals business of Armour and Co. to become in 1971 the 21st largest chemical company in the United States. Similarly, ICI America, which was a relatively small company, acquired Atlas Chemicals to establish a significant United States base; BASF consolidated its subsidiaries (now including Wyandotte Chemicals) to become BASF-Wyandotte, while further developing its growth as Dow Badische.

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[12] In 1973, the United States chemical consumed, as feedstock and fuel, about 8.6 per cent of total United States consumption of oil and natural gas (converted to same base). If the estimation was made that the chemical industry would grow 6.5-7.0 per cent per year between 1973-1985 and 5.0-5.5 per cent between 1985-2000, then it would consume 18 per cent and 37 per cent, respectively, of all United States conventional petroleum and NGL supplies. In other words, these estimates indicated that the chemical industry would consume about 75 per cent, in the year 2000, of all the petroleum that was in use in 1973 (10.9 million barrels per day). "What is Feedstock Worth?" (Article by Chem-System Hydrocarbon Processing, April 1976.)

The reciprocal interest of United States firms in the European theatre, during this period was limited. The penetration that the firms had made in the immediate post-war period, as Europe searched for capital and management, had run its course. By the mid-1960s European nations had come to believe that American financial control in chemical and general industry was reaching something of the order of 25 per cent. European concern and the 'loss-of-jobs' syndrome in the United States both contributed, through United States Government intervention, to the virtual banning of the flow of new United States investment into Europe. Also, in the low-cost oil environment, with the Europeans becoming dependent on imported naphtha, United States chemical corporation did not see the feedstock situation bright enough to deepen their European investments.

Even though United States chemical firms were also increasingly aware of the country's depleting resources position in crude[13], and anticipated prices to rise for crude and naphtha as a result of rising dependence on Middle East crudes, they made little effort to develop alternate feedstocks, as coal. United States industry, like the European, believed that the most immediate problem was developing the capability of their naphtha crackers to accept gas oil.

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[13] United States Crude Production and Reserves Position (1974 view)

Unit: 10^9 barrels

	1960	1965	1970	1974
Crude Oil Production	**2.47**	**2.70**	**3.33**	**3.07**
Proved Reserves	31.6	31.4	39.0	34.2
Reserves to Production Ratio	12.8	11.6	11.7	11.1

'Proved Reserves' includes North Slope of Alaska. If excluded, 1974 R/P ration reduces to 8.0.

Source: "What is Feedstock Worth"? Hydrocarbon Processing April 1976.

The oil companies, on the other hand, moved rapidly into research for utilising coal as energy source with focus on "clean energy". While this has implications to new chemical feedstocks, as is indicated in a separate section of this document, what is important to this discussion is the move by the oil companies, during the period, to acquire coal mines and coal-processing companies and to redefine their role as being in the 'energy business'. Thus, as with naphtha, if the chemical industry was to seek, at some date, coal as feedstock, it could find the oil industry acting both as its supplier as well as its competitor.

INDUSTRIAL RESTRUCTURING IN THE
POST-1973 PERIOD

One of the important findings of the survey is that industrial change and technology development are taking place in the advanced countries not only in relation to factors such as energy/feedstock costs, availabilities and the logistics of the supply chain but also in response to political changes in the Middle East area and the geopolitics of new petroleum discoveries.

While the quadrupling of oil prices in 1973 had immediate impacts on chemical corporations and forced them to, variously, re-assess their feedstock options, reconsider expansion plans, re-align their linkages with respect to their immediate feedstock/fuel suppliers, etc. which, in sum, were really 'quantitative exercises' - the **second upsurge in oil prices (in 1979) has had a largely qualitative impact on them. Corporations in Europe, Japan and the United States have begun to concern themselves with having to change basic directions of business.**

The countries of Europe, Japan and the United States, aided by new resource developments consequent to the 1973 crisis have started to consider regional accessibilities and with the technological inputs that would be necessary to make the new resources economically viable. Thus, the European countries are examining linkages with North Sea oil and gas, the Japanese with Brunei, Alaska, Australia and Indonesian sources of coal, oil and gas, and the Americans with prospective raw materials in Alaska, Canada and Mexico including indigenous coal, tar-sands and shale. While the countries in general are cognisant of the fact that a vast, deep and well-established infrastructure exists which makes Middle East oil the most convenient and the most plentiful, yet each country has begun to map out strategies which would more uniquely service it. Consequently, any discussion of technological forces at work must, again, consider individual the structural framework of the three regions.

Unlike the possibilities of defining the postures of Japan and the United States, seen as regions as well as countries, Europe presents little scope for generalisation. Although effort will be made in this direction, useful discussion requires that it be considered as an area of separate countries.

THE EUROPEAN SCENE IN GENERAL

In the post-1973 period, the most important resource development in the European area is the establishment of the North Sea fields as significant and reliable sources of oil and gas. The ownership of the fields is based on territorial rights and is shared between Norway, **Denmark** and the United Kingdom. Because the fields are located in a harsh physical environment, and investments for recovering the oil have been made during a period of steeply increasing material and construction costs, the economic viability of the new resource is vitally dependent on the maintenance of international crude prices at their present levels. While in terms of balance of trade, the principal beneficiaries are the United Kingdom and Norway, the important consequence of the North Sea fields to Europe is 'regional' and strategic access.

This access is, however, only specific to the chemicals industry and in terms of its feedstock needs. First, in a substantial number of the North Sea fields, the crude is 'paraffinic' which is particularly suitable for olefins production via the naphtha cut. The industry would be in a position to pay a premium for the naphtha over what it would otherwise fetch as gasoline. Secondly, because the North Sea fields yield associated gas, a substantial quantity of LPG[14/] is co-produced with fuel gas which are surplus to the requirements of the United Kingdom and Norway. Thus LPG becomes an optional feedstock for the chemical industry. Thirdly, the process of separating LPG from associated gas yields natural gas liquids (NGL) which are ideal for chemical producers whose main products are olefins. Although it is unlikely that NGL would be transported to continental Europe, it is practical and economic to transport ethylene made from it.

[14/] The section on feedstocks amplifies the technological options in the use of feedstocks.

However, the North Sea fields have little significance to mainland Europe in terms of being a source of energy. The estimated ultimate reserves of the North Sea area, of gas and oil (about double that of Venuzuela's) are only sufficient to cater for Britain's needs for about 15 years. Thus it would be exploited and phased for United Kingdom's own long-term requirements. The options open to the European chemical firms (including those of the United Kingdom) consequently depend on the competition the chemical industry, as a whole, faces with respect to other users of hydrocarbon materials.

In Western Europe, the four countries - the United Kingdom, the Federal Republic of Germany, France and Italy - are the major industrial ones. These four countries are also the dominant users of energy and feedstocks. Led by them, the overall consumption of energy in Western Europe is quite close to that of the United States. It is of interest to note that although the energy-mix of Western Europe is different to that of the centrally-planned economies of Europe - the Union of Soviet Socialist Republics (USSR) and Eastern Europe - their levels of energy consumption are quite close[15/].

Petroleum is a major energy source for Western Europe, as it is for Japan and the United States. Here again, it is found that Europe's consumption is quite close to that of the United States.

Almost all of Europe's imports are from the Middle East and has a large refining capacity of about 700 million tonnes.

[15/] Primary Energy Consumption (1975)

Unit: Million tonnes oil-equipment per annum

	Crude	Natural Gas	Solid Fuels	Others	Total
Western Europe	664.7	154.2	246.5	122.1	1187.5
United States	764.2	515.7	342.1	118.4	1740.4
Central Economies	454.0	282.2	638.7	53.5	1428.4
World	2701.8	1108.3	1889.1	373.1	6155.0

Source: ECOSOC DOCUMENTS

Over the years, Western Europe has become a significant user of natural gas, 87 per cent of which (in 1979) comes from domestic wells and 13 per cent from imports (USSR, Algeria and Libya). Natural gas has grown from 2 per cent of all energy in 1960 to 19 per cent in 1979.

Consistent with international trends, the chemical industry of Western Europe is not a large user of energy (fuel and feedstock - 12 per cent) when compared to other sectors of demand[16/]. (However, it is one of the largest users of energy among the industries - 37.4 per cent in 1979). The consumption of energy by the West European chemical industry is given in Table 3.

Table 3 *

Energy Consumption of the West European Chemical Industry (1979)

Unit: Million Tonnes Oil Equivalent

	As Feedstock	As Fuel
Solid Fuels	1.6	7.2
Liquid Fuels	116.4	41.0
Gaseous Fuels	29.4	32.1
Purchased Electricity	..	46.7
	147.4	127.0

* Source: Chemical Weekly (India) Jan. 27, 1981 (reproducing DEFIC data)

[16/] Energy Consumption pattern in the United Kingdom (1977)

	per cent	
Transport	- 21	
All industry	- 42	(chemical industry 12 per cent)
Residential	- 24	
All other	- 13	
	100	

Source: 'The Effective Use of Petroleum', Proceedings of the Institute of Petroleum, 1978 Annual Conference, Heyden + Son Ltd. London 1979.

The predominant feedstock for the European petrochemical industry is naphtha, which constitutes 94 per cent of all feedstocks used (gas oil 5 per cent balance NGL).

As the competing demand for naphtha is gasoline, it is instructive to obtain an appraisal of the gasoline/naphtha balance. This is illustrated in Table 4.

Table 4

Naphtha Balance in Western Europe 1977*

Unit: Million Tonnes

Supply		
Virgin naphtha (from atmospheric distillation)	120.4	
Synthetic naphtha	14.6	
Net imports	15.1	
		150.1
Usage		
Gasoline and Jet Fuel	106.0	
Petrochemical industry (feedstock)	39.5**	
Other	4.5	
		150.0

* Source: 'The Outlook for Traditional Petrochemical Feedstocks in Western Europe' Muller, R.G. (SRI International). Symposium on Feedstocks for European Petrochemicals in the 1980s. Society of Chemical Industry London April 24, 1980.

** CEFIC gives European naphtha consumption as 51.5 million tonnes in 1979 with EEC consumpting 44.6 million tonnes.

The geographic pattern of naphtha usage by the European chemical industry is as follows (CEFIC):

		per cent
Benelux	-	18.5
Federal Republic of Germany	-	34.5
France	-	17.9
Italy	-	11.9
United Kingdom	-	17.2
		100.0

indicating the large role that **the Federal Republic of Germany plays in** the chemical industry.

Since virtually all petrochemicals in Europe are derived from naphtha-cracking operations, ethylene capacity can be taken to illustrate the relative positions of the industry in Europe. This information is presented in Table 5 (CEFIC):

Table 5

Ethylene Capacities in Western Europe(1980)

	(Unit: '000 tonnes)	per cent
EEC Area		
Benelux	3140	19
Federal Republic of Germany	4355	27
France	2450	15
Italy	1600	10
United Kingdom	2015	13
	13560	84
Other		
Norway and Scandinavia	825	5
Austria	265	2
Spain	1070	7
Portugal	300	2
	2460	100

Total European ethylene capacity 16,020,000 tonnes.

These figures may also be seen in reference to **Comecon** ethylene capacity. By end-1982 this capacity is expected to be 5.75 million tonnes in comparison to 19 million tonnes in Western Europe[17/].

About 10 per cent of the ethylene produced in Europe is exported outside the West European block in the form of ethylene-derived chemicals[18/].

It is also of interest to obtain an appreciation of the size of the European business in chemicals to that of the United States **which has** long been the leader. In Table 6 data for the United States and

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[17/] The corresponding end-1982 capacities for the United States and Japan are estimated to be 18.8 and 5.5 million tonnes, respectiv

[18/] Ethylene Consumption in Western Europe

	Unit: Million Tonnes		
	1964	1974	1978
For locally consumed derivatives	4800	8975	9955
For export, net	(40)	1325	1080

Source: 'Light Olefin Trends in Western Europe' Russel, R.W., (Philips Petroleum Chemicals) Hydrocarbon Processing, May, 1980, p.223.

Europe are presented.

Table 6

Estimated Production of Chemicals* - 1980

Unit: US $ billion

	Europe	United States	Other**
Commodities	48	40	44
Pseudo Commodites	50	38	40
Fine chemicals	26	20	15
Speciality chemicals	21	24	14
	145	122	113

* Note - All countries except centrally planned economies.

** 'Pseudo-commodites' differ from 'commodities' in that they are sold on performance expectations rather than product specifications. Likewise speciality chemicals (as pesticides) differ from fine chemicals (as ascorbic acid) by being purchased on performance. Source of data: C.F. Kline + Associates, United States.

This importance of Europe is highlighted when one compares the respective situations in thermoplastics (Table 7):

Table 7

Comparison of Major Thermoplastics Consumption in Western Europe and Unites States (1976)

Unit: '000 Tonnes

	W. Europe	United States
LDPE	3100	2400
HDPE	1180	1250
Polypropylene	770	1040
Polystyrene	1620	1880
PVC	3300	2100
Speciality plastics	460	520

With this background, it now becomes possible to review the strategies of the four major industrial countries of Western Europe in relation to the development of their chemical industries and likely changes in directional policies. In following the discussion it is important to recognize that primary attention has been paid to the views of major corporations, basically as expressed in the course of the survey.

The United Kingdom

As will be readily recognized from the foregoing, oil and gas discoveries from the North Sea will have their greatest impact on the United Kingdom. Among the major Western nations, it is expected to be self-sufficient in oil and gas til at least 1990 as Figure V[19] illustrates. While North Sea oil made its entry into the United Kingdom mainland just 2-3 years ago, natural gas has been in substantial use since 1968 (growing from 2 per cent of United Kingdom's total energy consumption to 19 per cent by 1980). It was able to use much of the infrastructure built for earlier coal gas distribution.

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[19] 'The Effective Use of Petroleum' (OP.cit.) p.13

The North Sea oil reserves are estimated between 3500 - 6500 million tonnes, and that of gas, 1500 million tonnes oil equivalent. The United Kingdom's total energy requirement is presently about 260 million tonnes crude oil equivalent per year. Coal and nuclear energy are almost solely used for electric power generation.

The sectoral distribution of energy usage in the United Kingdom is as follows:

	per cent
Transport	17
Industry	37
Chemical feedstock	5
Household/commercial	41
	100

The above pattern of consumption has been characteristic since the mid-1950s, and the important facet of this pattern is that it is expected to be retained for the remainder of this century.

While United Kingdom plans a growth rate of 3 per cent in GDP to 2000, conservation measures are expected to help in a gradual decline of total energy usage (Figure V). An important aspect in United Kingdom planning is the goal that its industrial output and sophistication should grow at such a rate, prior to decline in indigenous oil and gas resources, that it would have a balance of payments position such as to readily warrant future import of petroleum liquids - mainly for road transportation. Economic planning for a low growth rate in GDP - to extend its oil resources - is generally not favoured in the United Kingdom as it is opined that there would not be sufficient market incentive for new technology development, including that needed for energy-conservation.

The United Kingdom currently consumes about 19.8 million tonnes of naphtha, of which 30 per cent services the petrochemical industry, and the balance mostly the gasoline market. The 1977 energy-mix of the chemical industry (of which petrochemicals is a part) stood as follows:

	per cent	
Solids	4.1	
Liquids	33.8	
Gas	25.2	
Purchased electricity	36.9	(for chlorine, etc)
	100.0	

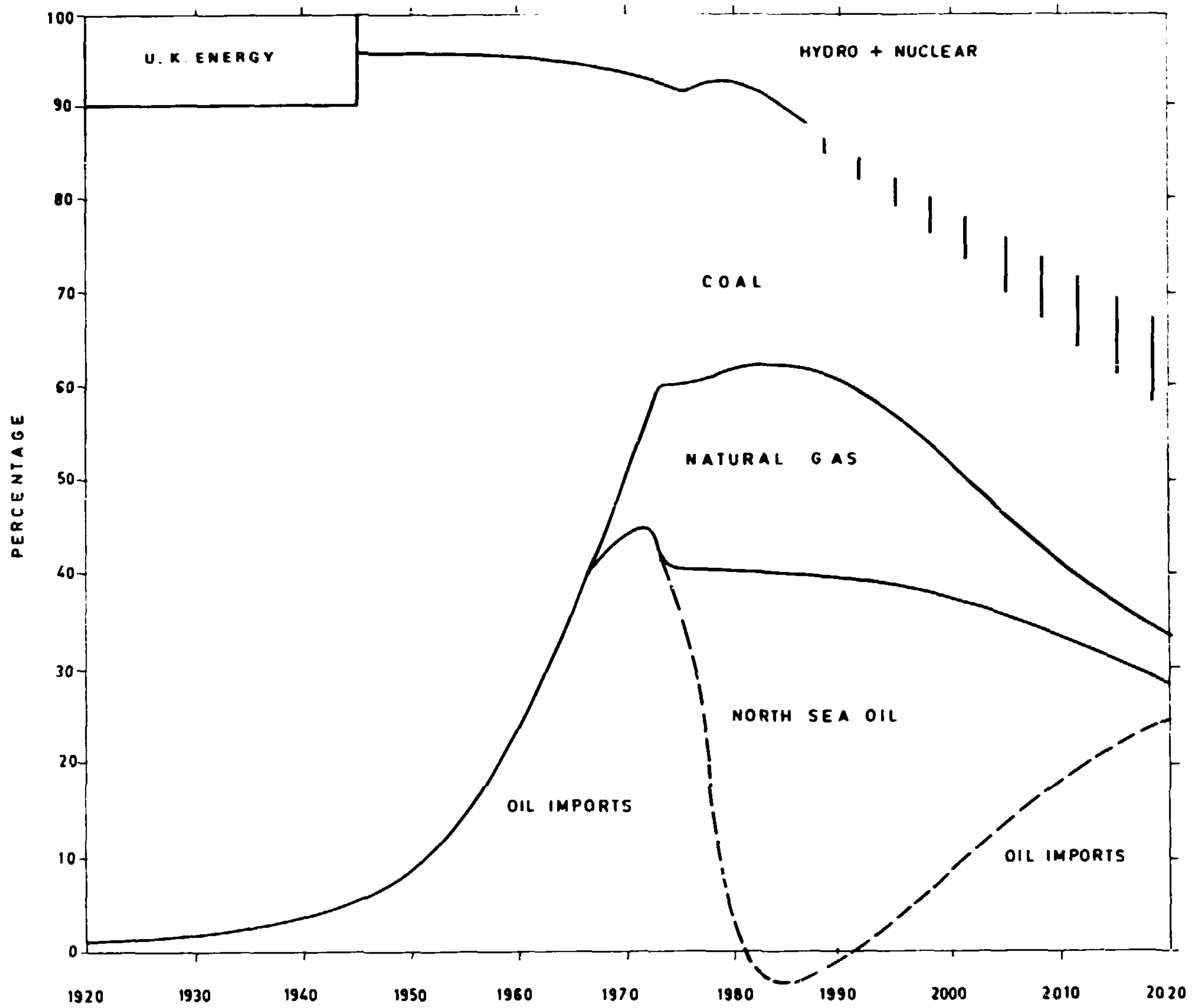

FIG. V MARKET SHARES BY FUEL OF UK PRIMARY ENERGY 1920-2020

As in the processing of natural gas for fuel, LPG and NGL (ethane/propane) can be produced, and LPG is also a byproduct of crude distillation, Britain has the option to substitute them for olefins production. However, since naphtha will not be in short supply (in the country's planning for utilising its North Sea resources) existing naphtha crackers are not expected to take recourse to alternate feedstocks. Since in this situation LPG and NGL would be surplus to the United Kingdom's internal requirements, there is general expectation that these latter feedstocks would become available to Europe.

In the case of NGL it **would, of course, be indirectly available.** Exxon and Shell, in a joint-venture, and Dow Chemicals have announced plans to establish ethane crackers in Scotland, The United States company, Occidental Petroleum, is also pursuing investment in this area. The dominant concern of these companies is commodity exports-styrene, EDC, the polyethylenes, etc.

Shell, Exxon and BP already have significant cracking capacity in the United Kingdom (with both Shell and BP substantially forward-integrated into chemicals). ICI is alone among the chemical companies with major cracking facilities.

ICI has been concerned with factors associated with feedstock security. Since it does not have an 'in the ground' position[20] in oil and gas (like BP), or historical access to oil (as Shell), it has had to ally itself with BP and Phillips Petroleum in separate 'joint crackers'. ICI, however, obtains a major part of its naphtha through owned refineries, which are essentially 'chemical refineries' designed to optimise the output of chemical feedstocks - olefins and aromatics.

Both ICI and BP, but particularly BP, have significant interests in the European **continent.** BP has refineries in Germany, France and the Netherlands, and is associated, as stated earlier, with Bayer in Erdolchemie, a joint-venture for the production of olefins and polyolefins. BP Chemicals has also **deepened its involvement in petrochemicals by recent**

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[20] It is understood that ICI has recently moved to obtain ownership of some of the smaller North Sea fields.

acquisitions of Union Carbide's holdings in Bakelite Xylonite (in the United Kingdom), of Monsanto's polystyrene operation (in France), and of Rhone Poulenc's holding in the French company, Naphthachimie. ICI, too, has European manufacturing interests and its recent major move is the announced establishment of a $500 million facility in Wilhelmshaven, Federal Republic of Germany,for the manufacture of vinyl chloride and PVC (based on ethylene and ethylene dichloride -EDC- supplied from ICI's United Kingdom plants). Both BP and ICI also have large interests in the United States.

Britain's very favourable position in feedstocks (and energy) does not create an urgent demand for the development of alternate feedstocks. Because of the accessibility and convenience of petroleum liquids and gases (NGL), established technologies for their use, their relatively low environmental impact, and their placement in a well-developed infrastructure, there is little motive in the United Kingdom to change feedstocks, even if coal - of which the United Kingdom has ample reserves - should prove to have a lower conversion cost than the petro-materials.

While British Gas Corporation (a public sector organization) is doing serious research on coal gasification, and to a lesser extent on coal liquids, the exphasis is on energy applications - keyed to Britain's requirements after the North Sea fields begin to seriously decline.

To Britain, and more particularly to ICI, coal has significance only in relation to new international manufacturing operations, as in Canada, Australia and South Africa - and to a certain extent, India (all of which countries have coal and substantial British interests). It might also be noted that BP owns (or has interests in) coal mines in Australia, Canada and South Africa.

However, it is questionable as to whether United Kingdom firms will pursue technological development wholly in terms of their international manufacturing interests.[21]

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[21] African Explosives and Chemicals Inc (AECI), South Africa, in which ICI has 40 per cent equity, is doing joint research with Mobil on ethylene-from-coal technology.

Federal Republic of Germany

The Federal Republic of Germany (FRG) is the largest producer, the largest consumer and the largest exporter of petrochemicals in Europe[22]. Its chemical corporations are among the largest in the world. It has long been the fount of chemical innovation. And petrochemicals constitute a pivotal industry in the German economy. Thus, a study of the structure of the German industry is particularly important.

Germany's energy-mix, (1978), was as follows:

	per cent	
Crude oil	54	
Natural gas	15	
Coal	20	
Lignite	7	
Others	4	
	100	= (5.5 million barrels oil equivalent per day)

The country's requirements of crude and natural gas are wholly imported.

The energy requirements of the chemical industry (which includes petrochemicals) is as follows (1975)[23], and shows, the large role that

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[22]

Unit: Million US $

	FRG	UK	France	Italy
Total value of production of chemicals (ISIC 351 + 352) - 1977	44279	25663	21917	15299
Total exports of chemicals (SITC 5) 1977	14296	6753	6534	3156

(Source: ECOSOC Chem/R.45/Annex 1. Aug. 10, 1979)

For comparative purposes, corresponding figures on a "order of magnitude" basis for Japan and United States (for 1978) are:

	USA	Japan
Production value	129,000	60,000
Chemical Exports	11,000	4,900

[23] Comparative energy consumption in Europe (the chemicals industry) - 1975

Unit: '000 MT Coal equivalent

FRG	UK	France	Italy
19890	13400	11750	16400

It should be noted that these figures include energy which is eventually 'exported' out of the country in question (in the form of products).

solid fuels (energy) play in the German chemicals economy. About 60 per cent of the total energy need is in feedstocks, the rest represents fuel needs.

The dependence on solids reflects the country's general planning objective to maximise the use of its very substantial lignite, brown and hard coal reserves wherever feasible. Nuclear energy is not expected to play a significant role in the country's energy programme because of public opposition. This is in contrast to the situations in France and the United Kingdom where nuclear energy - for power generation - has general public acceptance and is expected to gradually build up to provide the prime base for electric power generation, with coal and gas eventually used only for 'peak-shaving'.

The Federal Republic of Germany also plans to reduce its dependence on the use of petroleum distillates for energy generation and electric power (heat uses) so that the needs of distillates for transport and chemicals can be maximised. Germany's present mix of fuels for power generation is illustrative of this strategy:

	per cent
Fuel Oil	8
Natural gas	20
Coal	27
Lignite	30
Other	15
	100

However, as German hard coal is one of the most expensive in the world and lignite resources are being stretched so as to ensure a measure of reliability in the long-term, the country is progressively moving to larger and larger imports of natural gas, with Germany's consumption, at 60 million tonnes coal-equivalent, representing 25 per cent of total West European consumption and about 18 per cent of Germany's total energy utilization. By 1990, the gas consumption is expected to increase to 77 million tonnes coal-equivalent. This becomes significant when it is recognized that the country does not expect to consume, in total, any more hydrocarbon-based energy than it is now consuming. Practically all of this gas will be consumed for its heating value (power generation and residential/commercial heating).

Assurance of natural gas supply and its maximal deployment are important goals in Germany. Figure VI depicting the elaborateness of the West European gas grid thus shows its highest density in the Federal Republic of Germany[24]. The country's present sources of gas are the Groningen fields of the Netherlands, North Sea, and supplies from the USSR (estimated at 15 per cent of total). However, as it is expected that the output of the Groningen fields will decline steeply after 1985, new needs are expected to be met from the USSR and from North African supplies (as the new Italian grids connect up with the north European - Figure VI).

Germany's energy strategy highlights three factors of importance to the petrochemical industry:

(i) that since the heat-user industries will be serviced by lignite and natural gas, the main consumers of petroleum products will be the transportation and chemical industries;

(ii) with fuel oil and heavy stock usage for electric power substituted by other sources, they can be cracked[25] to naphtha/gasoline, thus increasing the contribution of the latter to the transport/chemical-industries energy pool (without a corresponding enlargement of overall national consumption); and

(iii) the general non-availability of lignite as a raw material to the chemical industry as it is pre-empted for power generation[26].

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[24] 'Gas-Energy of the Future', Brecht, C., (Ruhrgas AG) Hydrocarbon Processing, Nov. 1980 pp. 76-0

[25] Federal Republic Germany's once 25-26 per cent production of heavy oils in its refineries has already been reduced to 18 per cent by cat-cracking. BASF's Wintershall refinery is scheduling to get the percentage down to 13 per cent.

[26] Under German Law, the use of lignite is generally forbidden for all purposes except electricity generation. The import of coal from the USSR, Poland, or even from the United States, while cheaper alternatives to the extraction of German hard coal, is unpalatable in the German political environment. Brown coal is economic but Rheinbraun Kohle, which mines 80 per cent of FRG's brown coal, supplies it to parent utility company.

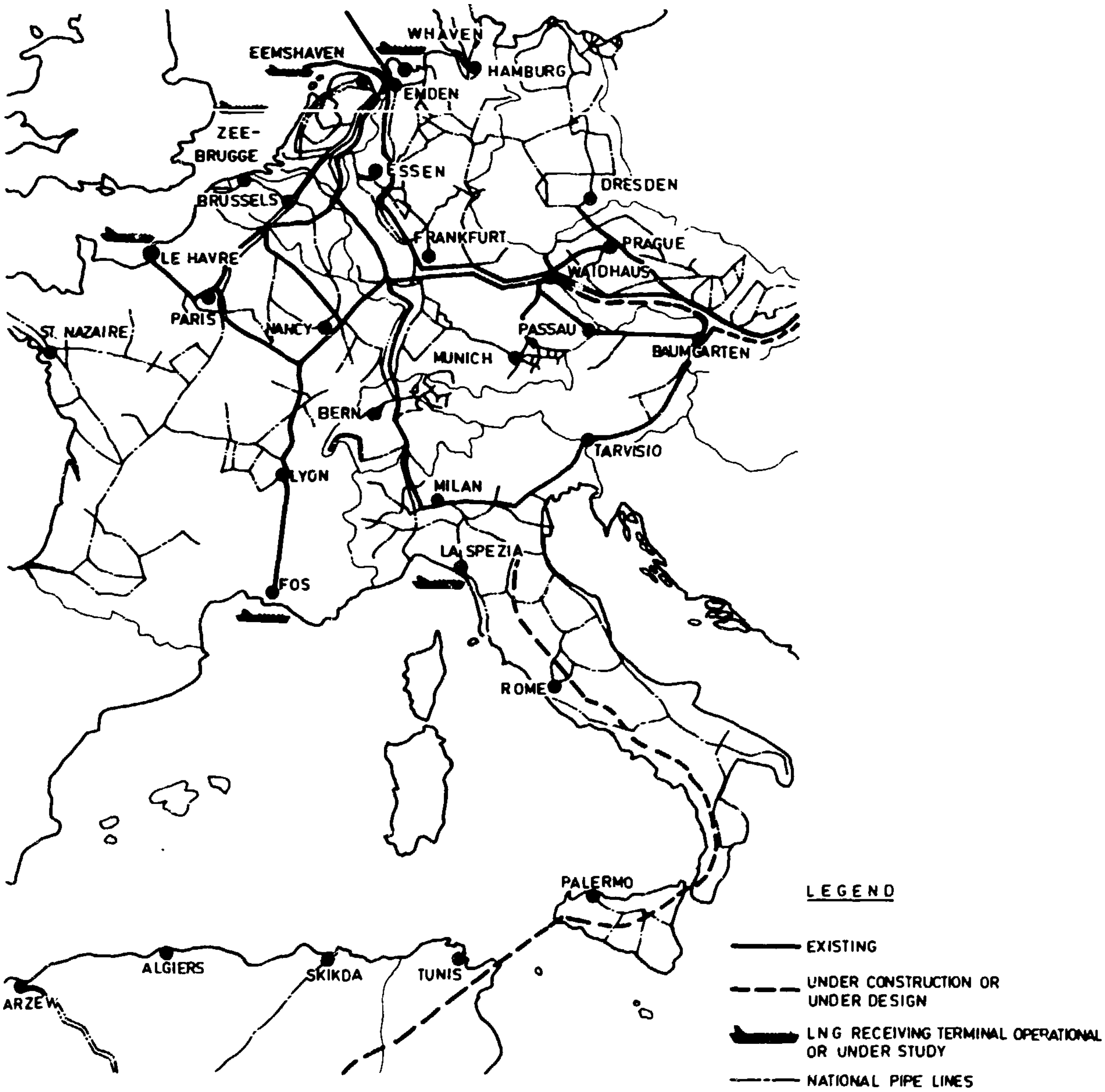

FIG. VI EUROPEAN NATURAL GAS TRANSMISSION SYSTEM

With the demise of 'coal chemistry' in the post-war period, and the abandonment of acetylene (through any route) as a raw material by 1972, the entire German petrochemicals industry is at present based on naphtha, both for the production of olefins and for the aromatics. The industry processes 37 per cent of all naphtha used in Europe (for chemicals) and has 27 per cent (4.4 million tonnes) of Europe's total ethylene capacity. The largest part of this capacity is concentrated in the Cologne area with ethylene grids [27] connecting the latter with a second large concentration in the Rotterdam - Antwerp area (the Netherlands). Virtually all the best known names and producers of petrochemicals - as **Hoechst,** Bayer, BASF and Veba/Huels of the 'German Group', AKZO, Solvay and DSM of the Netherlands Group and Gulf, Caltex, Exxon, Shell and BP of the 'oil-majors group' - are located on this grid and both take and supply ethylene into it (Figure VII).

Following from Germany's strong international position in petrochemicals, the aforesaid geographic concentration of the industry, the well established infrastructures for natural gas and ethylene movement (so too for liquid chemicals which are predominantly **transported on the Rhine),** together with the significant place of the oil majors in Germany's industry (see later) it becomes readily apparent that German planning will tend to operate in a manner to sustain the contribution of the industry with minimum disruption to its basic and traditional structure.

As a consequence of this situation, the survey shows, that it is unlikely that technological or investment inputs in the Federal Republic of Germany will be directed - in the coming decade at the very least - to the substitution of naphtha. Focus on naphtha is also not vitiated by the growing European access to North Sea sources of LPG since the latter is a better co-feed with naphtha rather than a one to one substitute (for olefins production). Likewise, imported ethylene from forthcoming ethane-crackers of Scotland or Norway can be fed into the North European ethylene grid minimising any concern that supply disruptions in crude oil or naphtha can adversely affect the working of the industry[28].

27/ Ethylene - keystone to the Petrochemical Industry, Kneil L., et al., Marcel Dekker, New York, 1980, p. 56.

28/ The North European ethylene grid stores ethylene in saltdomes. Its inventory level has been designed to soften politically-motivated short-term disruptions.

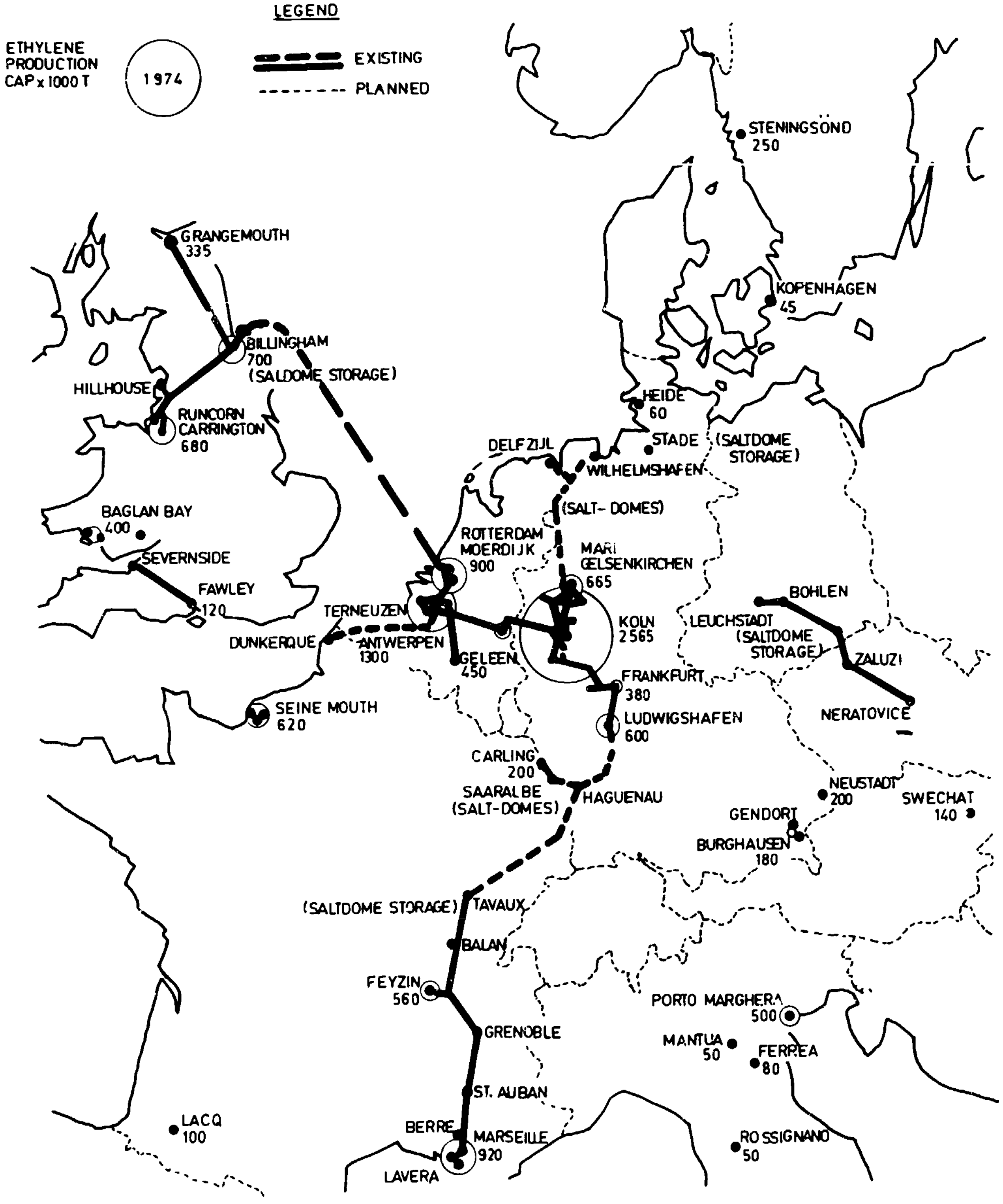

FIG. VII ETHYLENE PIPELINES IN WESTERN EUROPE

Additionally, the growing replacement of fuel oil (heavy stocks) in power generation will act to increase the supply of light cracking feedstocks as LPG and 'synthetic naphtha'.

There are other and equally significant reasons for expecting the sustenance of naphtha as the prime feedstock, the most important of which begs the question: will German firms establish new crackers (of any type) to produce olefins in the Federal Republic of Germany?

While undoubtedly with German economic growth the need for olefin-based chemicals and plastics can be expected to increase, it is not a coincident requirement that new cracking capacity be established in **the Federal Republic of Germany - even on national strategic considerations**[29/]. There is every indication that **the Federal Republic of Germany's requirements** of olefins can be economically met by production based in the United Kingdom, in Norway or from the ethylene grid. Equally significant is that Norway's new olefins crackers and those planned to be built in Scotland (and possibly those of Eastern Europe) are, to a substantial extent, oriented [illegible] obtaining access to Germany's large market.

This line of reasoning implies that with little motive for building new crackers in Germany, the strategy of remaining on naphtha in existing crackers is consolidated rather than weakened.

Importantly, the survey reveals that Germany's strategic objectives relating to hydrocarbons security are being met by the resources developments in the North Sea area and increasing availability of natural gas in the immediate West European periphery (USSR and Algerian gas).

The pivotal objectives of **the Federal Republic of Germany's** corporations are their sustained individual growth, viability and independence, consistent with the carefully **nurtured national market environment. For the achievement** of such **firms in the Federal Republic of Germany appear to be moving away from dependence on 'upstream products' towards that on 'far downstream' products.**

[29/] With the Federal Republic of Germany's membership of the European Economic Community, German olefin producers can, for example, locate themselves in the United Kingdom.

This shift of focus is evident from the new relationships the chemical firms have developed with the oil majors.

Transnational oil majors - Caltex, Marathon, Exxon - play a significant role in the Federal Republic of Germany as refiners and olefins producers and have a favourable economic impact at the national level because of their historical access to oil supplies[30]. This 'accessibility' has led the German chemical corporations, particularly Bayer and BASF of the 'Big Three' (who are amongst the top ten chemical companies of the world[31]) to seek 'alliances' with them.

The 'nucleus' German companies (Bayer AG, Hoechst AG, and BASF AG) have, however, opted for an 'arms length' relationship with producers of olefins even though they themselves may be engaged in olefins production in these joint-ventures[32]. This is unlike the structure of firms such as ICI (in the United Kingdom or Europe), Montedison (in Italy) or the major chemical corporations of the United States, who are back-integrated, at the very least, to olefins production.

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[30] The firm DEMINEX has just been founded in Germany for independent access to international oil. Its membership is constituted of the federal Government, German oil firms (Veba Oel, Wintershall) and chemical firms (as URBK). It is already engaged in the North Sea area.

[31] Ranking of 10 largest chemical companies by assets (1979)

1.	Bayer	- $	13.6	billion
2.	Dow Chemicals	-	10.3	"
3.	BASF	-	9.9	"
4.	ICI	-	9.6	"
5.	Du Pont	-	8.9	"
6.	UCC	-	8.9	"
7.	Montedison	-	7.4	"
8.	Ciba-Geigy	-	7.2	"
9.	Rhone-Poulenc	-	7.1	"
10.	Hoechst	-	6.2	"

Du Pont's recent merger with Conoco puts it at the top of the list, a position it held till the early 1970s.

[32] As discussed earlier, BASF is tied up with Shell in Row and Bayer with BP in Erdolchemie. Hoechst has no alliance in FRG with oil companies but has an 'arms length' relationship with URBK. This company, in which Hoechst reportedly has a 25 per cent equity interest, produces olefins and polyolefins.

The survey indicates that the creation of these joint-ventures is, in substantial part, consequent to the recognition by the nucleus companies of four factors at work in the general petrochemicals economy. The first of these is the emergence of a market for 'commodity petrochemicals' - products that are bought in bulk, in competitive bidding and which do not require technical service from the supplier. The second is that the technological processes for the production of these petrochemicals have reached a level of maturity with the result that good products are available from numerous firms - at the national, regional and international levels. The third factor is the 'natural advantage' that oil producers would have in manufacturing feedstocks (olefins and aromatics) whose contribution to the manufacturing cost of the commodity chemicals has been steadily climbing to upwards of 70 per cent. The fourth factor is that commodity plastics and chemicals are more susceptible to economic downturns than proprietary products. Further, there was ample evidence available that oil majors wished to penetrate into the petrochemical markets because, with OPEC action, their role in oil was largely and merely reduced to its processing.

The 'arms length' position provides the advantage to the nucleus companies that olefins can be procured competitively while enabling the companies to use their well-developed R+D structures for the creation and the deepening of positions in high value proprietary products (pharmaceuticals, pesticides, etc.). Essentially, this strategy also permits the nucleus companies to retain their historical independence from the oil companies.

Consequently, the survey finds the German companies (in the Federal Republic of Germany) diversifying into proprietary products (including speciality plastics) which now contribute upwards of 60 per cent to sales revenue. Principally, the companies have sought products which are low in 'petroleum content', are generally freight-insensitive and whose successful marketing requires the exploitation of their international brand-name based service and distribution networks.
In the case of the sales-mix of Hoechst, for example, only one-third is directly petroleum-related and the balance two-thirds high-technology proprietary products with a low 'petroleum content'.

However, the companies have recognized that total severance from commodity chemicals, giving the field to the oil companies, would certainly diminish the large cash flows that high tonnage production usually provides. Furthermore, with growing investment opportunities in developing countries, 'presence' in commodity chemicals would be necessary as the firms were identified with the products.

The above discussion shows that there are three disincentives at work which tend to diminish Federal Republic of Germany's importance as a developer of those technologies which will result in the use of non-traditional feedstocks for the production of basic petrochemicals. These are:

(a) geo-political assurances arising from the new North Sea hydrocarbon resources and the increasing availability of natural gas (energy form) from the USSR and the Mediterranean littoral;

(b) continuity in the availability of naphtha as a basic feedstock by virture of:

  (i) the substantial presence of oil majors in Germany;

  (ii) catalytic cracking of heavy petroleum products ('bottom of the barrel' products) as a consequence of them becoming surplus;

  (iii) the physical infrastructure that efficiently services the naphtha-based chemicals industry; and

(c) the shift in the developmental focus of the nucleus German companies to proprietary products with a low 'petroleum content'.

It is believed that this is not limited to the short-term. The dependence of German firms on naphtha is expected to continue to the end of this century (and perhaps beyond it) even though prices of raw materials are expected to increase and flows from traditional sources, and the North Sea, reduce. The survey shows that for continued reliance on naphtha, German firms,like other European firms (see later), will move to areas relatively rich in petroleum or petroleum-like raw materials (shale, tar sands) - Canada, USA or Mexico.

This stance of the corporations on naphtha as a continuing feedstock, of course, appears surprising in view of the historical contributions Germany has made to 'coal chemistry', the vast accumulation of experience in German corporations and the decline in the price advantage that has so far favoured petroleum to coal.

In the view of the producer companies of the Federal Republic of Germany, and of its engineering companies - Linde, Uhde and particularly, Lurgi - it is not technological under-development that limits the use of coal in Germany but a combination of economic and political considerations. German-developed technology (as Fischer-Tropsch synthesis) is, in fact, in commercial use in South Africa in large plants (Sasol complexes) oriented to petroleum-like fuels and/or 'petro' chemicals. Similarly, German technology is in use in India for the manufacture of 'synthesis gas' for ammonia fertiliser. The position in the Federal Republic of Germany is that with lignite (otherwise an excellent base for the production of syngas) reserved for electric power generation, and hard coal too expensive to mine (though plentiful), German utilization of coal requires that it be imported from Poland, USSR, Australia and the United States. While economic in terms of cost this alternative is, at present, unacceptable in terms of the country's domestic politics. But this is not the dominating factor. The level of investment required for the utilization of coal for the production of feedstock is manifold, larger than what would be involved in a petrochemicals complex of optimum size[33/]. The financing of such investment either requires that German firms combine together or calls for Government financial involvement in manufacturing enterprises. The post-war independence of the German corporations would be vitiated by the joint efforts, and furthermore, such a venture could attract anti-trust provisions of the EEC treaties. Also, in the market economics of Germany, Government financing, and thus the element of control in production facilities, would not be acceptable to the chemical firms. For these reasons utility of German coal-chemistry and technology is said

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[33/] Environment protection requirements, further, sharply raise investment costs. The disposal of solid residues is a major unsettled question.

to lie outside of Germany[34].

In the above interpretation of the German situation the focus has been on major directions in new technology (if any) in view of the country's hydrocarbon needs and resources. This analysis does not imply that no technological effort at all will be made in the country to utilize coal indigenously for producing chemicals - or that technologies for producing chemicals from synthesis gas or methanol (which latter feedstocks can be derived from coal, natural gas, biomass, petroleum distillates or residues) will not be purused. There is in point of fact, a considerable amount of research in coal utilization that is being funded by Government - and entrusted to engineering company/producer company combines for development. However, the indication of the survey, based on interviews with major manufacturing corporations, is that with their growing abandonment of upstream products as important profit-generators the full developmental and entrepreneurial resources of the companies will not be in these directions.

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[34] In the discussion of the United States situation, it will be shown that German coal-based technologies have high practical relevance.

France

The structure of the petrochemical industry in France, while it has some parallels to that of Italy, differs considerably from that prevailing in the United Kingdom, the Federal Republic of Germany and the Netherlands. The most predominant difference is the role of 'public sector' companies (which are joint-stock companies with traded stock) in the ownership and management of some of the country's major chemical firms such as ATO Chimie, CdF Chimie and Chloe, a pattern that has steadily evolved over the past 20 years. It is important to recognize that these public sector companies (as Elf-Aquitaine, Totale and Charbonnages de France) are in the 'energy business' (petroleum mainly) with majority ownership by Government[35].

Despite indirect Government holdings, the chemical companies operate autonomously in a laissez-faire environment, in competition with each other and with privately-owned chemical companies as Rhone-Poulenc (once, France's largest chemical company), Produits Chimiques Ugine Kuhlmann(PCUK,a subsidiary of giant Pechniney-Ugine-Kuhlmann), Naphthachimie and the subsidiaries and joint-venture enterprises of transnationals as British Petroleum, Hoechst, Solvay and Cie, Exxon, Shell NV and others. However, it is of interest to note that, today, many of the private companies in France are, in themselves, subsidiaries of oil majors, including the country's renowned Naphthachimie (now wholly owned by British Petroleum after its acquisition of 50 per cent of the stock hitherto held by Rhone-Poulenc).

The association of the French chemical companies with oil interests, while recent, is not an expression of a need for feedstock security - as is the case with ICI, Bayer or BASF - but a reflection of the general restructuring of French industry with growing State capitalism - and to a subordinate extent, the desire of the oil companies to forward-integrate to chemicals in order to overcome the disadvantage of Government control on the prices of petroleum products. To the chemical companies, oil company involvement has, of course, indirectly given them a warranty of energy and feedstock supplies.

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[35] For example, Government ownership extends to 67 per cent in Totale and in Elf-Aquitaine via holdings through CFP - Compagnie Francaise des Petroles - a 100 per cent Government company.

In principle these warranties or assurances are of limited value to the chemical companies. France is not a producer of oil (except for small production at Laq in the Aquitaine District)[36]. Its once major owned source, the Saharan fields which it discovered, are now under Algerian control. Thus, 'domestic' French companies, even if in association with Government, are in a poorer position than the chemical subsidaries of foreign oil companies, Exxon, BP or Shell, which have historical access to Middle East oil. However, the saving grace for most of the chemical companies of France basically comes from the country's pioneering energy strategy.

France's strategy rests on nuclear energy (based on its substantial uranium reserves) to correct its overt dependence on petroleum, which along with gas, supplies 71 per cent of the country's current needs of energy. By 1990, it is France's ambition to have nuclear energy rival petroleum as an energy source[37]; a programme without parallel in any other country. While France has some coal it is expensive to mine. Hence it is imported. Coal is expected to be used only for power generation and then only as a 'peak-shaver', relegating to fuel oil, now providing about a third of the fuel needed for electricity generation, a very minor position in that respect[38].

36/The French public sector oil companies have concessions, or are present in all the major fields of the North Sea (British, Norwegian, Danish, German and Dutch), particularly in the **Norwegian** Ekofisk fields (now yielding to the French 15 million tonnes per year of crude). French companies also have concessions in Indonesia, Congo, Gabon, Nigeria, Canada and Labrador.

37/France's energy programme is implicit in this forecasted shift.

	1978	1990
Oil	60.0	30.6
Gas	10.5	16.3
Coal	17.4	12.6
Nuclear	3.7	30.2
Others	8.4	10.3
	100.0 (1)	100.0 (2)

(1) 380 million BPD oil equivalent
(2) 484 million BPD oil equivalent
Plan revealed at "Venice Summit" May 1978.

38/ Natural gas is generally not used in France for electric power generation.

Essentially the thrust of this development is that petroleum would basically come to be used for transportation and for chemicals production, without large competing demands for other usages. Thus, France will need to seek supply assurances only for such requirements[39/]. Coincidentially, because of France's accent on nuclear energy, electric power is expected to be more widely used for home and commercial heating[40/] releasing natural gas - which France imports[41/], but also produces to a limited extent from declining fields - for other usages, including energy and feedstock needs in chemicals.

Even in respect of transportation, it is France's objective to reduce the use of petroleum by mixing gasoline with methanol and (to a lesser extent) ethanol - energy orientations which are not paralleled in the United States, FRG or Italy. While ethanol is expected to be biomass-based (France has a substantial agricultural base), methanol is mainly expected to be imported from Algeria and other North African sources, manufactured from natural gas.

[39/] The recent merger of Elf-Aquitaine and Texas Gulf Corporation can be interpreted in this light.

[40/] Using nuclear energy to provide the 'base load' in electrical power generation requires that usages for such power be found at times of low electric power demand - nonpeak hours and in the summer months. (In France, as in Europe, electricity is cheaper than fuel oil or natural gas. With 1972 = 100 for all three energy forms, 1981 price indices are 350, 900 and 650-700 respectively.

[41/] In the forms of LNG from Algeria and Libya (and from some of the Gulf States) and piped gas from the USSR.

Consequently, unlike the emerging situation in the United States and FRG (and also the Netherlands) where North Sea developments carry the primary assurance of continued petroleum supplies to the chemical industry, France's chemical industry surprisingly obtains that assurance as a 'fall out' of the country's emphasis on nuclear energy. Alongside this, it should also be noted that as France has substantial refining capacity (about 170 million tonnes or 25 per cent of West European capacity), a large volume of the 'bottom of the barrel' products, now mostly expressed as fuel oil and used substantially for electricity generation, will become available as 'cracking stock' for transportation fuels and chemical feedstocks.

The emergence of this favourable situation has the net effect of dampening the 'driving force' to search for technologies which can substitute the use of petroleum distillates in the manufacture of chemicals. Besides this, there are also other factors which collude in dampening the "driving force". First, as France has traditionally been a better contributor to the 'petroleum engineering', 'exploration' and 'refining technology' sectors (Technip, in engineering, and Institut Français du Pétrole, in exploration and refining technology, are known world-wide) than to petrochemical technology, there is no 'push' emerging from historical involvement in raw materials. Also without adequate focus on petrochemical technology, most of France's present stock of technology is imported (for example, Solvay's HDPE) or imitative developments (although proprietary) of technologies first established and developed elsewhere (as low density polyethylene). Second, as a result of a combination of factors as inadequate technology leadership, European overcapacity and the absence of backward linkages to oil, privately-owned French chemical companies have been either shedding business or merging with companies to obtain broad-range multi-sector interests. Illustrative of the former is the recent shedding of business by Rhone Poulenc leading to the formation of Chloe (40 per cent Elf-Aquitaine, 40 per cent Totale, 20 per cent Rhone Poulenc) and the acquisition of Naphthachimie's chemical business by British Petroleum. Illustrative of the merger is the formation of the conglomerate Pechiney Ugine Kuhlmann, PUK (earlier independent organizations with chemical interests) with its petrochemicals subsidiary, PCUK[42/]. These changes have the effect, of course, of reducing technological efforts for the independent survival of

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[42/] The latter, in itself, has recently shed some of its business to CdF Chimie, to BASF, to Montedison, etc.

competing units (i.e. defensive research). Thirdly, French chemical companies, following to some extent their European counterparts, are well on their way to increasing the content of 'far downstream products' in their sales-mix, with decrease in their attention to olefins and petrochemical intermediates, leaving them to the oil companies. (Thus, PCUK's present sales mix comprises speciality products to the extent of 70 per cent whereas in the late 1960s it was heavily oriented to the 'commodities').

Consequently, the survey once again finds that in France, as in the United Kingdom and the Federal Republic of Germany, national energy strategies have the rather unexpected but beneficial effect of allowing existing manufacturers to continue to rely on conventional technologies. Further in the particular structure of the industry in France, one does not even witness a desire by the chemical companies to remain independent of the oil companies as, for example, is the express stance of Hoechst, in Germany, and of the United States companies (see later), or the 'arms length' approaches of Bayer, Badische and ICI. Hence and again, the impetus for the development of technology to stay independent is weakened, if not absent.

Italy

A major feature of the present day structure of the Italian petrochemical industry is the near total state control of productive capacity. With the exception of Montedison, in which Government does not have a major holding, all of Italy's once major private companies - Rumianca, SIR Consozio (a group of over 100 firms) and Liquichimica - are now controlled by central agencies [43] (through ENI/ANIC, the State-owned petroleum company and its chemical subsidiary). The technical press attributes the collapse of the private companies to management defaults, including industry overcapacity. It is feared that even in the case of Montedison, Government take-over might result as the company has had credits for nearly a decade and is heavily in debt. Thus, unlike the industry restructuring that is taking place in much of Western Europe, the energy situation is not its paramount cause in Italy.

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[43] Large sections of Liquichimica and SIR have reportedly been closed down due to overcapacity.

In contrast to the chemical corporations of the United Kingdom, Netherlands, the Federal Republic of Germany, and France, Italy's firms have historically concentrated their manufacturing activities within their national geographical area. And again, in contrast to European counterparts, the firms have been more oriented to commodity chemicals (and the like, as fertilisers) than to specialities. Only Montedison differs in having some international operations and a large component of proprietary products (as engineering plastics, pesticides) in its production-mix. Because of such orientation, Italian firms have been quite vulnerable to domestic economic swings, without scope for any compensating adjustment from favourable international investment and operations (other than from commodity chemicals exports) or from privileged positions in proprietary products (as, for example, pharmaceuticals in the hands of Bayer, Hoechst and ICI) which give a measure of stability to income.

While, as aforesaid, the energy situation does not appear as a primary causative factor for industry restructuring, a consideration of the country's energy requirements and resources shows that the industry is quite sensitive on that account. Italy has very modest reserves of lignite, coal and petroleum (annual production, 2 million tonnes) but it is better provided with gas which, hitherto, has supplied about 40 per cent of the country's need (of that energy form). However, of the four countries of Europe being considered in this document, Italy is the least self-sufficient in energy (only about 15 per cent). Italy thus imports about 100 million tonnes of petroleum a year, sizeable amounts of gas (as LNG from Libya and piped Soviet gas) and of coal for electric power generation. The following is an approximate pattern of Italy's energy consumption:

	per cent
Solids	8
Oil	75
Gas	10
Hydroelectric, Geo-thermal, etc.	7
	100

Partly as a result of having a warmer climate, and partly due to its lower standard of living, per-capita energy consumption in Italy is between 50-60 per cent that of general European consumption which abates its overall energy demand.

The use of nuclear power for energy, which would reduce dependence on oil, is opposed by domestic pressure groups and unless Italy imports nuclear energy from France (being discussed) this source is not expected to meet any but a negligible part of the country's demand.

Consequently, as Italy does not have the solid fuel resources of FRG, the public's acceptance of nuclear energy as in France, the off-shore oil and gas resources of the United Kingdom, or the large on-shore gas fields of the Netherlands, the country is in a poor position to affect interfuel substitution, the keystone of the European energy strategies. Furthermore, as Italy does not have a significant presence of international oil majors, or extensive concessions in oil-producing territories, it is more prone than its European counterparts to supply swings. This susceptibility is particularly significant in Italy as it is the largest 'refiner' in Europe and is an exporter of refined products to that area.

Italy's energy policy consequently reduces to a two fuel policy - natural gas and petroleum. In respect of the former, the country's plans call for imports of gas, partly as LNG from Algeria and Libya, but more predominantly as piped gas from Algeria (for which a submarine pipeline is nearing completion), the Netherlands and from the USSR.

In respect of petroleum, ENI has moved to form a 50:50 joint-venture with United States Occidental Petroleum, in which arrangement ENI obtains access to oil (together with an interest in Occidental's United States coal mines) in return for providing the American company a stake in Italy's petrochemicals industry.

While these strategies provide a certain measure of feedstock security to Italy's chemical industry, it is more exposed to competition from fuel demands than its European counterparts. Thus, the chemical industry competes with 'oil energy' needs of the electrical power industry, the transportation industry, and even from residential heating needs[44].

The survey consequently reveals that there is absence of a significant motive force in Italy for the development of alternative technologies (alternative feedstocks) for the manufacture of basic petrochemicals. Five factors, appear to account for it:

(a) Italy's poor resources position in all energy (feedstock) forms providing little economic advantage if one is substituted for the other;

(b) no slackening in competing demands for petroleum distillates (as is otherwise the situation in peer European countries) promising some future availability as feedstock;

(c) entrenched commodity positions which have led **to the failure of** companies as SIR, Liquichimica and Rumianca, in contrast to the relative stability of Montedison which has **a good proprietary position** in specialities;

(d) the urgent need to rehabilitate the disadvantaged companies; and

(e) the penetration of oil companies, as Occidental and ANIC into the commodity chemicals area with their intra-company accessibility to feedstocks.

To these factors one may also add two other disincentives:

(a) that arising from Europe's and Italy's overcapacity in basic petrochemicals, making the utilization of existing capacity a better economic proposition than a new facility based on new technology;and

(b) the freight situation that makes Italy a readier **market-place** for Arab petrochemicals (when they are produced) than the other markets of Europe.

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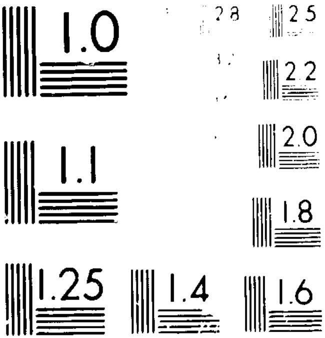
[44] Italian law prohibits use of fuel oil in residential heating. If natural gas of LPG linkages are not available, heating needs are met by gas oil in Italy.


1.0
2.8
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

THE JAPANESE SCENARIO

While, as will be seen in this review, the Japanese Government and major petrochemical corporations have embarked in new directions as a result of changes in oil prices and supply, structural relationships in the industry have hitherto changed far less than in counterpart industrialised countries. By 1976, for instance, the chemical industry demonstrated that it could absorb the 'oil shock' of 1973 with its corporations maintaining the independence and vitality which have characterised them in the post-war period. Even the second round of steep crude price increases in 1979 appears to have had little influence on domestic structural relationships. Corporate mergers, the formation of joint-ventures with oil companies or back-integration to oil through acquisition, which in one way or another have taken place in Europe and the United States are largely absent in Japan. However, at the same time, the recent political upsets in the Middle East area, and the restructuring occurring in the international industry have caused a pause in the expansion of chemical industry capacities. Japan's corporations now appear to be addressing themselves to two major issues:

(a) to what extent should they persevere with their present product lines?

(b) should relocation to sources of energy/feedstock supply or near product markets be the new directions?

The Petrochemicals Industry in the General Economy

To place these issues in perspective it is necessary to recognize that the chemical industry of Japan (inclusive of petrochemicals), although substantial by world standards is, today, more in the nature of a service industry to the rest of Japanese industry rather than an important one in its own right. That is, it does not have the stature of steel, automobiles, ship-building or the consumer-electronics industries. It contributes less than 5 per cent of the output of the manufacturing sector, constitutes less than 4-5 per cent of the value-added by all industry and represents only some 3 per cent of the country's exports of about $ 100 billion. It is critical because of the support it gives to the export of consumer electronics, automobiles and textiles and because it efficiently substitutes for products which would otherwise have to depend on imported alternative materials.

The sustenance of the industry, however, greatly depends on the ability of the country to meet its energy and feedstock needs. In this respect it is, like counterpart industries of the advanced countries, the most dominant consumer of energy among the manufacturing industries. In Japan's case the situation is heightened as its chemical corporations also refine most of the aluminium produced in the country. Additionally, because of emphasis on commodities in its product-mix, and limited technology alternatives at the present time, the country places a large demand on liquid feedstocks which, of course, have been tightest in supply.

Paralleling European development, Japan's petrochemical industry is almost wholly naphtha-based. Naphtha requirements for the petrochemicals are now equal to that used by transportation. This has the consequence that domestic generation of naphtha is insufficient to meet both demands and imports are needed. Since domestic naphtha, in itself, is produced from imported crude, the attention of the industry is directed to measures that Japan, as a whole, takes to obtain assurances of such supplies and importantly that of source stability. These are highly strategic factors since the country imports about 90 per cent of its hydrocarbons.

Japan presently obtains about 40 per cent of its crude and 50 per cent of its imported naphtha through the oil majors[45]. But, as the supply sources for the majors is essentially the Middle East, the country's objective is to decrease dependence both on crude and on the Middle East.

The mix of Japan's total energy usage, and its intended 1990 composition are presented below[46].

	1978 per cent	1990 per cent
Oil	72.0	49.8
Coal	14.3	17.8
Natural gas	4.5	9.9
Nuclear	4.2	11.7
Hydro-electric, etc.	5.0	10.8
	100.0	100.0
	(=7.14 billion barrels/day, oil equivalent)	(=12.36 million BPD - OE)

45/International oil majors (Exxon, Mobil, Caltex) are refiners in Japan but as joint-venture subsidiaries of Japanese oil companies, notably Nippon Oil, Japan's largest. None of the majors is associated with ethylene production.

46/Declared at the Venice 'Energy Summit' (1978). By 1990 Japan's energy demand rises by 73 per cent in contrast to declarations of 27 per cent by United States and France and 63 per cent by Federal Republic of Germany.

The use of coal is expected to be doubled because of its availability in 'politically stable' areas as Australia[47/] and Canada and that of natural gas quadrupled with country-assisted LNG projects in Japan's'proximity'[48/] as Brunei, Indonesia, Thailand and Alaska. Similarly, Japan is planning projects in Indonesia and elsewhere so as to obtain NGL and LPG, petrochemical feedstocks, from proximate "politically stable" areas.

Despite such moves (which, to repeat, are directed at assurances of supply rather than inter-energy economies) Japan in 1990 would still be importing 20 per cent more crude, and crude derivatives, than it did in 1978. As logistics dictate, most of such supply will continue to be supplied, at least to 1990, from the Middle East.

Survey Findings: Industry Directions

The survey finds that on the basis of these factors, and in recognition of the urgent changes taking place in the international structure of the chemical industry, the corporations of Japan will, in all probability, move in the direction of:

(a) reducing the emphasis on the commodities that is present in their domestic product-mix;

(b) extending their overseas involvement and investment which will, however, have a commodities orientation; and

(c) maintaining capacity levels for commodity products in the domestic market within the existing structural framework and consistent with maximum servicing of internal demand.

[47/] Idimetsu Kosan, Kobe Steel + **Mitsubishi** Chemical have established the Victoria Brown Coal Development Corporation in Australia for the exploitation of brown coal, including its liquefaction and with the objective of servicing Japan's energy needs.

[48/] Distance to Japan

Brunei - 4100 - 4500 km
Indonesia - 4400 - 6000 km
Abu Dhabi -12000 km

In terms of the consequences of these changes to the development of technology, the survey's findings are that Japan's petrochemical companies will:

(a) integrate forward with new technology;
(b) import technology for 'new generation' feedstocks, when developed; and
(c) pursue with its 'improvements and adaptions' orientation to imported technologies both for older and newer technologies.

The clear implication of these expected developments is that Japan will continue to rely on petroleum and conventional hydrocarbon feedstocks for its basic industry and that large efforts at substituting feedstocks is unlikely to take place.

The rationale for these findings follows.

Commodities Emphasis in the Japanese Petrochemical Industry

The emphasis on commodity products in Japan must be appreciated in the light of the following contributive factors:

(a) in the post-war period, the country **focused** on maximised production of the then new materials of commerce - synthetic textiles, plastics and the like - which could, both directly and indirectly, aid export earnings, and which, in the cost-price structure prevailing then, would most benefit from scale economics;
(b) technologies for commodity chemicals and plastics were available on a 'direct licensing' basis from United States and European firms without tie-ins to foreign investment, which situation was in line with the objective of Japanese corporations to be, as far as possible, sole operatives in the domestic market; and
(c) inadequate managerial and technical skills, together with funds, in the early post-war years limited scope for new product research and delayed corporate acceptance of risk in the utilization of novel but untried chemistries.

In later years when the **corporations** could have pursued new products research, intense domestic competition between Japanese companies pre-empted them of necessary funds.

This emphasis on commodities, however, exists only at the level of the petrochemical corporations. Scores of firms, as Takeda or Asahi, produce high value-added specialities (pharmaceuticals, coatings, speciality polymers, etc) based on materials purchased from the petrochemical corporations. These firms are not affected by feedstock price increase, and of course, feedstock availabilities, to the same extent as the producers of the basic petrochemicals. Thus, the need to integrate forwards into speciality products, to obtain value-addition and profitability, is more a characteristic need of the petrochemical industry than a need of the overall chemical industry.

In regard to the scope available to the domestic industry to expand its capacity base, even in the context of attractive alternate feedstocks, cognisance must be taken of the following factors.

Japanese aggregate capacity is as large, if not larger, than those of the countries of Europe. However, capacities at the level of individual companies are, for most products, substantially smaller than those of leading international companies[49/] and thus scale disadvantaged. This has occurred, to a large extent, as a result of MITI's intervention in the industry to distribute opportunity sequentially (the 'queue system') to contending firms, the characteristic role of MITI[50/]. It has had the consequence of denying scale advantages to individual companies, and thus, the need to improve scale.

[49/] Capacity of the largest producer (1978), Tonnes

	United States	Europe	Japan
Ethylene	2,200,000 (UCC)	1,100,000 (ROW)	770,000 (Mitsui)
LDPE	680,000 (UCC)	840,000 (ROW)	260,000 (Mitsubishi)
HDPE	280,000 (Soltex)	325,000 (Hoechst)	226,000 (Mitsui)
PP	520,000 (Hercules)	320,000 (Montedison)	196,000 (Mitsubishi)
TPA/DMT	1,360,000 (AMOCO)	360,000 (Dynamit)	275,000 (Teijin)

Source: CEER, March 1980

[50/] Ethylene Capacities in Japan:

	Unit '000 Tonnes (1978)
Chemical Companies	
Mitsubishi Petrochemical	720
Mitsui Petrochemical	700
Sumitomo Chemical	565
Mitsubishi Chemical	530
Oil Companies	
Tonen Petrochemical	495
Maruzen Petrochemical	490
Nippon Petrochemical	480

The Japanese industry also suffers from the disadvantage of not having encouraged 'sectoral specialisation' - the emergence of international leadership which acts as a potent force for continuity on leadership lines. There are, for instance, 15 petrochemical complexes with near identical product-mixes (in each of which there may be several firms engaged in producing chemicals[51]). At the same time, unlike the operations of companies in Europe and the United States, no Japanese company has a dominant position in a plurality of major products (as, say, UCC in the United States in ethylene, LDPE and ethylene glycol; or ICI in the United Kingdom in LDPE, polypropylene, paraxylene and DMT) or clear dominance in a single product (as Hoechst's 700,000 tonnes capacity in HDPE world-wide).

Another feature which discourages the continued involvement of Japanese companies in the national commodities market is the aging of its plants[52].

While recapitalisation to a certain extent is expected to take place in terms of domestic market needs, much of Japan's new capacities

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[51] It is a feature of the Japanese industry that several firms of different corporate identities operate within the same 'petrochemical complex'. In the past, this helped improve the complex's overall 'materials balance'.

[52] The following tabulation presents the average age of Japan's petrochemicals plants (1980) (MITI data):

Ethylene	11 years
LDPE	12 years
Polystyrene	13 years
SBR	15 years
Polypropylene	10 years
Styrene	10 years
Ethylene oxide	10 years

in commodities are expected to be outside of the country[53].

Besides these features, other considerations also limit scope for the industry to deepen its commodities involvement: growing shortages of industrial sites in Japan, the high price of electricity as the result of the country's use of natural gas as fuel[54], the cost of pollution control in a very sensitive society and the growing competition, from South Korea, on the one hand, because of their low cost labour and export subsidies, and, on the other, from the United States because of its cheaper feedstocks.

In reviewing the above conclusions it must be recognized that in Japan, with intense competition between firms in the domestic market, there is little scope for intercorporate accord, and much less a planning superstructure[55]. It is indeed rivalry

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[53] It is pertinent to note in this connection that at the time of OPEC's action in 1973, most of Japan's plants were newly installed and their average age lower than those of Europe and the United States, particularly of the large capacity plants. About seven new ethylene plants, each with over 300,000 tonnes capacity, came on stream after 1972. Hence even through crude prices soared, Japanese plants were able to operate at better efficiencies than those of competing countries. Consequently, they were able to absorb the price shock.

[54] Japan is moving to import commodity chemicals as ethylene dichloride (EDC) and acrylonitrile (AN) as they are not only cheaper this way but serve as an effective way of importing energy (electricity in EDC) or feedstock (as propylene in acrylonitrile).

[55] While MITI does formulate industrial plans such are not obligatory on the companies. It is said that the autonomy of Japanese firms lies in between those of Federal Republic of Germany and France (1980).

among corporations that has prevented mergers[56] between them or the development of 'arms length' joint-ventures (as has taken place in Federal Republic of Germany or the United Kingdom) which otherwise could upgrade scale of operations or permit them to obtain entrenched and dominant positions, in international terms, in particular products. Likewise, it is rivalry and pursuit of competition which has prevented oil-chemical ventures which could have the character of forward or backward integration and thus, scale rewarded[57]. However, through tariff and other mechanisms ("oil law") the Japanese Government have acted

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[56] Japanese petrochemical firms, to date, have also avoided any form of major association even in international projects, not uncommon (now) with United States firms (see United States section).

[57] In Japan's post-war history petroleum firms as Nippon oil and Idemitsu Kosan became prominent earlier than the chemical firms as Mitsui Petrochemicals and Sumitomo Chemicals. However, with the latter making enormous strides in petrochemicals, the oil companies started forward integrating into this field. With little prospect for the chemical companies to back integrate they were only able to obtain influence through minor investments in the oil companies. Thus, Sumitomo Chemical has a 16 per cent interest in Fuji Oil and Mitsubishi Petrochemical a 30 per cent interest in Kashima Oil. However, as a defensive measure, the chemical companies developed some speciality lines and general chemical business. Of Japan's 12 ethylene producers half have their own oil. The following data quantitatively illustrates the general positions of chemical and oil companies:

	Sales in 1979 (Billion US$)	Share of Petrochemicals
General Chemical Companies		per cent
Mitsuibishi Chemical	2.99	47
Mitsuibishi Petrochemical	1.55	78
Sumitomo Chemical	2.50	36
Asahi Chemical	2.46	14 (excl.fibre)
Mitsui Petrochemical	1.33	100
Mitsui Toatsu	1.85	30
Petroleum companies		
Idemitsu Petrochemical	1.27	100
Nippon Petrochemical	1.22	100
Tonen Petrochemical	0.85	100
Maruzen Petrochemical	0.67	100

to create a pricing and distribution structure for naphtha **which** eliminates, to some extent, the need for oil-chemical **associations as** those of BASF-Shell and Bayer-BP in Federal Republic of Germany[58].

It is corporate individualism also that accounts for Japanese chemical firms now going abroad. Since 1973 Japan's "Big Three", for example, have taken vigorous steps to establish themselves overseas (see Table 8 below). Mitsuibishi has progressed substantially in its moves to enter chemicals production in Saudi Arabia (Al Jubail), Alaska (ALPETECO project) and Canada (with DOME Petroleum), Mitsui Petrochemical in South Korea (Yaesu Project-in operation) and Iran (Bander Khomeini) and Sumitomo in Singapore. However, as said before, in the case of Japan these investments and projects are not oriented to meeting the requirements of the Japanese domestic market (with perhaps exceptional cases as that of EDC) as they are meant to exploit the world market. In principle, they are similar to the overseas projects of the United States oil majors (see later).

Table 8

Japanese Joint-Ventures Overseas

1.	**Mitsubishi Petrochemical** With 15 'Group' companies, 13 oil companies and 11 petrochemical companies (The project is associated with that of SABIC-Dow Chemicals)	Joint-venture with SABIC in Al Jubail, Saudi Arabia: 450,000 Te Ethylene 250,000 Te LDPE 150,000 Te EG 80,000 Te HDPE
2A.	Mitsui Petrochemical (with Mitsui Company, Mitsui Toatsu, Toyo Soda and Japan Synthetic Rubber) in Bandar **Khomeini** - 85 per cent plant completed when Mitsui withdrew from project in June 1981	Joint-venture with National Iranian Oil Company: 300,000 Te Ethylene 160,000 Te LDPE and HDPE 170,000 Te EDC 150,000 Te VCM 240,000 Te Soda Ash

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[58] Pricing of naphtha in Japan, under the 'oil law' is on a cost-plus basis and unrelated to international naphtha prices. The 'cost' base is on domestic refining costs. MITI acts as the 'distributor' but naphtha distribution is on competitive bidding between the oil and chemical companies.

Table 8 (cont'd)

2B.	Mitsui Petrochemical With same group as above at Yaesu, South Korea	Joint-venture originally with Govt. of South Korea but now transferred to private party: 100,000 Te HDPE 80,000 Te PP 80,000 Te EG 350,000 Te Ethylene
3.	Sumitomo Chemical	Joint-venture with Govt. of Singapore and four private companies for 120,000 Te LDPE 100,000 Te PP and a joint-venture with Phillips Petroleum and Govt. of Singapore for 50,000 HDPE

Importantly (as will be observed from one of the footnotes), in all of these projects the product-mix is one of commodity products, areas most familiar to the companies and in whose context they have very effective technologies.

Technology Development

Contrary to popular notion, there are serious deficiencies in Japan's petrochemicals industry in respect of R+D capabilities, deficiencies which have become better understood under the impact of high naphtha prices. There are several causative factors:

(a) Severe inter-firm competition reduced the possibility of creating financial surpluses for long-term research;

(b) The strong tendency of company managements, arising from their traditional conservatism, to preferentially license out proven technology rather than experiment with 'home-grown' technology[59]. (Japan has a negative balance-of-trade on chemical technology exports/imports);

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[59] One of the principal disadvantages of utilizing proven technology, as Japanese firms have learnt, is that the 'improvements' which they effect automatically become the property of the licensors by contract provisions. Hence without effort, the competitive capability of the licensor company is maintained by these 'grant-backs'.

(c) The preferential allocation of available R+D funds to 'process adaptation and improvement' rather than new product research[60/].

(d) The 'home-market' orientation of the petrochemical manufacturers, etc.

Thus, one of the major new moves in the country is to upgrade its scientific and technological capacities, and in fact, the MITI motto for the decade of the 1980s is to become 'self-reliant' in technology.

Since this capability cannot be developed, within Japan, in the short-term Japanese firms have moved to sponsor research in private research organizations, in places such as the United States. In addition, they have entered into 'general research management' contract with American companies (as the Toa Nenryo Research Agreement[61/] with Exxon Chemicals) which permits the exchange of research results in particular fields. Also, in defensive posture and under the guidance of MITI, the chemical firms have agreed to form research consortia. One prominent such consortium is the C1 Chemistry Group[62/] - whose objective is to develop 'non-oil' routes to commodity petrochemicals.

60/ Japan's chemical industry is a large employer of research personnel and it spends considerable funds. It is the 'direction' of R+D effort that is in question:

Date: 1979/80	Industry turnover (Billion $)	Research expense (Million $)	R+D ratio per cent
Japan	46	1612	3.5
FRG	38	1937	5.1
United Kingdom	24	590	2.5
United States	114	4187	3.7

61/ A group of Japanese companies form the Toa Nenryo 'group'.

62/ Mitsubishi Gas has announced the development of a toluenecarbon monoxide route to terephthalic acid, which can be considered a 'C1 chemistry' technology development.

However, for the better part of the next decade, it is expected that Japanese research effort (expenditures of time and money) will be in support of conventional petrochemicals, improving energy and raw material efficiencies[63].

THE UNITED STATES

Amongst the major market economy industrialised countries, the United States is in the most favoured position with respect to energy sources -- developed and potential. Of the developed forms, it has large reserves of crude oil, natural gas, coal, uranium and hydro-electric power[64], and of the developable (or rather underdeveloped) forms, oil shale [65], tar sands, geo-pressured gas and biomass. This position is greatly augmented by the proximity of the country to the significant resources of Canada - particularly 'tar sands' - and those of Mexico (natural gas and petroleum).

63/These comments and inferences should not indeed deter the recognition of some valuable and basic contributions that Japanese firms have made to petrochemistry, utilized internationally - for instance, Nippon Zeon; butadiene extraction process, Nippon Kayaku's acrolein process, the Japan Synthetic Rubber (JSR) Cis-polybutadiene process and Shinetsu's VCM/PVC processes.

64/Energy Reserves - United States and other **regions**:

Unit: **million** tonnes oil equivalen

	Coal	Oil	Gas	Total
United States	154000	16000	7000	177000
Europe	67000	5000	4000	76000
Middle East	------	129000	29000	158000
USSR	232000	26000	46000	294000

Source: World Coal, August 1977, Reported in "Planning for Coal in 1980s, Mahendra R.G. Hydrocarbon Processing, October 1978.

65/The oil in United States shale reserves is said to exceed the oil reserves of OPEC.

At the same time the United States has been one of the most prolific users of world energy, particularly traded crude[66/]. Because of the imbalances between consumption and production, the United States imports about 50 per cent of its requirement of oil products. United States reliance on imports has historically emerged as a result of the country's deliberate policies to conserve its own oil resources and to utilize

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[66/] United States energy consumption pattern (1975)

Unit: Million tonnes oil equivalent

Crude oil	- 764.2	
Natural gas	- 515.7	Virtually all of domestic origin.
Solid fuels	- 342.1	
Hydroelectric, etc.	- 78.4	
Nuclear	- 40.0	
	1740.4	

United States consumption of crude compared to Europe and Japan (1979)

United States	- 960 million tonnes
Western Europe	- 740 million tonnes
Japan	- 292 million tonnes

Chemical industry's consumption of energy (1980) - 10^{15} Btu/yr

Crude oil	- 3.80
Coal	- 0.65
Natural gas	- 1.55
Purchased electricity	- 1.57
	7.57 = 215 million tonnes oil equivalent

Source: ECOSOC

low-cost foreign supplies[67/]. Policies to conserve oil, indeed, lowered natural gas prices so as to stimulate its consumption in compatible energy applications.

Middle East crude imports have been traditionally favoured in the United States because such crudes are very economically extracted, are light and easily transported, and significantly, they can be processed in relatively simple refinery configurations. However, because of the large United States dependence on OPEC - to the extent of 80 per cent of its supplies - the search and development of alternate energy forms are major objectives of the Government and of the United States corporations.

Oil Companies in the Chemical Industry

The traditional United States chemical industry has been greatly concerned with security in the supply of crude, the large role (control) the oil companies have in its distribution and processing[68/],

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[67/] In 1945, with the exception of Soviet reserves, most of the reserves lying outside of the United States were dominated by British and Dutch interests. Working from an exploration consortium in Iraq (secured as a consequence of Allied treaties) United States oil firms - now becoming rapidly 'transnational' - helped to develop Iranian and Saudi oil fields. (It is of interest to note that at the end of the war in 1945, the United States produced 63 per cent of the world's petroleum).

[68/] The chemical companies of the United States have, at various times, toyed with the processing of crude but till recently never given it serious attention. In Europe, on the other hand, firms as ICI, Montedison, SIR and BASF have considered it an important requirement. They operate captive refineries and directly procure crude from the world market.

the competition arising from the use of naphtha as gasoline[69] and of the decline in availability of natural gas liquids, NGL (perhaps, more accurately, the threat of decline of this feedstock), with drawdown of United States natural gas reserves. This concern is heightened by the emerging need of the United States companies to employ naphtha, in place of NGL, both on account of the decline in NGL availability and of its expected higher pricing on the phasing out of United States federal price controls[70].

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[69] At a 3.5 per cent growth rate in the economy between 1980-1990, the chemical companies would require (in crude oil equivalent terms) about 8 per cent of all crude utilized in the United States in 1990. Taking into account the world-supply balance expected at that time, the chemical industry might not be able to avail of this percentage unless United States conservation strategies in the uses of gasoline - including mandatory gasoline mileage stipulations - worked to meet the incremental requirements of the chemical industry. (The United States chemical industry consumes, less than 10 per cent - 23 million tonnes in 1977) of all naphtha marketed in the United States, compared to the 40-50 per cent levels in Europe and Japan.

[70] The inter-state distribution and pricing of natural gas is controlled by the United States Government. By 1985, the price of natural gas becomes wholly decontrolled after a series of phased price increases. On decontrol the price of gas is expected to rea[illegible] on a Btu basis, the price of competing oil fractions (typ[illegible] al oil). As ethane has to be extracted from natural gas by [illegible] gas processors, they undertake it on the basis of the premise the chemical industry can pay on the cost of extraction. The relatively low prices which chemical firms have paid so far for ethane, because of Government-depressed price of natural gas, will thus no longer be applicable.

The concern of the chemical firms must be judged in the context that the United States has the largest chemical industry of any country in the world, with production at $ 122 billion (1980) only a little below that of Western Europe as a whole ($ 145 billion). Equally, the United States industry has shown a steady growth trend ahead of GNP, growing at approximately twice the rate (1.9 multiplier). Furthermore, it has, for over a decade, consistently shown a balance-of-trade surplus.

Another 'oil-related matter' concerns the chemical corporations. They view the threat of growing oil company penetration into petrochemicals (illustrated in tables 9 and 10) as importantly as the threat that gasoline consumption could pre-empt it of its feedstock needs (particularly in times of general economic-political crises).

Large chemical firms have come increasingly to realise that as a consequence of OPEC's actions, the oil companies are rather rapidly losing their role in the management of oil and are being reduced to merely operating as 'processors of oil'. Oil company penetration into the fairly profitable chemical industry, thus was not only taking place but was becoming deeper.

Table 9

Petroleum company penetration into US petrochemical industry

	Unit: percentage of total capacity		
	1974	*1978*	*1980 (est)*
Plastics			
LD Polyethylene	39.5	43.3	45.9
Polypropylene	54.1	64.1	62.0
PVC	17.7	19.3	18.8
C3-based chemicals			
Acrylonitrile	24.5	13.8	13.8
Cumene	63.4	60.4	60.4
Propylene oxide	29.1	28.8	28.8

Table 9 (cont'd)

	Unit: percentage of total capacity		
	1974	*1978*	*1980 (est)*
C2-based chemicals			
VCM	35.4	25.4	25.4
Ethylene glycol	17.3	17.2	19.4
Aromatics			
Ortho-xylene	97.6	97.6	97.6
DMT	10.7	7.9	7.9
Raw materials			
Benzene	80.9	84.8	81.1
Ethylene	48.4	61.1	58.9
Propylene	73.2	79.4	75.7
Methanol	6.6	8.1	7.0

Source: The Myths and the Realities of the Oil Companies' Aggressive Move into the Chemical Business, First Boston Corporation (United States), Oct. 1977.

Table 10

The 'chemicals involvement' of leading US petroleum companies

	Unit: Billion US $ (worldwide - 1979)	
	Value of chemical sales	*Sales of chemicals as* percentage of total sales
		per cent
Exxon	6.69	8.5
Shell	2.60	18.0
Standard oil of Indiana (AMOCO)	2.53	12.7
Gulf oil	2.44	9.4
Occidental Petroleum	2.09	21.8
Phillips Petroleum	2.06	22.0
Atlantic Richfield (ARCO)	1.52	9.4

Source: C.H. Kline & Co. United States

To the chemical companies this penetration has had three important implications:

(a) They are competing with companies which are their raw material suppliers (naphtha, olefins, aromatics).

(b) The oil companies with their access to crude, and with the possibilities of adjusting refinery-mix to market-mix, would have a measure of structurally built-in feedstock flexibility, together with the scale economies of forward-integrated production, and

(c) if the chemical companies wanted to maintain their traditional independence (from the oil companies) they would have to move far downstream - into specialised products - or they would have to seek feedstocks outside the control of the oil companies.

To the oil companies, of course, the petrochemical industry has attractive aspects. First, commodities constitute the bulk of the industry's scales. These require for their marketing mass merchandising techniques (rather than close technical support to clients as required by speciality products) with which they were familiar[71]. Second, oil-producing nations, particularly the Middle East did not so much want participative aid in oil processing as high technology value-adding applications of petroleum. Thus, involvement in petrochemicals manufacture could give them access to oil ('crude entitlements') besides opening up to them a world market. Third, in 'alternative energy' industry they would coproduce materials as syngas or ethane which had increased valorisation as chemical industry feedstocks than as energy[72].

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[71] Mobil's acquisition of the Montgomery Ward Department Store Chain is also an expression of 'Mass Merchandising' capability.

[72] Gulf oil, for example, first developed its SRC-I (Solvent Refined Coal process) to produce mineral-free coal which would be environmentally acceptable. However, this process quickly gave way to the SRC-II process in which ash minerals catalysed dissolved coal to produce coal liquidss. These liquids appear particularly attractive for chemicals synthesis. A similar situation emerges in other 'coal chemistries'.

The Response of the Chemical Companies

In defensive posture, the chemical companies appear to have two broad strategies which work together and independently. Both strategies are oriented, in different ways, to obtaining a high degree of independence from the oil companies in terms of access to raw materials and energy. The first of these involves the use of raw materials which can be acquired without involvement with oil companies - the most important being coal and methanol[73]. The second of the strategies is to obtain independent access, wholly or substantially, to oil. The first of these can be seen as a 'technological', and the second a 'structural', solution.

It is **possible to perceive these changes in the manner** that they have taken place since 1973 (more specifically in the second half of the 1970s). Of the two strategies, the structural one is the more advanced, but even so, it has been somewhat compromised. As examples, Dow Chemical has been a leading exponent of backward integration and in this direction has an 'in the ground' reserves position to satisfy 15-20 per cent of the balance covered by 'dedicated pipeline capacity'. In addition, Dow has acquired reserves to the extent of 600 million tonnes of brown coal. The Company is also constructing a 200,000 barrels per day refinery at Freeport, Texas.

Monsanto, likewise, owns 30 million barrels of oil reserves and 600 billion cubic feet of natural gas. In addition, it owns and operates a 32,500 barrels per day crude processing plant at Conoco Oil's

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[73] About 70 per cent of United States coal production is presently in the hands of oil companies. (Information obtained during the course of the survey). The chemical companies (some of whom own coal, as Tennessee Eastman) are banking on independent access to the balance 30 per cent.

The large availability of concessionally priced natural gas ($1.80 per million Btu for use in Canada vs. $4.80 for exports) has attracted chemical industry involvement there in methanol (viz Celanese Corporation).

Louisiana refinery[74]. DuPont, while earlier making only 'half-way moves' to feedstock management - as its 1979-1980 agreement with Shell Chemicals to obtain one-third of its olefins requirements for 10 years - has just completed the largest take-over (merger) in United States history by its acquisition through majority control, of Conoco Oil, a resource-rich oil company. It has also and recently formed the Syngas Company in association with United States Chemicals to make syngas from heavy petroleum fractions. It has also moved into natural gas based methanol and is now the largest United States producer of methanol, displacing Celanese. (Methanol is, of course, a new and potential rival feedstock to petroleum fractions). Diamond Shamrock, ICI America, Great Lakes Corporation also have these 'oil interests'.

However, not all chemical companies are so oriented or need to be. Many derive substantial income from non-chemical or non-petrochemical businesses[75], such as the conglomerate UCC, Celanese Corporation or Hercules[76].

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[74] Conoco (originally, Consolidated Coal Company) reciprocally owns one-half of Monsanto's Chocolate Bayou (Texas) propylene and benzene plants. (The Monsanto - Conoco 'joint-venture' project, which does not have a separate corporate identity, is a capacity-sharing project, with no sales to third parties. It has been Monsanto's "largest ever" project).

[75] Chemicals Orientation of United States Chemical Companies

Sales Unit: Billion Dollars

	Total Sales (1979)	Per cent chemicals
DuPont	11.5	90.2
DOW	5.96	64.4
UCC	5.78	63.0
Monsanto	5.21	84.2
Celanese	2.91	92.6
Hercules	2.02	85.9
Eastman Kodak	1.78	22.1
PPG Industries	1.75	56.6
American Cyananid	1.69	52.9

Source: C.H. Kline + Co.

[76] Celanese is'C1-chemistry' based and Hercules is aromatics-based. UCC has very large interests in industrial gases, carbon and graphite products, metals, etc.

The 'technological strategy' is being pursued by many companies. The most prominent example of a chemical company 'building on a coal mine' is that of Tennessee Eastman which is constructing a coal-to-methanol plant at Kingsport, Tennessee for the production of acetic anhydride by the carbonylation of methyl acetate, wholly based on coal. However, many companies have established 'Cl-technologies' or are well in pursuit of them. Among the technologies are the Monsanto process for manufacturing acetic acid from methanol and carbon monoxide (commercialised since 1973); Union Carbide's process for manufacturing ethylene glycol from syngas (homogeneous rhodium cluster catalysis) targeted for commercial production by the mid 1980s; Rohm and Hass' research to produce methyl methacrylate from formaldehyde and methyl propionate; Monsanto's efforts to produce styrene from toluene and methanol, wholly a diversion from decades-old dependence on ethylene and benzene; and the efforts by several companies, among them UCC, to make ethylene from syngas, ethanol or methanol[77/]. Perhaps the largest single indication of the growing importance of **Cl-chemistry is the spearheading of the growth of methanol capacity** (a chemical dependent till very recently on adhesives-oriented formeldehyde to the extent of 50 per cent, and use as a solvent) by by DuPont and Celanese[78/].

77/This coverage does not include the efforts of European chemical companies in Cl-chemistry and the potential of their using them in the United States. In its 'West European' coverage, this study has minimised the impact of European development of new technologies for the European commodity chemicals market for reasons cited in that coverage.

78/In fact, Cl-chemistry appears to afford the chemicals companies (who produce over 90 per cent of United States methanol) a possibility of getting into the energy field. 'MTBE' is a new product on the world scene, an 'octane booster, based on methanol and isobutylene. Also one of the largest medium-term markets for methanol is for 'peak-shaving' in power plants (substituting fuel oil).

Technology Demand in the United States - The Largest Growth Market

Amongst the industrialised countries, demand for new technology is most pervasive in the United States (See 'Research and Development', this Section). This demand, for wholly different reasons, is evident in the attitudes of, and in the efforts being made by, both chemical and oil companies. Foreign companies, investing newly in the United States, constitute an important 'third force'. The need for feedstock independence in the case of chemical companies, and the desire to penetrate the petrochemical industry by oil companies are the most important expressions of this demand. There are, however, other very substantial reasons.

Demand for new technology arises from a combination of 'defensive' and 'aggressive' postures. In the case of the United States chemical companies, they are:

(1) The need to get away from oil politics - of the foreign and domestic varieties - and induced insecurity;
(2) To retain the mass marketing bias in chemicals;
(3) To recapitalise industry with energy-efficient equipment i.e. new processes for the transformation of raw materials with reduced energy consumption or better 'carbon efficiency'
(4) In recognition of the effect of physical resource limitations on the growth of European and Japanese business, to seek to gain world markets with scale-responding technology;
(5) To take advantage of the declining real cost of United States coal relative to oil;and
(6) To take advantage of infrastructure (Figure VIII).

For the oil-companies, too, many of the above factors apply as it is difficult to see them now (certainly in the United States) as 'outsiders' to the industry. However, their scale of involvement is much larger than those of the chemical companies.

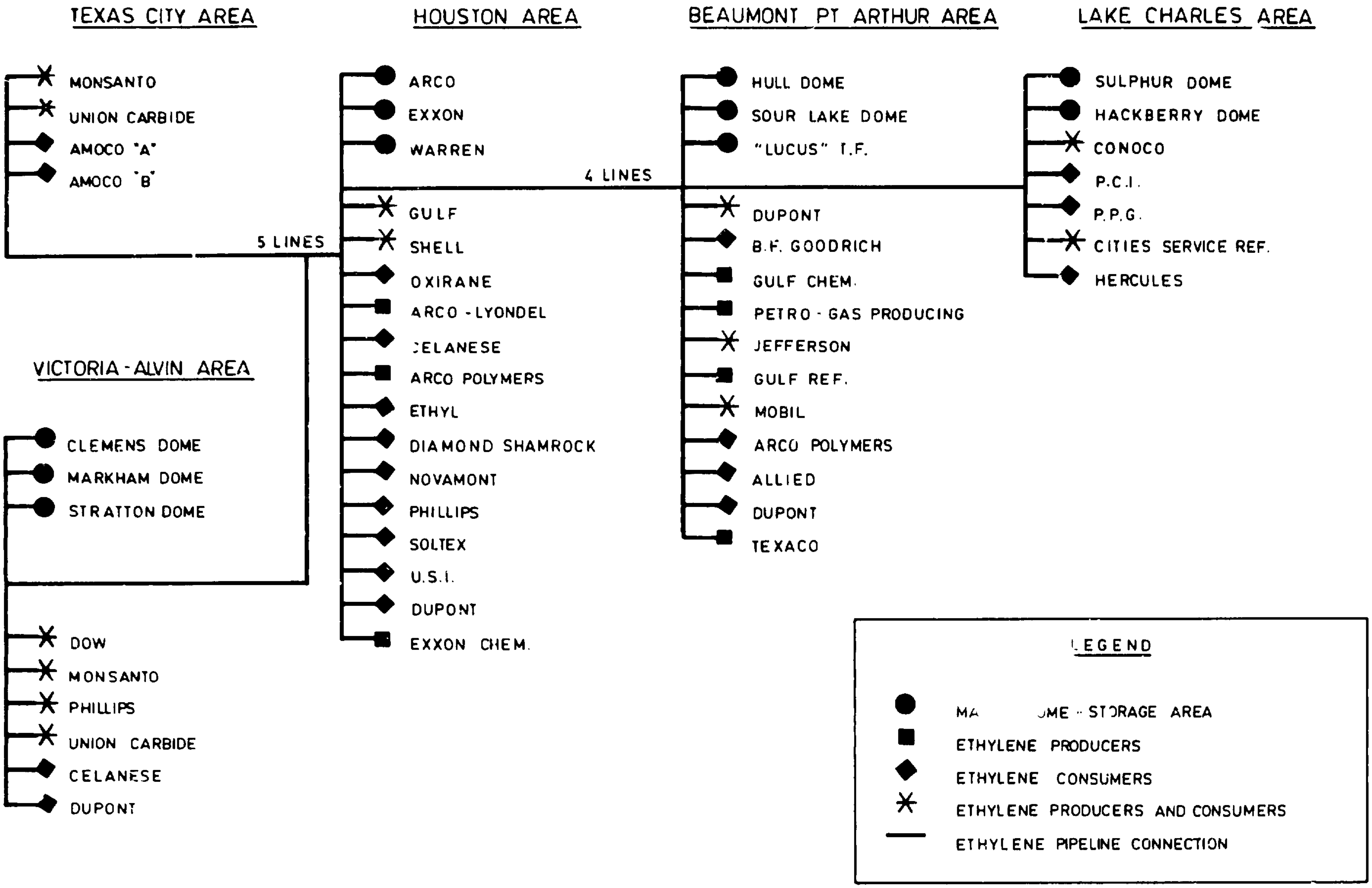

FIG. VIII **ETHYLENE FOR GREATER HOUSTON AREA**

Like the chemical corporations, the United States oil firms - with their growing foothold in the national and international industry - also perceive the demand for new chemicals-oriented technology. However, their perspective appears different and motivated by other factors:

(1) Opportunities available to further penetrate or dominate international chemical production as a consequence of the disadvantaged position of the resource-deficient (financial and raw material resource) European and Japanese corporations;

(2) The view that the rate of commercialisation of oil-based technologies (particularly, commodities-oriented) is entering a 'plateau period';

(3) Economic forecasts that the real prices of oil will move faster relative to that of coal[79] making the latter a cheaper base both for energy and chemicals in new 'technology packages';

(4) The likelihood that coal-rich countries as Australia, South Africa and Canada - and some of the developing countries - would offer incentives to capital when accompanied by such technology as would utilize coal in value-differentiating manner; and

(5) Likewise, the opportunity arising from the desire of the natural-gas producing countries and biomass-rich countries

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[79] Shell Oil (United States) have applied sensitivity tests to the price at which coal becomes an equal contender to oil for chemicals (Also see 'Research and Development'). Their 'high line' scenario considers oil prices rising 3.5 per cent (real) 1980-2000 and 1 per cent for coal, 1980-1990, and 2 per cent thereafter. The 'low line' considers a consistent no-growth real price for oil at the 1980 level and 1 per cent growth for coal, 1980-1990 and 2 per cent thereafter. The 'middle line' scenario is 2.5 per cent real growth for oil vs. 1 per cent 1980-1990 and 2 per cent 1990-2000 for coal. They show that ethylene glycol from coal-derived syngas is economic to that from ethylene now but that ethylene from syngas would be competitive to that from gas oil by 1988 (Source: W.W. Reynolds, Shell Oil, Company, United States. Chemical Week Conference, Houston (Texas) Nov. 20-21 (1980) in the paper entitle, 'The Changing Pattern of Petrochemical Feedstocks to the year 2000 and beyond'. (Mr. Reynolds was interviewed during the survey).

(as Brazil) to foster broadened usage of products as ethanol and methanol[80].

One of the major strengths of oil companies in this range of new opportunities - particularly of those companies which have substantial 'chemical arms' as Exxon, Gulf and Shell[81] is their very real past R+D experience, and conceptual depth, in developing energy-related coal-conversion technologies: the 'synfuel' technologies. Thus, the experience of Exxon and Gulf in the 'direct liquefaction' of coal by hydrogenation - the Donor Solvent(EDS) and Solvent Refined Coal (SRC I + II) technologies, respectively - to produce petroleum-like liquids[82] (pseudo-petroleum); the 'indirect liquefaction' technologies of Mobil Oil, the 'M Gasoline Process' (discussed later), to yield a straight-forward gasoline and product from methanol; and the quite recent Shell-Koppers and Texaco-Ruhrkohl gasification processes for producing 'medium-Btu' gas from coal.

80/Methanol it may be noted, while a more chemical-like material than oil-like i.e. it has very standard chemical and physical properties compared to oil which is dependent on source and processing, requires interestingly a servicing infrastructure - storage, transportation,distribution,handling - which is very similar to petroleum-based materials).

81/Shell Chemicals, United States is the largest ethylene producer in the United States, succeeding the ranking hitherto held by UCC.

82/The direct liquefaction technologies, because of their large need of expensive hydrogen in the process, the problems of commercially and (profitably) disposing all 'fractions' other than as heating fuels, and scale of investment have yielded to the 'indirect liquefaction' technologies, of which methanol and M-Gasoline are present favourities. Likewise, technologies developed for the production of SNG (synthetic natural gas), by methanation' of syngas' have yielded to 'medium Btu gas', as valuable for chemicals synthesis as an 'energy-carrier'.

Indeed such experience is being employed by the oil companies. Mobil has important technology programmes with AECI of South Africa (40 per cent interest held by ICI) for the conversion of methanol to ethylene; Exxon is working with the concept of ethylene production through the 'homologation' of methanol to ethanol (with parallel efforts being made by Shell and Gulf) and also with Fischer-Tropsch technologies for the production of a mixture of methanol, ethanol and propanol; Chevron Oil (Standard Oil of California) is developing a process for the production of ethylene glycol from syngas (eliminating the need to go through ethylene oxide with the concurrent advantage of using a non-oil feedstock); and so on.

Foreign Chemical Companies Investing in the United States

In addition to the above-listed efforts of United States chemical and oil companies, it is also necessary to consider the technology contributing role that is being played by yet another 'group' - European chemical companies investing in the United States. This is illustrated by Tables 11 and 12.

Table 11

Foreign Investment in United States chemical industry

	Total foreign investment in United States chemical industry	Percentage European
1973	$ 2.9 billion	71
1975	$ 3.8 billion	72
1977	$ 4.8 billion	77
1979	$ 7.1 billion	74

Source: DuPont, Society and Chemical Industry Centenery Conference Cambridge, United Kingdom (1981).

Some European Companies in the United States

- Corpus Christie Petrochemical (ethylene - 450 million lbs) which is a joint-venture between Champlin Petroleum, Soltex and ICI America (37.5 per cent);
- Soltex, (HDPE), a joint venture between Solvay + Cie (Belgium) and Texaco Oil;
- Mobay, once a 50/50 Monsanto-Bayer joint-venture now wholly Bayer. (Bayer has stated that it expects 20 per cent of its world sales from United States operations. Bayer also owns the Miles and Cutter Laboratories (pharmaceuticals);
- Dow-Badische, a 50/50 Dow chemical/BASF joint-venture (chemicals and fibres), since 1978 wholly owned by BASF;
- Hercofina - a Hercules-Petrofina joint-venture in para-xylene and DMT;
- American Hoechst - Styrene and HDPE in Bayport, Texas.

Table 12

Foreign firms' share in the United States Chemical Industry (Significant Areas)

	Unit: percentage of capacity		
	1974	1978	1980
Man-made fibres	18.3	17.9	17.9
Plastics			
HDPE	13.9	8.5	8.3
Polypropylene	17.1	20.5	21.1
Polystyrene	30.3	33.4	33.4
PVC	3.5	30.6	29.8
Chemicals			
Acetone	25.1	35.7	34.3
Caprolactam	40.5	47.2	47.2
Isopropanol	32.5	39.1	39.1
Styrene	22.1	24.0	24.0
TDI	37.1	36.9	38.9

Source: First Boston Corporation, United States (Consultancy Organization).

There are several reasons impelling the movement of European companies to the United States (very much a post-1970 phenomenon).

(1) The very obvious energy and material resources of the country;

(2) The consideration that United States markets for plastics (and supporting chemicals) is very considerable by virtue of the factors that United States per-capita consumption in products as film is below that of Europe because materials as paper, paperboard and the like are yet to be penetrated, and because new and large plastic product markets would be created as the United States auto industry restructures itself (by reduction of weight, etc.) to meet Government-mandated mileage requirements;

(3) The growing saturation[83/] and high-cost structure of the European market as exemplified, on the one hand, by underutilization of capacity in fibres, synthetic rubber, ethylene etc. and on the other, by the growing abandonment of the European scene by United States chemical companies, **spearheaded** by Union Carbide and Monsanto, the chemical subsidiaries of oil companies as Gulf, and by European companies themselves as Rhone Poulenc and Naphthachimie;

(4) The less rigid labour structure of the United States which enables 'workforce flexibility';

(5) The capital-raising capabilities of the American financial system;

(6) The vastness of the United States industrial structure which could accept technologies (and production) that were 'scale responding'.

83/Growth rate of plastics in United States, FRG and the United Kingdom

Unit: per cent

	1961/70	1966/75	1971/78	1874/78
United States	11	8	9(71-77)	3(74-77)
Federal Republic of Germany	16	10	6	1
United Kingdom	9	6	7	0

Source: ECOSOC

The possible relevance of European companies to technological development in the United States should be appreciated. The German producer companies, Hoechst, Bayer and Badische[84/] (important constituent members of old 'IG Farben'), and the German engineering companies of today - Linde, Lurgi, Uhde and Krupp-Koppers-Totzek - have long had association with coal technologies, as coal hydrogenation, liquefaction (the renowned Fischer-Tropsch processes, modern versions of which are employed in the three parallel Sasol complexes of South Africa) and gasification (the modern Lurgi, Koppers-Totzek and Winkler technologies, of which the Lurgi process is the present basis of United States largest coal gasification project - the Great Plains Gasification Project). Equally relevant are British developments in coal and distillates gasification, the latter widely employed, prior to the oil since use in 1973, for the gasification of naphtha to synthetic natural gas in the United States[85/].

While 'European-based' United States chemical companies, with the exception of Shell, are not currently active in the United States in research effort which is coal-directed, it is well known for instance, that BASF, Uhde, URBK and BUFT (energy agency of the German Government) have a joint programme with Mobil and the United States Department of Energy (DOE), in Wesseling and **Ludwigschafen**, for the development of technology to make ethylene from methanol[86/] (potentially derivable from coal) based on Mobile's zeolite process. There are also the Shell-Koppers and Texaco-Ruhrkohle joint demonstration projects in FRG for syngas.

[84/] While BASF owns coal mines in the Ruhr area and Hoechst has equity in URBK and in Ruhrchemie, each of which has substantial coal interests, the employment of coal for energy (or as feedstock) is inhibited by the fact that German coal is presently 250 per cent as expensive as fuel oil on a Btu-basis.

[85/] In the late 1960s - early 1970s period, United States pipe-line companies fearing shortages of natural gas and wishing to keep their pipelines full, commissioned twelve 250 million cubic feet per day naphtha-to-SNG plants. These were based on the technologies of Lurgi and British Gas Corporation. Since 1973 almost all have closed down.

[86/] It may also be noted that the most well-known production processes (technology) for methanol are the European-ICI, Lurgi, Uhde and Haldor Topsoe.

Investment and Financing of Coal-Conversion Projects

One of the important findings of the survey is that the speedy development and commercialization of new technologies is impeded by the large scale of investment required for utilizing them, together with considerations relating to the modalities of financing the investments. The survey findings, however, minimise such otherwise inhibiting factors as interest or corporate capabilities to develop technology, large uncertainities in technical factors, constraints to the penetration of new technologies in the current structure of industry, or similar road-blocks to technological progress.

Essentially, and consistent with the historical evolution of new feedstocks in the chemical industry (bacterial fermentation, coke-oven by-products,carbide-based acetylene, ethane and naphtha-cracking) the commercialization of 'new generation' technologies has required a 'magnitude jump' in investment scale (at the levels of the corporation and the industry). Independent of whether syngas-based or methanol-based technologies are selected, their viability depends on the mass-processing of coal. This is certainly the most significant scenario for the United States situation, particularly if the syngas route prevails. If it is further reckoned that the United States will be the first country in which such 'mass processing' occurs, by virtue of the size of incremental market for chemicals[87/], it is possible to conclude that, for a commercial facility, a corporate entity will perforce install, at the very least, only an optimum sized plant and that it will be 'one order of magnitude' higher than the largest existing petrochemical complexes.

This establishes one dimension in the scale of investment required. A second dimension emerges from industry recognition that because of logistical factors, as the geographical distribution of chemical plants,

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[87/] Shell estimate that even as early as 1986, North America's consumption of ethylene (with the economy growing 3.6 per cent, 1980-2000) would be 29 million tonnes, 40 per cent higher than that of Western Europe, requiring 2.6 million tonnes of incremental ethylene capacity, equivalent to about eight 'world-size' ethylene plants (naphtha based).

it would be infeasible to have a wholly 'chemicals-dedicated' coal processing plant (syngas or methanol)[88]. The basic facility will need to be directed to meet the requirements of both energy and feedstock uses, with energy needs constituting the dominant demand for such a plant. That is, investment should actually be seen as related to that of the largest crude-processing plants rather than the largest chemical feedstocks plants.

A third dimension in rating investment in the new technology is the logistics of location. In the high energy price era, energy firms have come to realize that it is no longer economic to transport coal overland[89] that - barring some technical factors for which solutions are seen - it is only attractive to move coal-energy in its secondary forms, as syngas, SNG, methanol, etc. Thus, industry consensus (in the United States) is that coal must be converted ex-mine. This, of course, has implications in corporate ownership of coal mines[90].

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[88] India's experiments with two fertiliser-dedicated coal-based syngas plants has shown that it is not possible to absorb capital costs even in 'world-scale' ammonia plants.

Combining energy and chemical usages of syngas improves the overall thermal economy of the plant as its now being widely recognized in the 'cogeneration' concept tying electric power stations to chemical plants.

[89] Coal slurry pipelines appear attractive however. (In one major concept oil is slurried with methanol).

[90] For instance, it has been recently reported that Gulf oil has purchased the largest coal-producing plant in the United States.

The investment levels in these 'megaprojects' is estimated anywhere from $3-10 billion. In the two large United States Government-approved coal based synfuel projects (coal liquefaction), that at Newman, Kentucky (Gulf's STC-I technology) and the other at Morgantown, W.Va (Gulf's SRC-II technology), the present projected investments are $3.9 billion and $3.3 billion, respectively - with production rated at 50,000 **barrels** per day (cf. $300 - $400 million for an equivalent - sized petroleum refinery).

Also, these projects are two to three times the projected cost of the largest of current (ongoing) oil-processing projects (conventional technologies) as Esso Nederland's Flexicoker at Rotterdam ($1 billion), the Woodside Petroleum Project ($1.4 billion) or New Zealand's methanol-to-gasoline plant ($670 million including methanol production), etc.

Production Consortiums

While because of their large ownership of coal mines, the oil companies are promoting these 'megaprojects', it is generally conceded that such projects would financially (and in other respects) strain the largest of the corporations, leaving aside considerations as to their willingness to accept the risk[91/]. The companies thus seek to form multi-partner enterprises i.e. 'production consortiums'. In the United States legal environment such consortia would not only be very novel but subject to close Governmental scrutiny under the country's far-reaching anti-trust legislation. While thus, pooling of investments by major oil companies or by major chemical companies[92/] would appear risky, they are nonetheless believed necessary if such projects are to be initiated.

[91/] That prices of crude can drop constitutes one element of this risk.

[92/] In the recent flux of corporate bids for Conoco Oil, won by DuPont, Conoco's management are said to have successfully averted take over by (or merger with) Mobil and Texaco on considerations of anti-trust action, even though Mobil or Texaco would have made their moves only after giving full consideration thereto. The DuPont-Conoco merger still leaves open the possibility of anti-trust action in view of Monsanto's very sizeable joint-venture with Conoco.

Consequently, the potential probability of these consortia being formed cannot be discounted. While in the interim its most important forms in the United States are expected to be those of petroleum companies combining with utility companies (the electric power generation, natural gas production, gas transmission/distribution, and such like)[93] or consortiums without 'oil major' involvement[94] it is important to recognize that large and internationally significant investment associations, between oil majors, chemical majors, and oil-chemical majors are indeed taking place outside the United States[95]. Illustrative of these investment associations, in the chemicals area, but not necessarily coal-based, are the **Exxon-Shell** investments in Saudi Arabia's ethylene-polyethylene complex (in which Shell supplies ethane-cracked ethylene to **Exxon** for LLDPE production) and their proposed investments in Scotland (where the product interchange roles are reversed); the **Dow-Shell-Mitsubishi** proposed olefins plant in Alaska, the Petrosar refinery-cum-petrochemical (operating) facility jointly owned by DuPont of Canada, Union Carbide Canada and Polysar Ltd (Canada); **Dow-Mitsubishi** venture (ethylene, ethylene glycol) in Al Jubail, Saudi Arabia; Exxon-Mobil venture in Australia to produce ethylene from gasoil; the Dow-Mitsui Toatsu ethane-based EDC project in Australia; and the like.

One of the major thrusts of the above discussion is that because of a whole array of favourable factors - physical resources position, product markets, size of private sector corporations, innovative capability etc - the United States promises to be the most fertile ground for the consummation of present day technological development, and at the very least, a technology leader of the post-1980 generation.

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[93] The survey finds one oil major anticipating the formation of two such consortia by 1982/1983 and between eight to nine by 1990.

[94] As the six-member consortium recently formed for coal-to-medium BTU gas (syngas), viz: Airco, Conoco, PPG, Cities Service, United Energy Resources and Bechtel.

[95] Even though antitrust legislation is applicable to United States incorporated companies working outside the United States geographical area. Indeed the survey reveals that such associations are in the nature of 'test cases' for testing scope for antitrust action and as preludes to the formation of such consortia within the United States.

RESEARCH AND DEVELOPMENT

Industry Emphasis on Commodities

It is a finding of the survey that business emphasis on commodity chemicals is one of the major forces that is taking the chemicals industry of the industrialized countries, particularly the United States, back to serious research on feedstocks - a focus which has been generally absent in the last 20-25 years[96/].

During the last quarter of a century the thrust of most petrochemical R+D has been directed to:

(a) processes to make commodity chemicals where the costs are scale sensitive;

(b) processes oriented to 'product-tailoring', the development of products that are suitable to particular end-uses (e.g. coatings, detergents, adhesives) in other words, the function-oriented 'pseudocommodities';

(c) downstream products of high value-adding character - the 'fine' and 'speciality' chemicals, often of a proprietory nature (engineering plastics, pesticides, pharmaceuticals, etc).

There are many visible indications of this renewed emphasis on commodities:

- The 'back-integration' and 'resource in the ground' positions being taken by chemical companies as Monsanto and Dow; the recent DuPont-Conoco merger and the 1979 DuPont-Shell olefins joint-venture.
- The new **'backward-orientation' of Du Pont to feedstocks which is a reversal** of its role as basically a specialities and proprietory products company ('Nylon polyamide', 'Dacron' Polyester, 'Teflon' PTFE, MYLAR terephthallate film, etc)

[96/] In the United States, Union Carbide has had serious interest in the past on the development of new chemical feedstocks. This has been in efforts as the 'agglomerated bed fluidisation' technique for syngas, coal hydrogenation for 'coal liquids', and more recently, direct crude cracking (the ACR Process). In Europe, however, considerably more effort was placed, 25 years or so ago, on 'direct cracking' of whole crude - the 'sand' and 'coke' crackers - and a little later, on the cracking of distillates as ethylene feedstocks.

- The large incursions being made by oil companies, and foreign chemical companies, into the United States(and worldwide) commodities market.
- Large investments now being made by corporations as Celanese and DuPont in commodity materials as methanol[97/], and
- Large-scale investments made, or being made, by UCC and Dow Chemicals in the United States in LLDPE (seen as expressions of their continuing to seek strong technology positions in commodities)[98/].

Research orientation to commodities also springs from efforts to reduce the energy-content of the present processes. New energy saving technology, for example, is reported to have improved the yield in ethylene plants by 15 per cent and reduced energy consumption by 18 per cent. The proliferation of LLDPE technologies can also be seen as an expression of oil price induced technology.

Emphasis on commodities also emerges from the growing perception that while specialities, fine chemicals and proprietory products are certainly value-adding and offer a means of slowing down decline in the downtrend phase of the business cycle, they are nonetheless susceptible to the cycle, except, perhaps, a few categories as pharmaceuticals[99/], and closely indexed to the consumption of the

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97/Celanese and DuPont have between them 56 per cent of United States methanol capacity of 1521 million United States gallons (1981). Both companies are establishing themselves overseas viz. DuPont in Canada, and Celanese in Saudi Arabia (600,000 Te) and in Alberta, Canada.

98/In Europe and Japan, too, new investments are taking place in LLDPE - CdF Chimie in France, DSM in Holland, Mitsui Petrochemical in Japan. It may be noted in this connection that immitative replication of LLDPE technology appears to be as important as licensing as a mechanism of technology diffusion and can be interpreted as a means sought by the companies to maintain market segmentation in commodities.

99/In many major chemical corporations, pharmaceuticals from an important part of the product mix - viz. Hoechst, Baye_, ICI, Montedison, DuPont.

commodities (e.g. consumption of anti-oxidants is proportional to overall off-take of thermoplastics). At best, therefore, orientation to specialities appears as a 'short-term' strategy representing either a defensive posture or a means of temporarily obtaining strong market positions (i.e. patented products).

Research orientation to commodities, in the time frame of this study, is orientation to feedstocks. Commodity chemicals are not about to be substituted by other chemicals or by other materials. In the past thirty years, with probably the exception of polypropylene, or revolutionary materials have emerged to change the basic order of major chemicals as ethylene, benzene, polyethylene or PVC in the chemicals pantheon.

Essentially then, there is substantial business focus on 'building-blocks' type of research projects rather than, hitherto, on 'end-use' projects.

Involvement of Oil Companies in Chemicals Research

The petroleum companies are, however, more involved in feedstock research than the 'purely' chemical companies. This arises from their recognition that although more oil will be found as prices climb, high prices will sponsor the development of new energy alternatives. Energy research in the area of hydrocarbons is also research in petrochemical feedstocks. Consequently, while both oil and chemical companies are,today, petrochemical commodity oriented, most of the research relating to them (i.e. feedstocks) is with the oil companies.

Major current research projects involve the extraction of oil from shale (being highly paraffinic it is an excellent 'stock' for petrochemicals' and from tar-sands (too aromatic for most chemicals use); the direct and indirect technologies for the liquefaction of coal (one of which - the Mobil route to gasoline - shows high promise of being a method for large-scale production of ethylene and propylene) and the syngas - range of technologies, which can support 'C1 Chemistry'.

Impediments to the Emergence of New Technology

There are, however, impediments to the successful realisation of these technologies. Mostly they are of an economic nature. Among the most important are the following:

(a) Petroleum price swings. Despite OPEC's four-fold price increase in 1973, the real price of petroleum declined between then and 1979 contrary to expectations of steady upward trend. In mid-1981, again, price declines were evident after the second round of price increases in 1979. This 'saw tooth' pattern of price progression has tended to:

  (i) Affect the continuity of funds for research into into new alternative feedstocks; and
  (ii) In the case of well-proven technologies - as extraction of oil from shale - of postponing investments to utilize technology.

(b) The escalation of foreign crude prices, together with the United States programme of decontrolling price of natural gas (allowing it to rise), have resulted in phenomena as the 'natural gas bubble' - a sudden spurt in reserves[100/] (reported and unreported) which has the impact of allaying industry concern on continued availability of conventional hydrocarbons; and

(c) The increasing 'trade-off cost' of alternate feedstocks as reported by ICI (UK): ICI has found that over the past 15 year period the trade-off price at which a 'new technology feedstock' matches the price (real price) of crude, or a distillate, has consistently moved upwards despite the teaching of 'learning curves' that accumulated research experience should have shown by now an inflection to lower cost.

[100/] The 'Overthrust Belt' in the Rocky Mountain area of the United States West is felt to be a major new area of natural gas availability and it is now being vigorously exploited by oil companies and independents.

To a certain extent, also, there is industry recognition that it would be in OPEC's interest to control oil prices and supplies so as to keep petroleum "ahead" of alternative feedstocks. United States industry, consequently, exerts pressure on the Government to increase its commitments to energy R+D on the argument that OPEC action calls for a counterpoised 'national response'[101/].

General Lines of United States Research

Among the competing replacement materials to crude, certain preferences (consensus) emerge in the United States situation:

- The most difficult area of substitution is that of gasoline and diesel (for transportation) because of large volumetric usage rate[101/] and their extensive physical and marketing infrastructures.
- Because of the levels of capital costs involved, state of technology and enterprise the expected sequence of investments in crude-replacing/crude-substituting technologies will be in the order: shale, coal, tar sands.
- Only capital requirement considerations deter coal-to-syngas projects in the United States, not technology[102/].
- In the United States the cost of syngas from coal would be cheaper than that from heavy residues at 1979 prices.
- Syngas from United States coal at 1981 prices leads to cheaper methanol and acetic anhydride than petroleum-based feedstocks.

[101/] United States demand for liquid fuels (1980)

	Million barrels per day	
Transportation	9.4	(10.0)
Residential/Commercial	3.2	(3.9)
Industrial and Utility	5.9	(6.4)
Chemicals feed	1.4	(2.5)

Bracketed figures are Shell Oil's forecast for 1990
(Source: Hydrocarbon Processing, Sept. 1979, page 109)

[102/] Syngas, it may be noted, is the basic feedstock for hydrogen (in refineries), ammonia, methanol and oxo-alcohols in currently existing and operating technologies.

- Coal-to-SNG will not be a practicable proposition in the United States till at least the turn of the century; the natural gas 'bubble' in the United States and gas availabilities from Canada and Mexico considerably allay the need for current action.

Most United States industrial research effort, the survey finds, is for direct use of syngas for those chemicals which are derivable from methanol. The principal arguments for the approach are:

(1) Syngas is both a energy-material as well as a feedstock and hence would be responsive to economies of scale;
(2) On the other hand for coal-based methanol to achieve similar economies it would need to be a gasoline blender or a gasoline feedstock (Mobil M Technology); and
(3) In terms of the expected growth of the United States Chemicals market (incremental requirement), 'greenfields' facilities of substantial size can be contemplated; in these, captive syngas plants can be installed without a significant post penalty.

With coal mines principally in the hands of the oil companies, and the difficulty of moving syngas under pressure (with present technology) for distances over 250 miles (a Shell Chemicals figure), it is expected that the oil companies will be major sources of, and users of, syngas technologies[103/].

Time Scale for Syngas-based Ethylene

On the basis of projected coal petroleum prices Shell Oil[104/] estimates that, potentially, 15-30 per cent of all United States-produced ethylene/ethylene derivatives could be derived from coal-derived synthesis gas by the year 2000. However, on a world-wide basis, Shell forecasts that 8 per cent of the requirement of ethylene in 2000, or 6.4 million tonnes, will be derived from syngas.

[103/] It is anticipated that chemicals which can accept 'CO', the carbonyl group, in toto, as vinyl acetate or acetic anhydride, will be earliest technologies to be commercialised of the 'chemical group'.

[104/] Reynolds W.W., (Shell Oil), op. cit.

In the particular case of the United States, Shell anticipates that if only 5 per cent of all syngas forecasted[105/] to be produced in the United States by 2000 was employed for the manufacture of incrementally produced ethylene/ethylene-derived chemicals, coal would be able to penetrate conventional feedstocks to the extent of 27 per cent.

If, however, because of its availability for energy, 10 per cent of syngas was employed by the chemical industry the Company estimates that two-thirds of all new capacity for C-2 chemicals by 2000 would be met by syngas-based ethylene.

There are two assumptions in Shell's estimates:

1. Coal-based syngas will be economic;
2. Scale-efficient syngas-to-chemicals technologies will be developed.

Assuming:

(a) Certain patterns of increase in United States crude and United States coal prices;

(b) The emergence of 'second-generation' syngas manufacturing technologies;

(c) Forecasting certain future-applicable syngas-to-ethylene conversion costs, Shell shows, in the aforesaid analysis, that even at present prices of coal and crude, coal is cheaper than crude for the 'to be developed' technologies. That is, present trends in coal and crude prices are attractive enough to spur the search for syngas routes - in other words, the United States chemical industry is already sensitized to the situation and is working to exploit it.

[105/] Shell's estimates of production of 'synfuels' in the United States

Note: No technological uncertainties. Other forecasts are consistent with these numbers.

	Unit: million barrels/day	
	1991	2000
Coal gasification	480	1100
Coal liquids	320	1355
Shale Oil	540	1000
	1340	3455

One of the questions that arises in discussing prospects for new technologies is: Will new processes be adopted and oil-related ones deleted? Both Dr. Reynolds, author of the Shell Paper, and Dr. Maisel of Exxon[106/] have shown[107/] that there are about 100 or so major chemical processes in use by the petrochemical industry at any time, and that expecting 30-40 per cent of them to be replaced (by 2000) in the anticipated industrial restructuring is to expect the probable.

Differing Approaches of Oil and Chemical Companies on Alternative Feedstocks

Oil and chemical companies in the United States appear to discount two potential developments for which there are a few major sponsors (ICI, BASF):

(1) the use of methanol as a direct feedstock for ethylene by-routes as the Mobil; and

(2) heavy residues-derived syngas for chemicals.

There is also **disenchantment** with natural-gas-derived syngas for chemicals on a long-term large scale continued use basis.

The basic reasoning of the companies for these assessments is partly economic and partly technology.

[106/] Both of whom were interviewed during the survey.

[107/] Process Changes in United States Chemical Industry 1940-70 (Maisel)

	1940	1950	1960	1970
Number of major petrochemicals (excluding polymers)	62	68	86	88
Number of processes in use	16	85	99	109
Number of new processes:				
- added	6	16	2	
- replaced	7	16	18	
- deleted	4	18	10	
	17	50	30	

Source: D.S. Maisel "Trends in the petrochemical industry" Chem.Eng. Prog. Jan 1980 p.17.

The companies believe that in 'tomorrow's price structure natural gas will be the same price (on a calorific basis), as petroleum fractions, and independent of whether OPEC's petroleum prices move up or down, more and more of United States oil and natural gas will be derived from 'environmentally hostile', and consequently, high-cost areas. Thus, relative to coal, both natural gas and petroleum fractions will be on a rising cost curve[108]; it therefore follows that syngas or methanol made from natural gas would tend to be more costly than if made from coal.

The technological argument mostly applies to methanol's use as a feedstock in the United States. The question raised is: when there is no theoretical impediment to direct syntheses of certain chemicals, including ethylene, from syngas why should effort be expended on going through an unrelated intermediate, methanol?

In respect of the use of heavy-residues ('vacuum column bottoms') for syngas production, the arguments against it (again, in the context of United States usage) are:

(a) at 1979 prices of residues and coal, the partial oxidation of coal (for which excellent technologies exist) is cheaper than that of oxidising residues; and

(b) as residues can be and are hydrocracked for gasoline, the volume available to the chemical industry will be basically determined by United States gasoline economics, and hence it becomes an 'uncertainty' for chemicals users. (Residues, however, are presently used by DuPont in the United States and by BASF in FRG for syngas-based chemicals).

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[108] The following prices of coal (1979) show its high relevance in the United States compared to that in Europe:

		$/GJ	$/tonne
United States	- East	1.0	25
	- West	0.6	11
Europe	- United Kingdom power station delivered	2.4	62
	- import, Rotterdam	1.5	40
Australia		0.6	14
South Africa (high-ash integrated mine)		0.4	8

Source: ICI
GJ = gigajoule

On the use of syngas technologies for chemicals, the approaches of United States chemical and petroleum companies differ. The chemical companies believe the clearest near-term ('this decade') application of syngas has already been proved by Monsanto's acetic acid process (which is now used for 40 per cent of the world's capacity), i.e. when the CO group is wholly assimilated into the product molecule. In the view of oil companies, 'need' will propel technology development. As the plastics group of chemical products is the largest user of ethylene[109/], syngas-to-ethylene will continue to be an area of valid pursuit. Syngas is also seen by chemical and oil companies, but with somewhat sharper focus by oil companies, as a means of strengthening 'oxygen-bearing' plastics, as polyacetals (which are already in commercial use derived from formaldehyde) and 'polyketones' (which were developed by DuPont and ARCO but subsequently abandoned), and the like, since the substitution of oxygen for carbon[110/] would lower the intrinsic cost of these high performance materials.

Since a direct 'syngas to ethylene' route has not emerged which is viable in technological terms, the thrust of research effort of some of the oil companies[111/] is to employ the 'homologation process' for ethanol, (known for some 30 years) despite its multi-step character. (The process 'homologates' methanol to the higher alcohol, ethanol, from which ethylene can be derived by conventional technology).

[109/] The largest volume of United States ethylene is produced by the oil companies.

[110/] Likewise, improving the 'carbon efficiency' of processes, i.e. the maximum retention of carbon in the technological conversion process, is a major industry objective in United States research.

[111/] Dow Chemical is reportedly working on the Fischer-Tropsch model to obtain C2-C4 paraffins from syngas for use as ethylene feedstock.

Biochemical Approaches

The survey finds, at the same time, widespread United States interest, as in in Europe (by chemical, oil and engineering firms) on upgraded fermentation technology approaches to ethanol, despite their recognized limitations in respect of scale. However, it appears that the objective of these efforts is to formulate a 'response' to developing country needs of intermediate-level technology. Brazil's 'gasohol' programme has exerted a catalytic effect on United States corporate programme of research.

Both chemical and oil companies are investigating new biochemical routes to the commodity chemicals, both through gene-manipulating and enzymatic techniques. While the specific objectives for which grants and investments have been made have not been disclosed, it is known that Monsanto has equity and other funding investments in the three leading biogenetic firms - Genex, Genentech and Biogen - which are doing work on biosynthesis of chemicals. On the other hand, it is known that Standard Oil of California has engaged Cetus Corporation[112] (a leading biogenetic organization in the United States) for developing commercial routes to ethylene and propylene oxides (from ethylene and propylene, respectively) via Cetus-discovered routes employing bacterial enzymes - 'Cytochome 450'[113].

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[112] Genex has Monsanto capital via Innoven, a venture capital company controlled by Monsanto. Cetus has equity investments from Standard Oil of California, Standard Oil of Indiana and United Kingdom's Distillers, a subsidiary of BP. Biogen is believed to have Monsanto equity.

[113] It is also known that the bacterium methylococcus capsulatis can convert ethylene and propylene to the oxides. However, in the absence of appropriate genetic manipulation techniques, yield continues to remain poor.

The United States industry as a whole has traditionally invested, in absolute terms, more in R+D than its European and Japanese counterparts[114]; but in terms of the ratio of R+D funds to sales turnover it does not emerge superior. In fact, private assessments show[115] that leading United States chemical corporations invest less than their European equivalents.

The apparent anomaly between this specific assessment of research effort and the general assessment made in this document that United States corporations lead world research in new technology is explained by the consideration of two factors:

(a) European and Japanese firms are primarily oriented to improving the 'specialities' content of their domestic business;and

(b) investments by United States oil companies in 'chemicals research' is inadequately reflected in the United States figures because such investment would appear 'energy research'.

114/Research Expenditure in advanced countries (1977)

Unit: Billion Dollars

	Chemical Industry Turnover	R+D Expenses	Ratio of R+D Expense to Turnover
United States	114	4.19	3.7
Federal Republic of Germany	38	1.94	5.1
United Kingdom	24	0.59	2.5
France	22	0.75	3.5
Japan	46	1.61	3.5

Source: OECD Statistics

115/R+D Expenditure of leading chemical corporations (1979-1980)

Bayer	1.43 billion US dollars
Hoechst	1.40
BASF	1.16
DuPont	0.93
ICI	0.92
DOW	0.60

Source: Rhone Poulenc data quoted by 'Chemical Engineering' Feb 9, 1981.

FEEDSTOCK ECONOMICS AND TECHNOLOGICAL IMPLICATIONS

I. METHANOL

Introduction

Largely as a consequence of the events in 1973 which changed international energy price structures, methanol, a rather dormant chemical commodity (world consumption of about 12 million tonnes) has begun to show the promise of becoming a rival and a substitute to naphtha, in practically all applications of the latter: as a transport fuel (gasoline), a stationary fuel and a petrochemical feedstock. While wide-scale usage of methanol does call for major technological developments to take place in methods of both its production and utilization, its distribution does not face one of the principal hurdles to the penetration of new technology - the need to create an infrastructure for movement of the product. Methanol can indeed be serviced by that already created for petroleum products - ocean tankers, storage vessels, onshore distribution systems and the like. The importance of such a facility to methanol is readily recognized by the consideration that the petroleum infrastructure (particularly in the west) has basically been laid in an era of low-cost energy.

While bold moves are being made by the industrialized countries to broaden the uses of methanol, the pace is slow because in these countries most of the effort is being expended to improve the energy and raw material efficiencies of conventional materials and processes. However, in the perspective of this study, developing countries have much to gain by accelerating the development of methanol-using technologies, the most crucial considerations being that practically every developing country has at least one resource large enough to support volume methanol production, and that, at the very least, a developed 'first generation' production technology is already being employed, in one country of the world or another, utilizing such resources.

In the particular focus of this study on **methanol**, it is relevant to mention the opinions of one of the chemical industry's leaders:

(1) Prof. Matthais Seefelder, Chairman, BASF has been quoted in the technical press as saying (in 1980) that 'methanol holds greater potential than any other product in the chemical industry';

(2) Mr. John D. Macomber, President, **Celanese** Corporation (1980) has said that methanol has been transformed "from a workhorse to a racehorse";

(3) Mr. Robert Malpas, President, Halcon International (USA) that by the year 2000 "methanol will become a major feedstock........." (Society of Chemical Industry Centennial Conference, Cambridge, United Kingdom 1981); and

(4) Mr. W. Duncan, Deputy Chairman, ICI (UK) has expressed the opinion that "ethylene production from cheap coals via methanol is now a commercial proposition" (Society of Chemical Industry Meeting, March 6, 1981, Dublin).

Most importantly, international recognition of this product is most convincingly portrayed by galloping new capacity and consumption at a time (1981) of cyclic industrial decline.

Present Status of the Methanol Industry

Presently international capacity for methanol[116] is about 13.5 million tonnes (1979) distributed as follows:

	per cent
North America	- 31
Western Europe	- 27
Eastern Europe	- 22
Rest of the world	- 20

Virtually almost all of the world's present consumption of the product is as a 'chemical'. Its quantitative offtake is about a third that of chemical naphtha, and currently they are non-overlapping raw materials. It is interesting to note that there appears to be some

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[116] "The industrial uses of associated gas" UNIDO/GOIC (Gulf Organization for Industrial Consulting)Study 30 April, 1981.

relationship between the propensity to consume ethylene to that of methanol:

	Kgs Per-capita 1977 consumption (Relative to the United States)		
	Japan	United States	Federal Republic of Germany
Ethylene	0.7	1.0	0.9
Methanol	0.7	1.0	1.1

(United States: Ethylene 11.2 million tonnes
Methanol 2,9 million tonnes)

While the largest methanol plants are in the United States, large units are also operating in other parts of the world. Table 13 presents capacities of typical plants. **It is instructive to note that the largest capacities are with some of the world's most prominent chemical corporations, and that there are very few non-chemical companies in methanol production. Natural gas is the feedstock for almost all of these plants, with the exception of the Japanese plants which are now operating with imported LPG. Only in South Africa is methanol produced from coal.**

Current Applications of Methanol

In the context of this study it is useful to consider present day applications of methanol under two categories - those which were in use pre-1975, and those post-1975 (now essentially energy-related uses as will be expanded upon). In Table 14, the usage of methanol in the United States and the "world", as estimated by Celanese Corporation[117/] (of the United States) is presented.

117/Chemical and Engineering News, April 7, 1980 quoting Celanese data. Celanese data is closely paralleled by a third source: The United Stated National Alcohols Fuels Commission.

Table 13

Typical Capacities of Large International Plants - Methanol (Mid 1979)

	Unit: Thousand Tonnes
United States	
Borden, Geismar, La	220
Celanese, Clear Lake, Tex	545
DuPont, Beaumont, Tex	545
Monsanto, Texas City, Tex	270
United Kingdom	
ICI, Billinghan	380
ICI, Billinghan	180
Federal Republic of Germany	
BASF, Ludwigschafen	230
URBK, Wessling	450
German Democratic Republic	
At Luena	230
Netherlands	
Methanol Chem, Delfzil	300
Romania	
At Victoria	180
Japan	
West Japan Methanol, Osaka	300
East Japan Methanol, Chiba	240
Mitsubishi Gas, Nigata	180
South Korea	
Taesung Methanol Yaesu	300
Mexico	
Pemex, San Martin	135
Libya	
National Methanol, Marsa El Berga	300

The distribution of methanol's pre-1975 usages in the Unites States, and as a contract, European consumption is presented below:

Unit: per cent

	United States (1978)	**West Europe (1979)**
Formaldehyde	50	49
DMT	5	5
Methylamines	5	5
Methylhalides	5	3
Acetic acid	5	1
MMA	5	3
Solvent	10	34
Misc.	15	
	100	100

While methanol is used in the manufacture and processing of a large number of chemicals, it basically has had till very recently, only two major applications - (a) as a raw material for formaldehyde whose largest use in turn, is for plywood adhesives (urea and phenol-formaldehyde resins) and (b) as a solvent.

Table 14

Celanese Corporation Estimate for Present Usage of Methanol and Forecast

Unit: 000 Tonnes (1980)

	United States		**World**	
	1980	1990	1980	1990
Group A				
Pre-1975 uses	3300	5745	11670	20000
Group B				
Post-1975 uses Chemicals				
SCP	0	0	90	270
Fuels (+ energy-related)				
MTBE (1)	240	675	315	945
MTBE/TBA blend (2)	30	900	30	1200
Gasoline blending	30	4500	60	5130
Peak-power shaving	10	1500	10	1500
	3610	13320	12175	29045

(1) MTBE = Methyl tertiary butyl ether
(2) TBA = Tertiary butyl alcohol

The growth of methanol consumption has generally been proportional to the housing construction industry. Since its debut as a tonnage chemical around about 1950, methanol has grown at the rate of about 10-15 per cent in the industrialised countries till a slowdown was forced by the energy situation in 1973.

Although new uses for methanol developed in the course of time - as methyl methacrylate and DMT, these did not give basic new directions to methanol's usage. Single-cell protein (SCP), an animal feed protein supplement which has been in development since 1970, and which once promised to become a large consumer of methanol, has yet to prove so[118/].

The only significant new requirement for methanol has been as a raw material for acetic acid, Monsanto's revolutionary technology[119/] for acetic acid production replacing conventional hydrocarbons as naphtha, butane,LPG, ethanol, and most importantly, ethylene as raw material base. Because of the diverse corporate and geographical sources from which methanol can be obtained, and because of reported high energy savings in the Monsanto process, the new technology (a precursor of the C1 technologies) has the potential of replacing all other routes to acetic acid (except in low capacity operations). It is reported by Monsanto that currently about 40 per cent of the capacity in the developed countries has been, or is in the process of being, replaced by the new route. Chem. Systems has estimated that W. European consumption of methanol for acetic acid would grow, by 1990, 22-fold over the 1979 level.

Fuel and Energy-related Applications of Methanol

Since the late-1960s, there has been considerable interest in methanol as a ' secondary energy carrier', a method of conveniently and economically moving the 'primary energy' in natural gas and coal. This interest was

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[118/] Only ICI makes methanol-based SCP ("Pruteen") currently at about 60,000 tonnes per year in a pilot plant (to be shortly upgraded). Chem Systems have forecasted methanol consumption for SCP in W. Europe at 550,000 tonnes in 1990 (Hydrocarbon Processing,March 1981).

[119/] See section on Acetic acid. The Monsanto process catalytically reacts methanol and carbon monoxide to form acetic acid.

abetted by the availability of large crude oil tankers which can alternatively be used for methanol. There was also a 'second level energy interest' in methanol - it was environmentally very acceptable because of the absence of sulphur, ash, etc. in its usage. Thus power stations in densely populated areas of Eastern United States and in Japan sought to employ it.

Natural gas discoveries in Libya and Algeria, during the 1960's, gave further impetus to methanol. However, the gas-producing countries came to quickly realise, as will be discussed later, that in the production of methanol more energy was lost (i.e. more natural gas was consumed) than in the production of the alternate energy carrier 'liquefied natural gas', LNG, the basic form in which natural gas is ocean transported today. Hence, export of methanol was discouraged.

With the energy pricing moves of 1973, the feasibility of using methanol as fuel was further dampened - in terms of the overall concepts prevailing then[120].

Today, the use of methanol in the energy field has emerged indirectly - through environmental considerations. As Table 14 indicates, these usages are expected to nearly quadruple in the United States, and increase 250 per cent in the world, by 1990.

'Peak power shaving' is a particular requirement of the United States Eastern Seaboard where methanol is beginning to be used as turbine fuel in direct and 'combined power' cycles. Methanol is thus a **supplementary** fuel to power stations using oil or coal as base-load fuel[121].

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[120] Simultaneously, the indication of OPEC member countries that they would price natural gas on the same basis as crude, even dampened the prospects of LNG.

[121] With its declining availability and increasing price, natural gas is expected to reduce its contribution as a 'base load' fuel to United States power generation.

A second new usage for methanol as energy material, arises from its use as MTBE - methyl tertiary butyl ether - an octane booster more acceptable than TEL (tetraetnyl lead), the prime octane improvement chemical additive for gasoline till the end of the 1960s. Since 'octane boosting' is characteristically an American demand (it provides a 'fast take-off' capability at moderate cylinder compression ratios), the rest of the world uses it only in small quantities. Since increasing the aromatics content of gasoline also confers octane improvement, the potential for MTBE is partly conditioned by the availability of such an alternative. MTBE, however, makes a substantial economic contribution in the marketing of gasoline. It enables the use of a less expensive wide-range gasoline fraction (distillation range). Methanol however, is sometimes also blended into MTBE formulations so as to improve the auto engine's requirements of 'front-end volatility'.

Direct blending of methanol into gasoline - to save on naphtha (discussed later) - is practiced in France and the FRG (such usage totalling 200,000 tonnes in 1980 according to Chem Systems), but this use is presently not significant in the United States (Table 14).

In the aggregate, as Table 14 shows, if only the conventional lines of methanol usage are extended, United Stat[illegible]sumption increase about **four-fold between 1980-1990. Group B uses (post-1975 uses),** however, increase a phenomenal **twentyeight-fold. In W. Europe, the corresponding figures are 70 per cent and five-fold (Table 15).**

Table 15

Estimate of W. European Usage of Methanol[122]

	Unit: 000 Te	
	1979	1990
Group A (pre-1975 uses)	2932	3985
Group B (post-1975 uses)		
MTBE	100	340
Gasoline blending	200	200
Acetic acid	25	550
SCP	2	550
	3259	5625

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[122] "Chemicals from Methanol" Martin E. Sherwin, (Chem. Systems) Hydrocarbon Processing March 1981.

New Applications of Methanol

If new technologies now being developed are successful, methanol will take over the role that naphtha has played in the energy and chemical industries - that is, methanol, a chemical industry feedstock, will penetrate into the materials of the energy sector to become a major 'energy material'.

While the focus of this study is on the role that methanol, or other materials, can play as feedstocks in the petrochemical industry, methanol's placement as an energy-carrier needs to be considered as it is through such usage that it will greatly influence the economics of its overall utilisation.123/

A particular reason for this joint review is that the most promising technology for upgrading the energy content of methanol - Mobil Oil's 'MTG process' - is likely to be the conceptual process for converting it to ethylene, the chemical industry's most important raw material intermediate.

Before pursuing this matter, certain 'externalities' must be disposed of:

(i) the availability of methanol from countries which have predominantly large fossil resources - as North Africa - thus, prospects for international trade in methanol fuel; and

(ii) present scope, worldwide, for methanol to be utilised as a 'stationary fuel'.

'Economic nationalism' appears to militate against the production and export of methanol fuel (made from natural gas) in countries such as those of North Africa on the reasoning that only 55 per cent of the energy (as natural gas) entering the methanol production system is available in product methanol fuel (the rest, conversion loss), whereas if natural gas was alternatively converted to LNG, the corresponding availability is 83 per cent; that is, the nation can market more of its calorific value in its resources in the form of LNG rather than in methanol.

123/It was indeed naphtha's low price in the 1950's, as a surplus refinery stream, that led to the development of naphtha cracking and reforming technologies.

This type of conservancy practice would not apply to the use of coal for methanol production - coal is more abundant and free of resource monopolies - however, the capacity level at which methanol becomes viable, when based on coal, is very large, bringing into play both investment requirements and logistical factors[124/] which do not apply to gas-based methanol.

As regards the use of methanol as stationary fuel, only the existence of very stringent environmental regulations (United States East Coast, Japan) will encourage it. And for a nation that has natural gas, there is little point (and no economic value) in converting it to methanol if it can be readily piped to points of usage.

The implication of these factors is that:

(a) large international movements of methanol, from developing country, sources, cannot be expected: and

(b) methanol usage as energy will essentially be in the transportation sector.

Methanol as Transportation Fuel

Thus, for the scenario of the type presented above, the alternative most worth investigating is the usage of gas-derived methanol as a transportation fuel[125/].

Two technological alternatives have emerged in this connection - the direct and indirect usage of methanol.

In the direct use of methanol, several options are available, all of

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[124/] A 1800 tonnes per day methanol plant is said to require a 30,000 deadweight ocean-going vessel to lift the daily cargo.

[125/] Scope for the use of compressed natural gas or LNG in personal transportation (as opposed to mass transportation) has drawn very little attention. In times of emergency, all forms of combustibles have been used in transportation - wood, charcoal, coal, LPG, kerosene, etc. Some LPG is said to be used currently for automobiles in Italy and the United Kingdom.

which are being technologically pursued in the industrialised countries:

(1) methanol as a direct gasoline blender to the maximum possible extent consistent with minimum modification of automobile engines (already practised in France);

(2) methanol with additives, blended to the maximum extent consistent with known technology of engine modification (being attempted by Ford in Brazil); and

(3) 100 per cent substitution of gasoline with methanol using new engine technologies (prototype by Ford Mercedes, Volkswagen).

Of the indirect methods, the most important evolution is that of Mobil's MTG (Methanol to Gasoline) Process, or M-Gasoline process, which converts methanol to a mixture of hydrocarbon components - aromatics, branched paraffins, etc. - almost identical to gasoline in composition and usage with an octane number of 93 (which is very attractive for the United States auto industry).

The Mobil 'M' Gasoline Concept

In 1976 Mobil Oil announced the development of M-gasoline employing 'zeolite chemistry' with methanol as feedstock. The critical part of Mobil's process[126] is the use of 'shape-selective' zeolites, the ZSM-5 series, which it has extensively developed and which are covered by numerous patents. While the process has been demonstrated in a 4 barrels per day pilot plant in the United States, it has attracted international attention as a consequence of the decision of the New Zealand Government to build a commercial size plant, 13000 barrels per day or 600,000 tonnes per year capacity, sufficient to run one-third of the country's automobiles[127].

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[126] As explained in the Introduction, this document minimises its attention to manufacturing technology so as to maintain "issues" in focus. Detailed information on processes etc. would often be available in the references cited in the footnotes or in explanatory footnotes.

[127] The production facility is believed funded by the New Zealand Government, Mobil Oil and British Petroleum. Construction contracts (General Contractor, Bechtel) were awarded in 1979 and the plant is expected to be in operation in late 1984. Foster-Wheeler, United States has responsibility for developing process design. The methanol plant (4500 TPD) is based on ICI technology and will be engineered by Davy-McKee. Total project investment (including methanol plant) is reported as $670 million. The methanol plant will use natural gas from the country's Maui fields. Mobil has selected the 'fixed bed' version of its process. It is believed the New Zealand Government has priced its gas concessionally so that 'M' gasoline would be competitive to that made from imported crude. According to Syn Fuels (McGraw-Hill) Dec. 10, 1979 issue, gasoline will be obtained at $23/BBL with natural gas cost at $1.05 per million BTU, versus a ex-refinery (New Zealand)cost of $31/BBL for conventional gasoline made from imported crude.

A basic limitation of the present version of the process, its 'fixed bed' principle[128] is sought to be overcome by a 100 barrels per day fluidised bed pilot plant now being constructed by a five-party development consortium (Uhde, URBK, Mobil, United States Department of Energy, DOE, and BUFT, the FRG equivalent of DOE) in FRG.

There are many considerations which made 'M' gasoline a very viable competitor to the direct use of 100 per cent methanol as an engine fuel[129]:

(1) No need for the development of wholly new engines with high compression ratios (14:1 vs 8-10:1 for gasoline);

(2) Elimination of the need for a new marketing infrastructure to merchandise methanol, the existing petroleum infrastructure can fully service 'M' gasoline;

(3) Its higher energy content; methanol which requires that 50 per cent more tankage be provided on a vehicle for obtaining the same mileage as with ordinary gsoline (or with 'M' gasoline); and

(4) Potential toxicity of methanol which is particularly severe is circumvented along with the erring tendency of lay customers to identify methanol with ethanol as beverage.

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[128] While the 'fixed bed' technology enables scale-up to larger aggregate sized plant, it requires multiple stream operation. Fluidised bed technology will enable scale up so that the number of parallel streams can be minimised. In Mobil's view, a 100 b/d prototype will give sufficient information for direct scale up to commercial sized plants.

[129] Technically, methanol (and ethanol), as fuel, is compatible for automobile usage as the following data, on the properties of the fuels, show:

	Methanol	Ethanol	Premium gasoline
Research Octane No.	112	110	96
Motor Octane No.	92	90	84
(R+M)/2	102	100	90
Heat of Evaporation (kilojoules/kg) (Note 1)	1100	902	861
Flame Temperature, oC (Note 2)	470	392	478
Fuel Air Ratio (Stoichio-metric) (Note 3)	0.155	0.111	0.069

Note (1) The alcohols vapourise less easily but by the same token are more storable

(2) low flame temperature leads to lower NO_x **emissions**

(3) since methanol and ethanol are oxygen-bearing, while gasoline is not, they require less air for combustion.

Per unit volume, methanol has only 50 per cent, and ethanol 68 per cent, of the energy of gasoline.

If, on the other hand, methanol-blended (petroleum) gasoline is compared to 'M' gasoline, only 10 per cent methanol can be blended in without engine modification (or changes in infrastructure). A greater disadvantage is that even slight contamination of the blend with water leads to 'phase separation' (the separation of layers - at all points of the distribution system and in the automobile).

However, the practicability of 'M' gasoline being used as a transportation fuel needs to be gauged in the economic context. If only 1 per cent of United States consumption of conventional gasoline (9.4 million barrels/day) was substituted by 'M' gasoline, then 9 million tonnes of 100 per cent methanol would be required per year[130] that is, 75 per cent of the world's present consumption of methanol (or 2.5 times that of current United States consumption). If methanol production was coal based (see later discussion), the required investment for this 1 per cent penetration level would be approximately $2 billion (in 1977 US$)[131].

In regard to pricing of 'M' gasoline (coal-derived via methanol), relative to that of petroleum gasoline, a United States Department of Energy study (1980)[132] provides the following data:

Unit: Cents per United States gallon

	Conventional Gasoline Crude at, $/BBL			M-Gasoline		Methanol	
	10.89	14.00	27.00	100%	5%[133]	100%	10%(blend)
Price at plant gate	34	47	100.00	106	37	43	35.7
Cost to motorist (¢/gallon)	61	74	127.00	133	64	62	64
Cost to motorist (Cents/mile[134])	2.34	2.84	4.90	5.12	2.46	4.96	2.5
Relative cost	1.00	1.21	2.09	2.18	1.05	2.11	1.0

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[130] Very approximately, 0.40 barrels of 'M' gasoline is derived from 1 barrel of crude methanol. LPG gas is a byproduct of the MTG process (9 per cent of feed methanol). LPG can, however, be recycled to the syngas system if such is integrated to the MTG production unit.

[131] Based on calculations presented in CEER (Chemical Engineering and Economic Review, Japan) July 1979.

[132] Overview, Production Application and Economics of Methanol and Gasoline from Methanol fuels. Study prepared for United States Department of Energy, February 1978 by TRW Energy Systems Planning Division.

[133] M-gasoline as blended into conventional gasoline.

[134] 26 miles per US gallon for car operated on gasoline.

The study, whose focus is on the ability of methanol to directly and indirectly reduce United States balance of payments, leads to the following set of conclusions:

- A 5 per cent blend of M-gasoline in conventional gasoline is very nearly competitive with current prices of conventional gasoline (possibly cheaper than the 'mixing cost') and requires no changes to be effected in infrastructure or that of automobile engines.
- M-gasoline is preferable to 100 per cent methanol, as the latter requires major infrastructural and distributional changes, besides substantial engine modification, and
- Unless crude prices rise above $27.00/bbl (in the United States) in 1978 dollars, M-gasoline is not competitive to conventional gasoline for 100 per cent replacement (if taxes on it are the same structure as on petroleum).

While recognising that M-gasoline is not the only alternative available for obtaining a transportation fuel, the aforesaid study, however, discounts the competitive capability of the Fischer-Tropsch liquids (see section on Pseudo-Petroleum Feedstocks) in the Unites States, in terms of gasoline quality, economics and production simplicity.

M-Gasoline vs Methanol Blends

The following constructional elements of cost show the disadvantage of blending methanol into conventional gasoline (United States situation, 1978) vis-a-vis the alternative of blending-in of the two gasolines.

Unit: Cents per US gallon

	5 per cent M-gasoline blend into conventional gasoline	10 per cent of methanol directly blended into conventional gasoline
Price after raw processing	37	35
Butane removal, addition of corrosion inhibitor and drying[135]	-	0.64
Modification to terminal	-	0.05
Price at plant gate	37	35.7
Transportation	6.0	6.1
Modification to gasoline station	-	1.2
Price delivered to station	43	43
Price, delivered-to-car (including taxes)	21	21
Car modifications[136]	-	2.2
Cost to motorist, ¢/mile	2.46	2.54

While in an automobile-dominant country such as the United States, the impacts of a new gasoline penetrating into the conventional scene are many[137], countries on the road to economic development could be find many advantages with the technology[138].

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[135] Butane must be removed from conventional gasoline (at the refinery) so as to reduce high vapour pressure materials (C4's) before methanol blending to conventional gasoline. (There is very little of C4's in M-gasoline) Moisture must be removed from Methanol or phase separation will occur. Even so, corrosion inhibitors must be added.

[136] To use 10 per cent methanol blend in gasoline, some rebuilding of parts is necessary (i.e. regasketing). The parts affected are carburettor, fuel pump, fuel filter, flex fuel lines and tank filter hose.

[137] M-gasoline or methanol blends are expected to find highest acceptance in the United States by 'fleet operators' (auto hiring agencies) who consume more than 20 per cent of all United States gasoline. Bank of America, one such operator, is extensively testing out methanol.

[138] In many 'non-oil' producing countries the demand for naphtha, as gasoline, often exceeds local production from crude, requiring import. Blending with methanol or with M-gasoline would be particularly attractive to these countries, significantly so if they own coal or natural gas.

The thrust of the above discussion is to underscore the fact that meaningful alternatives to reducing petroleum usage are emerging from energy-oriented technologies. As a result, situations are likely to develop by which the chemical industry might be able to 'ride' on raw materials being created in the context of energy. Further bulk movement of methanol for energy would, through economies of scale, bring about economic advantages to its use as a feedstock. Methanol thus emerges as an important candidate material for a restructured chemicals industry.

Methanol as Chemical Feedstock

A major petrochemical feedstock must fulfil certain techno-economic requirements. It should be:

(1) As close as possible, a hydrocarbon;
(2) Serviceable in an already developed, or easily developable, physical and marketing infrastructure;
(3) A 'commodity' purchasable on specifications and competitively available from plural sources;
(4) A volume or 'tonnage' material; and
(5) The base (or feedstock) for a span of major chemicals.

Naphtha, benzene and ethylene[139] meet all of these conditions satisfactorily and hence are in abundant usage. Natural gas, LPG, natural gas liquids (NGL), and ethanol, nearly meet all of the conditions. However, materials as calcium carbide, acetylene, coal, gas oil and syngas, although 'industry feedstocks' do not (even in respect of the first four factors).

Methanol nearly fulfils the first three requirements. It meets the fourth only partly, while a world scale production at 12 million tonnes per year does give methanol 'commodity' character, its usage is not comparable to chemical naphtha at 170 million tonnes or to ethylene

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[139] Ethylene is already being considered an independent 'utility' in the industrialised countries.

at 450 million tonnes, let alone natural gas volumes. The possible emergence of methanol as a gasoline supplement - directly and indirectly - however, holds promise of raising its status to a major commodity. It is only under the fifth requirement that methanol presently does not qualify as a chemical feedstock (very limited usages).

At the same time, C1 Chemistry and a new development at Mobil Oil, closely associated with M-gasoline, are likely to make methanol one of the chemical industry's major commodities. For the developing countries, this is, of course, a development of great consequence.

Methanol, like ethanol, differs from other industry's major feedstocks (hydrocarbons) in that it contains oxygen (50 per cent of its weight). However, unlike ethanol, it could not, hitherto, be dehydrated by simple means to give a 'building-block' hydrocarbon(such as ethylene in the case of ethanol). Consequently, industry effort has concentrated on utilizing the material as a commodity source of the carbonyl 'CO' group. While Monsanto's acetic acid and Tennessee Eastman's acetic anhydride processes are dramatic indications of new methanol-oriented technologies of high commercial value - and Chevron and Halcon are well on their way to making methanol a feedstock for two important chemical commodities, ethylene glycol and vinyl acetate[140/], respectively - it is Mobil's ethylene process which promises a real challenge to naphtha.

[140/] The Monsanto acetic acid process utilises rhodium iodide catalysts to promote the reaction between methanol and (syngas-derived) carbon monoxide to obtain acetic acid in a one-step reaction. The Eastman route esterifies methanol and acetic acid to methyl acetate and is then carbonylated, as with the Monsanto process, to acetic anhydride. In the Halcon process, methyl acetate is treated with syngas to drive ethylidene diacetate and this then cracked; per conventional chemistry, to acetic acid and vinyl acetate, the former being recycled for methyl acetate production. In the Chevron process, methanol is converted to formaldehyde, this is reacted with CO and steam to glycolic acid followed by esterification with methanol and reduction to the glycol. In almost all of these processes, chemicals production requires integration with methanol production because of large requirements of methanol, CO and syngas. In contrast to 'ethylene chemistry', the reactions in all the above developments are multi-step which usually has the implication of poorer yields than one-step processes.

The Mobil Olefins Process

While very little information has been published by Mobil on this methanol-based process - with a view to maintaining secrecy about its developments, (Mobil considers its technology as far-reaching), the following has appeared in the technical press: "By modifying the catalyst (Zeolite ZSM-5 based) and varying operating conditions, we can maximise light olefins (C_2-C_5) or aromatic products. Mobil investigators have been able to obtain light olefins as high as 70 per cent of the hydrocarbon products. Conditions can be chosen so that ethylene is a major constitutent of the olefins fraction........"[141].

The Mobil olefins process, like the M-gasoline process, makes use of the catalyst-bearing ZSM-5 zeolites to 'wring out water from methanol', yielding hydrocarbons. Through variation of catalyst chemistry, the formation of higher olefins, and their cyclisation to the aromatics (which yields gasoline) is prevented[142]. Hence a 40-60 per cent selectivity to ethylene is anticipated by development of the process.

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[141] S.L. Meisel (Mobil Research and Development Corporation) "New Synthetic Routes from Mobil" (page 13). The Royal Society, London May 22, 1980.

[142] The chemistry of the process is not well understood. On the basis of its resemblance to the M-gasoline process, which is better reported, it is said to involve the dehydration of methanol to a dimethyl ether, with both methanol and the ether then 'dehydrating' to carbenes:CH_2 fragments. The carbenes then polymerise to ethylene and participate in chain progression to propylene and the C4's. In the M-gasoline process, the olefins then dimerise to form closed-ring compounds, the aromatics. Alkylation, transalkylation, etc. also take place to yield branched paraffins and methyl benzene analogs. However, while they may be formed inside the zeolite. hydrocarbons larger than C-10 cannot diffuse out the zeolite structure. Hence the hydrocarbon mix resembles gasoline, in composition, rather than to gas oil or crude. In both the gasoline and ethylene processes great economy is possible because they do not require a water-free feedstock. Crude 'fuel methanol' is acceptable to both the processes. The Mobil processes, it is important to note, do not produce oxygenated byproducts which would reduce yield. The processes stoichiometrically yield only hydrocarbons and water.

In 1976, Mobil and African Explosives and Chemicals Inc (AECI), **South African organization** announced a joint programme for research into the ethylene process. In 1979, BASF announced that it was putting up a 180 tonnes per year pilot plant, based on Mobil's catalyst at Ludwigschafen, Federal Republic of Germany. Firms in several countries, including ICI in the United Kingdom, are viewing the process seriously and committing funds to it.

Chem Systems[143/], a United States consulting firm, using patent information and data published in technical journals (a procedure often followed by consultancy companies) has constructed on paper a 'commercial process'for ethylene based on the Mobil process. Their study, which enables a comparison to the conventional naphtha-cracking process for ethylene[144/] provides the information shown in Table 16 and illustrates the immense economic potential of the new process:

Table 16

Naphtha VS Methanol: Ethylene Conversion Ratios

	Methanol feedstock	**Naphtha feedstock**
Ethylene yield	30-60 %	26-32 %
Ethylene-propylene, yield	70-80 %	44-50 %
Reaction temperature, °C	325-425	850
Steam feed, tonne/tonne	0-1.0	0.5-0.8

[143/] 'Chemicals from Methanol' Martin B. Sherwin (Chem. Systems), Hydrocarbon Processing, March 1981 Dr. P. Spitz, President of Chem Systems, United States was interviewed for this study.

[144/] Chem Systems had at one time supported the homologation process, thus obtaining ethylene from methanol-based ethanol. They now appear to strongly favour the Mobil route.

The wide range of yield is due to various levels of catalyst selectivity[145] assumed by Chem Systems. Using various assumptions, the Company has presented the economic data displayed in Table 17.

Table 17

Ethylene from Methanol - Investment and Operating Costs

	Assumed Carbon Selectivity to Ethylene per cent		
	40%	50%	60%
Methanol required per tonne ethylene	4.98	3.98	3.47
Total Fixed Investment for a 225000 tonnes/year ethylene plant (1979, IVQR), $ Million	195	167	147
Raw material cost, at $ 230 tonne methanol, $ per tonne ethylene	1052	862	735
Net cost of production after taking by-product credits	878	719	635

The above cost figures can be compared to prevailing prices (1979 IV Qr) for ethylene of $650-$690 per metric tonne, contract.

Essentially, for forecasting the efficiency of the methanol-to-olefins process, provision needs to be made for the 'learning curve'.
What is significant is that the Mobil process, requiring mild operating conditions, is unlikely to develop technical bottlenecks such as new construction materials, unknown effluents or catalyst activity and regeneration problems - since it very closely resembles the 'M' gasoline process which has passed the prototype stage.

145/Selectivity is the degree to which a catalyst system influences the reaction to yield the sought molecule in a context of several alternate molecules.

At the heart of the process is the catalyst[146] (and it is believed Mobil has moved more to protect its catalyst - by patents - than its process). In order to assess the probability of the Mobil Olefin Process becoming commercial it might be a valid exercise to review Mobil's commercial successes with its ZSM class of catalysts.

Since the 1950s MObil has been active in the development of various types of zeolite catalysts. Its earliest catalysts, deposited on the wide-pore substrates are presently employed in more than 95 per cent of the world's petroleum cracking (FCC) installations (although processes built around the catalyst have different owners).

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[146] As of May, 1981, 570 patents have issued worldwide on the ZSM-5 class of catalysts. In the United States, and in 14 other countries, Mobil has the very important 'composition of matter' patents.

The ZSM-5 catalyst is built on the ZSM-5 zeolite, which is a highly silicious aluminosilicate 'molecular sieve' with an intermediate-size pore structure, in between that of the Linde 5A sieves (used to adsorb normal paraffins) and the 9-10 Angstrom (diameter) channels of the widepore faujasite molecular sieves used in petroleum cracking catalysts. The zeolite is criss-crossed by two types of channels (see Figure IX) one of which is straight and the other sinuous. Both channels are 10-membered oxygen rings. By chemically blocking these rings with certain element atoms it becomes possible to prevent hydrocarbons larger than a certain size from diffusing out of this structure. Catalyst materials are impregnated into the zeolite's internal channels. While they (the catalyst materials) promote and direct the chemical reactions, the zeolite channels, by their size, length and path determine whether certain products formed within the structure can leave the structure, and if so, their rate of diffusion through the structure. Zeolite chemistry is often described as 'shape selective'. Perhaps a more apt description (that is now being used) is that of 'molecular traffic control' or MTC chemistry.

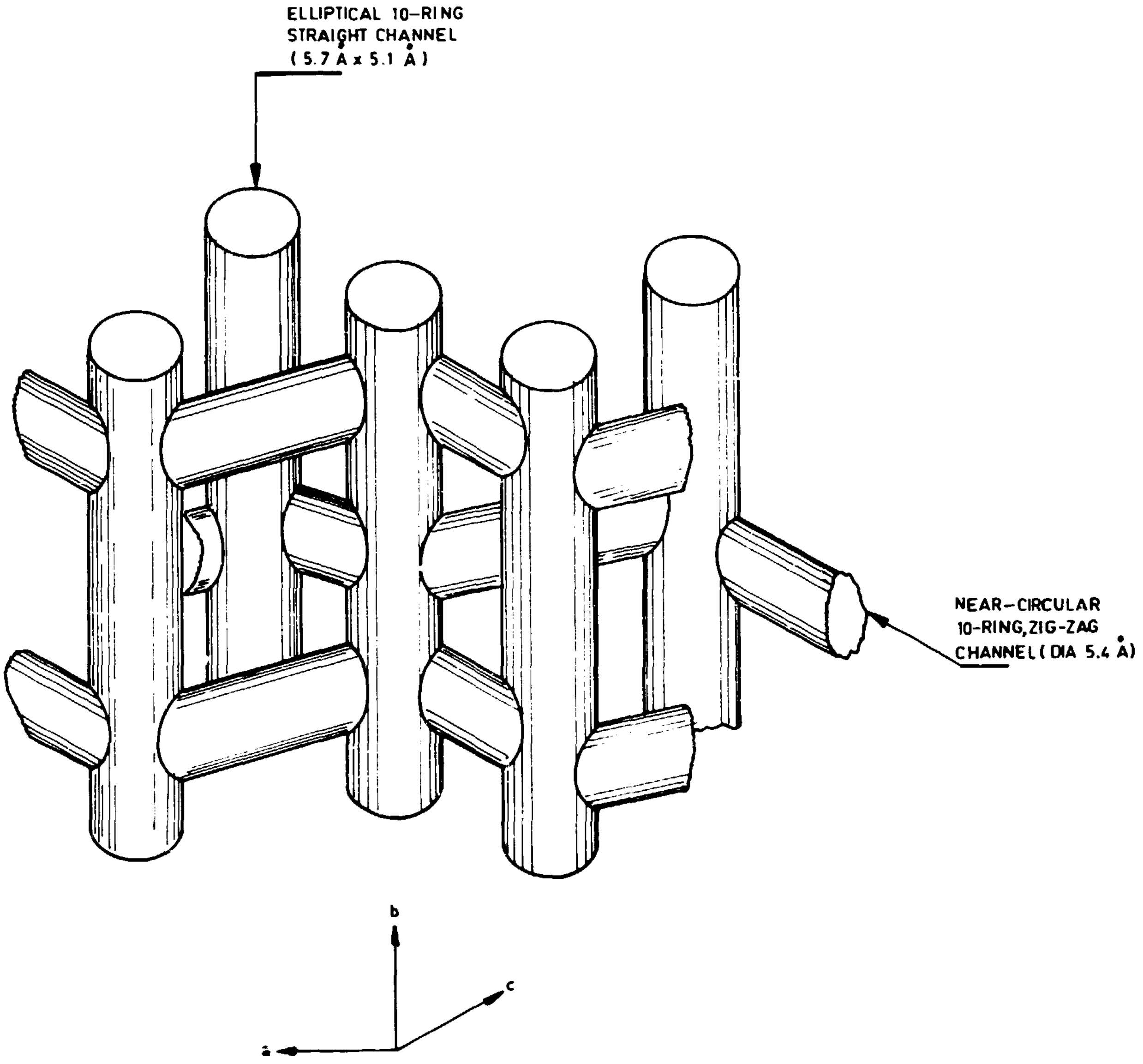

FIG. IX **POSSIBLE MODEL O̅F THE PORE STRUCTURE OF ZSM-5 AND SILICALITE**

The medium pore ZSM-5 zeolite catalysts were initially developed by Mobil in context with the 'dewaxing' of distillates[147/] and since then they have been extended to xylenes isomerisation; to the development of a new catalytic route to ethylbenzene (the precursor to styrene, one of the largest petrochemical commodities); to toluene disproportionation (to benzene and mixed xylenes); and now to the 'M' gasoline process.

What is very significant about these ZSM-5 class of catalysts is that they form a very substantial basis of all new technology in operation, most of it Mobil-developed. Thus, it is the basis, according to Mobil, of 60 per cent of world's p-xylene capacity; that Mobil operates internationally with its processes for dewaxing and toluene disproportionation (Naples petrochemical complex) besides having licenses for them (in People's Republic of China, for example, for the dewaxing process). Indeed, Mobil indicates, that 20 processes based on ZSM-5 class of catalysts are in commercial use internationally.

Thus, the feasibility of the ethylene route, which is based on this class of catalysts, must be judged in the context of the success already achieved by other processes involving these catalysts, and by the long-term 'presence' of the Company is catalysts (and in the fields of petroleum refining and chemicals manufacture).

Competition from the Syngas Route

While the subsequent chapter deals with syngas as a feedstock, it might be appropriate to discuss its competitiveness to methanol at this point.

Since methanol is made only from syngas, the question often arises as to why syngas cannot be directly converted to the chemicals[148/] bypassing methanol. By and large, as Section 1 shows, this is indeed the approach of the American oil companies.

[147/] Dewaxing takes place by hydrocracking and removal of straight chain and of methyl-carrying slightly-branched straight chain hydrocarbons. They reduce the 'pour point' of petroleum distillates, importantly, 'middle distillates'.

[148/] For the M-gasoline process, Mobil does indeed have patents for its production directly from syngas.

There are, however, advantages in going through methanol:

(a) Syngas provides superior economics to methanol only in large scale production (viz. coal-based production), but such production in most situations cannot be matched by offtake in chemicals. Therefore, the syngas producer must have firm energy outlets. On the other hand, methanol for products as ethylene[149] can be made at an economic volume level (viz. from natural gas) without the requirement that some of the production be used in other applications;

(b) Limitations on piping require that the user of syngas be located within a 250 mile radius (present state-of-the-art) whereas methanol's economics are not affected even by long distance ocean transport;

(c) Methanol as liquid is readily storable and can be transported using the petroleum fuels infrastructure. Syngas, on the other hand, must be used as it is being produced; furthermore its movement requires the creation of a specific infrastructure; and

(d) Methanol is available from a plurality of disparate sources and can be competitively purchased. Purchased syngas usually requires a firm user-producer linkage ('dedicated pipeline contracts').

In the emerging restructuring of the world chemical industry, it appears that methanol has better economics than syngas if 'internal' and 'external' economies are considered together. This would be particularly so if methanol was produced from natural gas and used regionally.

Methanol is particularly important for the developing countries whether they possess natural gas or not. Not only can it be made from other materials, as LPG or biomass, but for levels of feedstock consumption in such countries syngas could be uneconomic. Furthermore, because of a plurality of international supply sources (and surprisingly well distributed regional availabilities), it would be possible for the countries to phase-in the methanol industry, with chemical conversions first done on imported methanol.

149/In Mobil's technology, 'by wringing out water' no energy is lost from the process because water carries out no energy. All of the carbon in methanol becomes available in the product hydrocarbons. Hence, except for process heat losses, the thermal efficiency of the process is very high (Circa 90 per cent)

Raw Materials for Methanol

Methanol can, as said earlier, be manufactured from biomass peat, charcoal, lignite, hard coal, heavy residues of petroleum, petroleum distillates, LPG and natural gas. Indeed, at one time or another, all have been used. Presently methanol is commercially made from coal only in South Africa. In the rest of the world, with the exception perhaps of Japan, which leans heavily on LPG, the base is natural gas.

In terms of future development, coal appears as a more important material than natural gas, particularly in the United States.

While natural gas is geographically distributed more evenly than petroleum or coal its world reserves nearly equal to that of petroleum and its reserves/production ratio is better than crude oil its disadvantage as a raw material for methanol is that its pricing, on a heat value basis follows that of crude oil. This tie-in acts as an impediment to gas-based methanol emerging as a tonnage fuel or feedstock. For this reason, in the industrialized countries high-sulphur or high-ash coals, which are abundantly accessible and/or are low priced because of few alternative uses, are most pursued in terms of being future energy or chemical raw materials. Even so, it must be noted that in any process of making syngas (seen as a precursor to methanol) there is very substantial loss of energy value in coal[150]. Maximising the thermal efficiency of a coal process requires that saleable energy be co-produced with thermodynamically efficient chemical processes (as methanol). Thus, while methanol may be a large component or a small component of an optimised mix, methanol is an expected co-product of a 'coalplex' (and for which uses must be found).

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[150] In the coal's structure there are 'condensed' aromatic rings of high complexity. These hold resonant energy. When coal is converted to syngas, these rings are destroyed. Their energy is now transformed substantially into sensible heat. In process optimisation, this sensible heat is used at its highest temperature for energy-level conversion (i.e. running a turbine) and the exit low level turbine heat is used in chemical process systems.

In coal hydrogenation, it might be noted, high energy conversions result since the aromatic rings are preserved in liquid products.

Capacity levels of coalplexes are very high because only then do scale factors lower costs of production. In a study by DuPont for a 5000 tonnes/day coal-fed methanol plant (3500 TPD methanol), the investment estimate for 1983 completion was $803 million. Even so, costs of methanol production were high at $10 million Btu[151].

However, for a 2500 tonnes per day methanol plant based on natural gas (the largest single train plants made currently) investments would run from $200 million in the United States to $300 million in Qatar and $420 million in Indonesia. Relative to costs of production from various feedstocks the following production cost data of Uhde[152] is instructive:

Unit: $/tonne

Plant location	Raw material Natural gas (steam reforming)	Heavy oil (Texaco process)	Lignite (High temperature/ Winkler)	Hardcoal (Texaco)
United States	177-261	210	139	138
Arab countries	132-165			
Australia			158	164

Manufacture of Methanol

There are no technological limitations to the use of natural gas, petroleum residues or coal for the production of methanol. Natural gas is the raw material that is most used. The use of residues is known, even in high volume production - URBK in Federal Republic of Germany and DuPont in the United States being current users of the feedstock. The United States Department of Energy, partly based on knowledge made available through Sasol's experience, claims coal-to-methanol technology now available as 'state-of-art'.

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[151] In a study commissioned by United States Department of Energy, the investment for a 19 million tonnes per year (52000 tonnes per day) methanol plant amounted to $3.1 billion (1977 dollars for a 1977 **'instant'** plant). Such a plant would produce methanol sufficient to replace 2.9 per cent of the Unites States gasoline market with M-gasoline.

[152] European Chemical News (ECN Chemscope) - April 28, 1981.

In the case of biomass gasification, however, there is little commercial experience. Pilot plants are known to be operating in Sweden and other Scandinavian countries. Brazil has plans to make methanol from eucalyptus trees (via syngas)[153]. As said earlier, it is economics, rather than technology, which will determine the feasibility of the biomass route.

Consequently, in viewing prospects for methanol emerging as a large chemical feedstock - principally, as a source of ethylene in the 10-15 year future - attention needs to be focused on methanol synthesis from natural gas and on the prospects of this process (methanol process) yielding to still newer technological developments - in terms of reduced investment costs per unit of capacity, larger capacities per production stream, better energy efficiencies and the ability of the process to accept 'low quality' feed gases. If such new developments do indeed take place, then it should be possible to reverse the trend that now makes international trade in methanol difficult.

Technological progress in methanol has indeed been remarkable. Plant capacities have steadily risen from 150 TPD in the early 1950s to around 1800 today (operative). Pressure requirements for the process have been reduced to one-quarter or one-third of that employed in the early 1950s (4500 psi) enabling larger reactor volumes. The use of centrifugal compressors (in place of reciprocating compressors) have increased per-stream capacities. More robust catalysts and better methods of gas clean-up have contributed to reduced energy consumption. At the reformer end, better tube metallurgies have continuously led to efficiency improvements.

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[153] Davy-McKee have contracts from the Brazilian Government to design a 2000 TPD methanol facility based on atmospheric gasification of Eucalyptus trees. Here chunks of wood are fed into a fixed-bed gasifier fired with oxygen. About 3 tonnes of wood (35 per cent moisture) are consumed per tonne of methanol requiring 90 square miles of forest to support the facility.

Basically, the major change was brought about by catalyst technology, by the remarkable work done by ICI in the early 1960s. It is indeed in this area that most new development is expected[154].

Whereas in most areas of petro-technology, capacity advantages are becoming less important as operating costs begin to dominate fixed costs (75 per cent and over), in gas-based methanol plants fixed costs still dominate 60 per cent at 2000 TPD, methanol capacity[155]. Thus, scaling up is a viable incentive. This becomes a problem of several magnitudes when size-limiting coal gasifiers are integrated into the methanol synthesis plant.

Trends in Creation of New Capacities

Because of their physical and/or financial resources positions, USSR State agencies and the United States corporations are the most aggressive in new methanol plant construction. Two of the world's largest plants (2500 TPD) are about to be completed in the USSR, built by Davy-McKee. Celanese and DuPont, of the United States, continue their fight for methanol leadership. Celanese plans to build a 4000 TPD coal-based $1.4 billion plant in the United States while bringing into production a 1600 TPD plant in Saudi Arabia (joint-venture with SABIC and Texas Eastern) and a 2100 TPD plant in Alberta, Canada. The Province of Ontario, Canada is envisaging the building of 13 methanol plants, with and without association with United States firms. It is also known[156] that United States companies are planning to build a 25000 TPD coal-based methanol plant in Alaska.

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[154] While unrelated to methanol technology, it is of interest to note that for low density polyethylene catalyst technology has enabled pressure to be dropped from 15000 psi and higher in the 1950s to near atmospheric pressure today (in LLDPE).

[155] The Industry Uses of Associated Gas, UNIDO/GOIC Joint Study, 31 May, 1980.

[156] Chemical Insight, No.123.

In the United States of 48 applications received by the Department of Energy for financial support under the 'Synguels Program', 15 proposals concerned the production of methanol.

Concluding remarks

Methanol can be obtained, and in one country or another is obtained, from a variety of diverse carbonaceous sources - biomass, coal, petroleum residues, naphtha and natural gas. If this flexibility of feedstock usage is combined with an important recent development in methanol technology - the ability to make ethylene from methanol - there are very strong indications that shortages in, or the costs of petroleum feedstocks need not deter petroleum deficient developing countries from making bold moves into the planning of viable indigenous organic chemical and polymer industries. However, the commercial development and application of methanol-to-ethylene technology is a more critical need of developing countries rather than of the industrialized countries because of the greater ability of the latter countries to bear the cost of petroleum imports. Hence, the developing countries must take the initiative in the development of such technology either on an individual country basis or more effectively by collective action. Advanced country interest in methanol stems more from the **viewpoint** of its usage for the manufacture of gasoline, particularly in the United States where coal is both plentiful and low cost. The technological basis for the conversion of methanol to gasoline is provided by Mobil Oil's 'MTG Technology' (methanol-to-gasoline technology) based on otherwise well proven zeolite catalysts. Established beyond the prototype scale, the technology has been selected by New Zealand (and more recently by Argentina) for commercial scale production of gasoline. In the United States itself, the probability of using methanol-derived gasoline is determined not by technological uncertainties or operational costs as much as the level of investment required to substitute petroleum-based gasoline (about $2 billion fixed investment in new plant and equipment for each 1 per cent penetration of methanol-based gasoline into petroleum-based gasoline). Yet there is a distinct effort in the United States to start the process of penetration.

The commercial viability of the methanol-to-gasoline process has the important implication that the technology involved incorporates an intervening step in which ethylene or ethylene precursors are first produced from methanol before they are converted, in situ, into those chemical components that comprise gasoline. Mobil Oil is on public record as having stated that the company has the technology to arrest the process that leads to gasoline and divert it to the production of olefins. African Explosives and Chemicals Incorporated (AECI), a government controlled firm in which ICI has equity interest, is believed to be building a plant based on Mobil's ethylene technology with Mobil involvement.

Chief executives of firms which are heavily oriented to methanol, such as ICI, BASF and Celanese, are on record as forecasting that methanol will emerge in the next decade or so as the most important chemical intermediate. The largest producers of methanol - such as DuPont and Celanese - are presently making large investments to double and triple their existing capacities, indicating that methanol will no longer remain a dormant chemical commodity.

Because in the industrialized countries the existing petroleum infrastructure suffices for methanol storage and movement and their urgent demand is for developing substitutes to petroleum-derived energy, there is greater demand for methanol substitution for petroleum fractions for energy than as a feedstock for petrochemicals. However, developing countries may be able to take advantage of this methanol usage for energy to stimulate its application to petrochemicals. If methanol can be landed in Europe at reasonable costs, adequate incentive can be provided for the development of 'methanol chemistry'. The implication of this strategy is that methanol can lead to chemicals and polymers just as low-cost naphtha in the early post-war years led to petrochemicals (and to the substitution of carbide-based acetylene and ethanol as prime industry feedstocks).

II. SYNGAS

Introduction

Synthesis gas, or 'syngas', is a mixture of carbon monoxide and hydrogen, whose proportions are varied to suit application. It has two broad categories of use:

(1) as an energy carrier (or as an intermediate for the production of an energy carrier); and

(2) as a chemicals feedstock.

Syngas has a very marked disadvantage - it is not storable; but at the same time it also possesses a very strong advantage: it can be produced from a wide range of raw materials, from peat, biomass and coal, at one end of the spectrum, to vacuum gas residues on the other.

Since its commercial introduction as 'water gas' or 'blue gas' for town lighting, the volume of syngas usage has steadily enlarged. But its applications have significantly changed. If the use of syngas in its current and principal forms - for the production of ammonia, methanol, refinery hydrogen and oxo synthesis - is considered together with less significant uses for Fischer-Tropsch products and chemicals, its 'consumption' on a worldwide basis would exceed 200 million tonnes annually, certainly a large consumption figure.

Since almost all of today's syngas is directed to chemicals, it is primarily viewed as a chemical feedstock. But, like methanol (but not unexpectedly), it also shows strong signs of becoming an 'energy material', particularly for power plant peak-shaving. However, its large scale application as an intermediate to the safer, and more heat-intensive (calorific) energy form, synthetic natural gas (SNG) appears decades away because of improvements in international and regional availabilities of natural gas (as discussed in Section I)157/.

'Syngas chemistry' has important implications to developing countries, including the oil-producing developing countries (OPDC). For the non oil producing developing countries, it has the consequence that chemicals

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157/ SNG has a calorific value close to 1000 BTU per cubic foot; medium BTU gas (or syngas) is only a third of this, varying somewhat with composition.

(including, as will be shown, the thermo-plastics) can be produced from non-petroleum indigenous materials, or from imported low cost petroleum fractions as vacuum residues which are internationally traded. Importantly, in terms of trade among developing countries methanol can be considered a 'liquefied' form of syngas, capable of being moved efficiently.

For the oil producing developing countries, syngas represents a means of producing chemicals from the by-products of refining and gas-processing operations, or as a means of utilising natural gas at points which are not amenable to linkage to main gas grids. At the same time, the use of syngas technology in place of petrochemical technology, for the production of organic chemicals can have strategic implications; valuable petroleum materials could be diverted to those chemical or energy products which would be more value-adding.

Syngas as Chemicals Feedstock

The 1920s saw the emergence of syngas as an important chemicals feedstock with its employment for the production of ammonia and methanol by BASF (who developed the commercial forms of technology for both processes). However, its most conspicuous application as a source for a broad range of chemicals, by Fischer-Tropsch synthesis, was obscured by Germany's exploitation of the concept for the production of transportation fuels.

The Fischer-Tropsch process (now solely operating in the Sasol complexes of South Africa)[158/] yields a very wide product slate, from saturated hydrocarbons and mono-olefins (including ethylene) to alcohols, aldehydes, ketones and fatty acids (from C_1 to C_{35}). The choice of catalysts and promoters enables a degree of product selectivity. Product mix is significantly dependent on the CO/H_2 ratio.

158/Sasol is a public company which uses high-ash (30 per cent) coal for the manufacture of gasoline, diesel fuels and chemical raw materials. It started operations in 1955 (Sasol I) with an capacity level of 7000 bpd. Sasol II is reported as just commissioned rated at 40,000 bpd. Sasol III, duplicating Sasol II, is expected to be in operation in 1983. All three units are sited outside of Johannasburg. Sasol III is equipped with process options so that it can **maximise** either olefins or gasoline/diesel. For this new catalysts have been developed. The cost of Sasol II is reported at Rs. 2.4 billion.

The usual commercial objective in modern Fischer-Tropsch units (as Sasol) is that of maximising the proportion of liquid 'fuel-oriented' molecules - the aromatics, naphthenics and long chain saturates (branched and unbranched) - at the expense of olefins, low carbon number saturated paraffins and the oxygen-bearing molecules. This is done in a sequence of steps wherein the crude synthol reactor product is subjected to various specific processes (including the very modern) for molecular reconstitution to fuel-oriented components and then recombined[159/]. Oxygenates, particularly the alcohols, are recovered (from wash streams) for marketing as chemical products.

What is significant to this report is that synthesis gas, under catalysis, can directly yield saturated hydrocarbons, mono-olefins and oxygenates; that is, molecules with and without oxygen. The chemical use of syngas has, till very recently, however, been limited to the 'oxygenates' - methanol, oxo-alcohols, and less importantly, oxo-acids.

The basic hurdle to large-scale use of syngas chemistry has been the wide 'spread' of reaction products. Conventional catalysts and their modifications do not show remarkably improved product selectivities and yields - which, of course, are essential for meeting the alternative economics of the petro-technologies. It is a wholly new development in catalyst 'systems' that now promises viable new syngas technologies. Research thrust into syngas chemistry, along these lines, is abetted by several factors - the rising real price of petroleum, the emergence of superior methods for producing the syngas feedstock and concepts arising from '**breakthrough**' technologies in the energy field, very importantly the Mobil 'M' gasoline process.

[159/] As opposed to 'M-gasoline' treated in the previous chapter, the Fischer-Tropsch process yields a better diesel fuel than a gasoline although the complex produces both types.

There are three general approaches to new syngas chemistry, which pending clarification, can be classified as:

(1) the direct use of syngas to make intermediate feedstocks viz. LPG, ethyl alcohol, etc. which can then be processed by conventional chemistry (and existing 'hardware') to final products;

(2) the indirect use of syngas to make final products through new and special chemistry applied to the processing of intermediates, viz: Mobil's zeolite-based methanol-to-ethylene process of IFP's ethanol to aromatics process[160/]; and

(3) the direct use of syngas to make oxygen-bearing and non-oxygen-bearing chemical products viz. ethylene glycol, propylene through new technology (which bypasses the use of commodity intermediates).

Approaches (1) and (2) can be viewed as 'upstream approaches' whose objective is to maintain, as **far** as possible and without disruption, the well-established conversion technologies (downstream technologies) of today. They basically seek to establish new routes for today's industrial raw materials.

On the other hand, the last approach seeks to radically break away from modern petro-chemistry and its feedstocks. It is basically feedstock price oriented, and relies for its success on the availability of syngas as a consequence of its development for energy applications.

Upstream Approaches

Conventional Conversion: Work being undertaken by Dow Chemicals[161/] illustrates the most straight-forward approach to new syntheses of conventional materials. The Company is working on molybdenum catalysts, employed in the Fischer-Tropsch manner. The Company reports 'LPG' yields of 75 per cent; ethane and propane (ideal feedstocks for ethylene)are obtained at concentrations up to 60 per cent in a C_2-C_5 saturates mix (aliphatics).

[160/] Methanol and ethanol would, in this concept, be syngas derived.

[161/] 'Use Syngas for olefin feedstock'; Murchison, C.B. and Murdick, D.A. Hydrocarbon Processing, Jan 1981, p.159.

Likewise is the approach of Institute **Française** du Petrole (IFP), Exxon, UCC and Japan's **Sangami** Research Centre wherein oxygenates are selectively sought in Fischer Tropsch syntheses. It is reported that the product slate of the IFP technology is as follows:

	per cent
Methanol	23
Ethanol	40
n-propanol	20
n-butanol	14

from which, of course, the constituents can be separated if necessary[162]. While it is believed that IFP's work is fuels oriented that of Exxon's is ambivalent.

Unconventional Conversion Technology: The most outstanding development in the area is the use of Mobil's ZSM-5 zeolite catalysts (discussed earlier under 'Methanol') to crack methanol to ethylene and propylene, the technologies **up to the production of methanol, and that** from ethylene downstream, being wholly conventional. Ruhrchemie and BASF are also working on these lines.

Similar is the effort being made by Gulf, Shell, Ruhrchemie[163] and BP but with respect to improving on an older United States Bureau of Mine's technology (of the 1950s) - the 'homologation of methanol to ethanol[164] (ethanol would then be conventionally processed to ethylene).

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[162] This mix, it may be noted, has the property of 'solubilising' methanol when admixed with gasoline. It also permits a higher level of methanol concentration.

[163] Ruhrchemie (a large producer of oxo-chemicals) is said to be supported by the Federal German Ministry for Research and Technology in such research attesting to its importance to FRG.

[164] The homologation process involves the reaction of methanol with synthesis gas with a 'cocatalysts system' comprising of oxo catalysts (as cobalt carbonyl, with and without phosphine ligand modifiers) promoted by iodides, together with co-catalyst ruthenium complexes. Ethanol selectivity above 90 per cent is reported in literature (1). Gulf is reported as using rhodium catalysis.
(1) 'Ethylene - **Can Non-conventional Sources Compete**', Leonard, J.P. and Weiss, L.H. (Chem Systems) Symposium on Feedstock Alternatives, AIChE. Meeting, Houston, April 7, 1981.

Chem Systems[165] have estimated conversion costs to ethylene by the two processes, comparing them to conventional naphtha-cracking. Their calculations are presented below:

Basis: 1000 million lbs capacity, Ethylene, US Gulf Coast, 1990

	Naphtha gasoil	Methanol Homologation	Methanol Zeolite-cracking
Raw materials (A)	141.4	64.5	116.4
Utilities	(2.6)	6.7	7.8
Operating costs	2.7	3.3	2.3
Overhead expenses	11.7	9.5	10.1
Gross cost of production	153.2	84.0	136.6
By-products credit	(92.2)	(9.8)	(54.0)
Net cost of production	61.0	74.2	82.6

(A)	Naphtha	\$2.43/US gallon
	Gas oil	\$2.66/US gallon
	Methanol	\$ 625/MT
	Syngas (1:1 H2/	\$4.40/1000 std.cu.ft.

While undoubtedly the estimates are speculative - the technologies do not yet exist - the 'gross cost' of production favours the new technologies. Such a comparison may be valid in developing countries, including the oil producing developing countries. It is important to note in this context that for the level of ethylene production taken as a base, methanol production would need to be captive for both the new technologies[166].

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[165] Polyolefins: Key Derivatives in a changing Petrochemicals World (Part I), Peter Spitz (Chem Systems), 1981.

[166] If ethylene production levels were, say, 50 per cent of the above then purchased methanol may be a viable consideration. Such a situation would place the homologation process at a disadvantage because it needs a captive source of syngas.

Downstream Technologies

While the 'upstream' technologies' would normally be expected to be closer to fruition than the 'direct synthesis' technologies, the reverse appears to be happening. The most advanced of the direct-synthesis applications is the Monsanto acetic acid process which reacts methanol with carbon monoxide. This process has been commercial since 1973. A second major evolution is Halcon International's (Unites States) technology for acetic anhydride which is now being applied by Tennessee Eastman. The Company's interest in the Halcon route arises from its ability to utilise its own coal (which in the Company's estimation is already a cheaper feedstock than petroleum-derived ethylene[167/]. Patents issues disclose Union Carbide Corporation to be working on a wide range of products derivable from syngas, including a direct route to acetic acid bypassing the methanol intermediate required in Monsanto's process. The Company has also publicly indicated that its hopes to have an ethylene glycol production process operative by the mid-1980s, a possibility to be taken seriously considering that it is the world's largest producer of the commodity. In finding non-petroleum routes to ethylene glycol[168/] other companies - among them oil companies - have joined the race: Chevron (Standard Oil of California) and Atlantic Richfield (ARCO).

In all approaches to syngas technologies research routes to ethylene are being emphasized even though some of the processes straight forwardly yield 'ethylene derivatives'. Emphasis on ethylene deriv's from the fact that it is the only known route to the plastics.

[167/] The Company is believed to be using both Shell and Texaco partial oxidation technologies for syngas production.

[168/] A 'direct route' to ethylene glycol bypasses the need to make the intermediate ethylene oxide, which is both highly toxic and constitutes an explosion hazard. Additionally, when ethylene is converted to ethylene oxide the conversion per pass has to be held low for safety reasons which increases investment. While the direct routes minimise or eliminate these problems, they tend to be multi-step.

Direct one-step synthesis of ethylene (and of other low carbon number olefins and hydrocarbons) from syngas, using zeolite catalysis, is reported in a series of papers by the United States Department of Energy[169]. The zeolite used is 'Silicalite' (resembling in structure that of Mobil's), a development of Union Carbide's[170]. The importance of this announcement needs to be noted. It is indicative of the lines of work by major corporations who merely state that they are working on 'syngas to ethylene' technology.

The absence of developed technologies has not deterred major corporations from predicting the emergence of such or in 'preparing' for them. The forecasting exercise is perhaps best highlighted in a major paper by Shell Oil[171] which predicts that by the year 2000 syngas "could account for 8 per cent of the feedstock demand worldwide", and that, if crude oil prices were to increase at an average annual rate of 3.5 per cent in real terms versus 1 per cent for coal (which is an expectation in the United States) by mid-1990s syngas-derived ethylene would have a "clear advantage" over oil. Further, the paper predicts that if coal-based syngas is produced in the United States for synfuels, on the grounds of energy economics, then diversion of even 5 per cent

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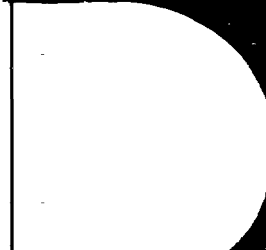
169/See 'Make Olefins from Syngas' Rao, V.U.S., and Gormley, R.J. Hydrocarbon Processing, Nov. 1980 p.139.

170/Silicalite is free of 'solid acidity' that characterises the Mobil zeolites. This feature, together with iron (Fe) catalysis, completely supresses the formation of aromatics while yielding to a high C_2-C_4 olefins management.

171/"The changing pattern of petrochemical feedstocks to the year 2000 and beyond" W.W. Reynolds (Department of Strategic Studies) Shell Oil Company. Paper presented at Chemical Week Conference, Nov. 20.21, 1980 Houston, Texas.



of it to chemicals (consequent to its availability)[172] could yield as much as 500,000 tonnes of ethylene/ethylene-derived chemicals by the year 2000.

There is also the 'preparation' for emergence of such technologies by the work being done by various engineering and producer companies for the production of methane-free syngas, as the following demonstrates.

Production of Synthesis Gas

Historically, in the earliest production processes for syngas, coke was the principal raw material with air, more than oxygen, the gasifying agent. During the Second World War coal supplanted coke but for its gaseous conversion oxygen was employed. The post-war period showed reversal to coke[173] till naphtha and natural gas emerged as internationally-traded commodities. This led to the creation of the catalytic 'steam reforming' technologies obviating the need for oxygen. In the early 1960s the partial-oxidation technologies evolved as fuel oil and 'heavy fractions' became surplus low cost alternatives to naphtha. Technology development, thus, was motivated by the emergence of newer raw materials and of their changing equivalent cost.

The implication of this evolution is that, today, virtually every carbonaceous or hydrocarbon material can be gasified to syngas by well-developed technological routes[174]. Syngas technologies, however, are being further and more avidly developed. This evolution appears

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[172] It will be recollected that in the 1950s, it was the free availability of naphtha (gasoline) which led to technologies as naphtha-carcking, naphtha steam reforming (to syngas) and catalytic reforming (production of aromatics).

[173] Large coke gasifiers, operating with oxygen were in use upto 1962 at Leuna, GDR and in BASF's works. DuPont, till the mid-50's operated coke gasifiers, using syngas for methanol. (It is interesting to note that DuPont first made polyethylene from coke-oven-derived ethylene).

[174] While biomass has not been commercially so employed, it sets no technological limits by virtue of its composition or structure. Whatever limits are there arise from 'allocative tasks' in economics, princiaplly in the uses of land and alternative schemes for the disposal of biomass.

tied to:

(a) scope for the utilization of syngas, from unit production system, simultaneously for chemicals and energy;

(b) the growing price competitiveness of coal, relative to oil, (particularly low ash and high-sulphur coals); and

(c) the emergence or re-emergence of surpluses in heavy petroleum residues, including heavy fuel oils, as a composite result of larger discoveries of heavy crudes (internationally) relative to light crudes and the creation of large refining capacities in Africa and the Middle East unbalanced by local or international demand for the 'bottom of the barrel' products.

In the advanced countries, however, there is only limited scope for the use of these residues for syngas generation. In Europe and Japan, with their need to maximise gasoline yields from crude, the tendency is to employ the residues for gasoline production using cracking technologies, already applied in the United States (hydrocracking and fluid catalystic cracking, FCC). Furthermore, in the environments of these regions, it is already becoming clear that the gasification of coal would be cheaper than using residues.

Consequently, the largest scope for utilising residues for syngas production lies in **the developing countries.**

With Shell and Texaco's partial oxidation technologies well-established for fuel oils (their use in ammonia process is widespread), and modifications thereof being now exployed for the gasification of coal (see later), they can indeed be considered as state-of-art technologies for heavy residues without technological **uncertainties**[175/].

175/It is the claim in Shell and Texaco partial oxidation technologies that dispersions of coal in residues (co-feeds) can be sent to the gasifier without economic and technical penalties.

Syngas from Coal

Because in practically all coal-gasification methodologies coal has to be fed in its solid form and ash removed (from the total system), again, in the solid form - mechanically complex tasks which become more acute with increasing processing capacity - the development of gasification technologies have been more 'evolutionary' than 'revolutionary' in character. This is indeed a generalisation emerging from the fact that all commercialised, or semi-commercialised, technologies in use today are modifications of processes that were basically operative in Germany in 1944, oriented to transportable and transportation fuels. Germany operated three important processes:

(1) the Lurgi 'moving bed';
(2) the Winkler 'fluidised bed'; and
(3) the Koppers-Totzek 'entrained bed' processes[176/].

Interest in gasification as a route to transport fuels has been maintained in the post-war period. But it has taken many twists and turns with changes in the availabilities of competing raw materials or of their prices. For example, from the mid-1960s to the time of the 1973 oil price rise, the gasification of naphtha to synthetic natural gas (SNG) was promoted and commercially practised in the United States as a result of expected declines in natural gas availability and as an attempt to 'keep gas lines full'. Again, on grounds of anticipated dependence on large crude imports, the United States Government supported a great deal of R+D in 'coal liquids' and coal-to-SNG routes ('synfuels').

The direction of present effort lies in the gasification of 'low-cost coals' - that is, coals which are becoming low in cost either because of their unsuitability for direct burning or because of their easy access. The direction, further, is to use generated syngas directly for energy (without conversion to SNG), and preferably, for 'energy-chemicals systems'[177/].

176/In reviewing their viability it would be useful to take into account that since their inception in the 1930s, over 100 Lurgi, 30 Winkler and 50 Koppers-Totzek gasifiers have been built and put into commercial operation. In Germany of the War period over 90,000 barrels per day of equivalent liquid fuel were produced through Fischer-Tropsch and Bergius technologies.

177/Syngas is also used in sponge iron production, whose level at about 6 million tonnes in 1975 is expected to increase to 90 million tonnes in 1990 ("Direct Reduction: Progress and Plans", Kalla, U and Steffen, R., Iron and Steel International, October 1977).

Figures X and XI[178/] illustrate the thermal efficiencies (heat values in derived fuels to that in fed coal) of and production costs for several gas, liquid and gas-liquid alternatives, using the Lurgi production route. (The relative scales of thermal efficiencies and production costs would be largely unaffected by choice of the gasification process). It is at once apparent that medium-BTU gas (which is the same as syngas when product is methane-free) is not only the most efficient thermally but also the lowest in production cost. Thermal efficiency becomes even more attractive (not shown in Figure X) if methanol or 'M' gasoline (which represents only a 10 per cent energy loss in its conversion from methanol) is co-produced.

Over the last five years, two important 'second generation' technologies have emerged promoted on the basis that a syngas system should, in commercialized form, serve both as a feedstock and an energy source (the latter to be viewed in new power generation concepts). These are the Shell-Koppers and Texaco-Ruhrchemie processes, both of which are now being operated in semi-commercial form[179/].

The common features of the two processes are:

- They are of the 'entrained bed' type;
- Any type of hard coal can be used 'regardless' of ash content (up to 40 per cent and caking/ash-fusion characteristics; HIgh levels of moisture and sulphur in coal are tolerated;
- They are operated at high temperature (above 1000°C) which has the effect of eliminating tars and liquid products (which plague other processes, including the Lurgi process, necessitating their recovery to meet environmental standards);
- They operate at high pressures (30 bar for Texaco, 80 bar Shell) leading to high 'specific capacities', ease of downstream gas 'clean up' and high thermal efficiency;
- The methane content of the gasified product is nil or extremely

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[178/] 'Convert Coal Now' Hiller, K. and Garkisch, O.L. (Lurgi Kohle and Mineral) Hydrocarbon Processing, September 1980, p. 238.

[179/] Both technologies are in operation in plants rated at 150 tonnes per day, located in FRG. The Texaco Ruhrchemie unit is at Oberhausen-Holten and the Shell-Koppers at the Harburg refinery of Deutsche Shell at Hamburg.

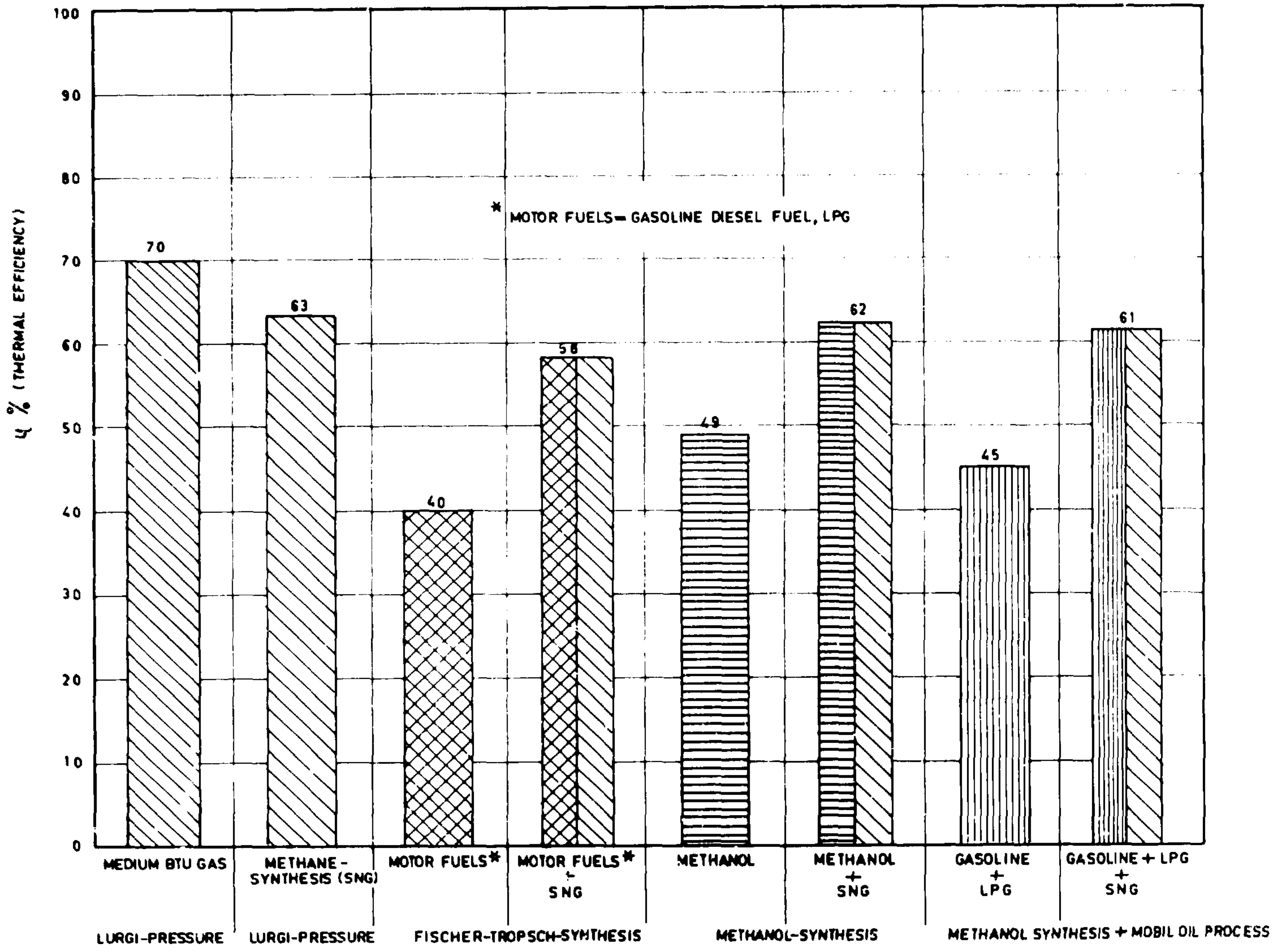

FIG. X THERMAL EFFICIENCIES OF PROVEN COAL CONVERSION PROCESSES

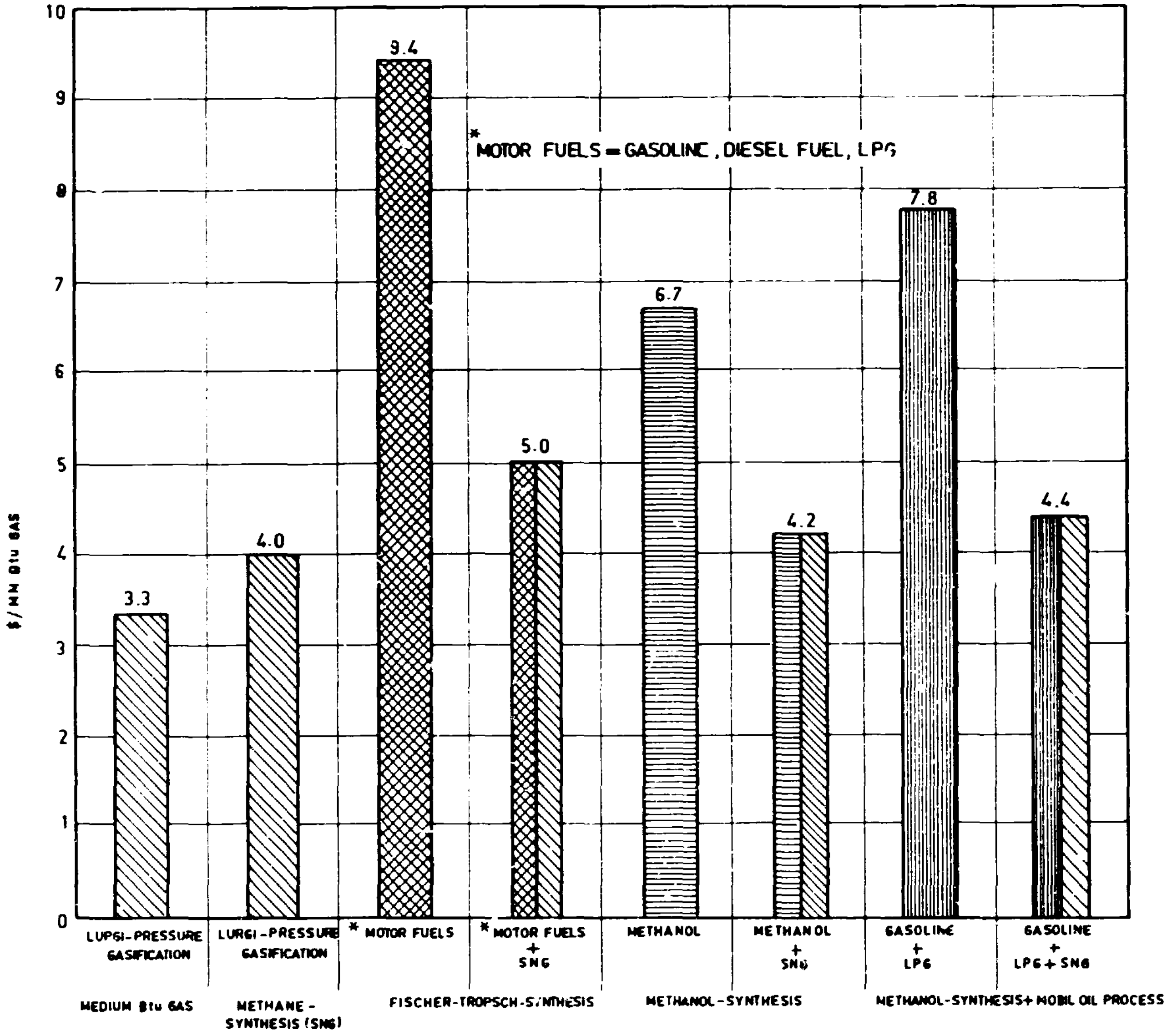

FIG. XI PRODUCTION COSTS BASED ON HEAT CONTENT OF PRODUCTS MADE FROM PROVEN COAL CONVERSION PROCESSES

low, making them very viable for the use as chemical feedstock[180];
- Ash is removed from the reactors as a liquid slag which reduces mechanical problems while permitting easy disposal.

The processes differ in the following aspects:

- The method of feeding coal to the gasification system;
- Methods of gas clean up;
- Suitability to coals.

In the Texaco Process, slurried wet-milled coal in thickened form is admitted to the burners, with evaporated water providing most of the steam required for gasification. In the Shell Process coal is dried, pulverised and fed to the gasifiers entrained in gas, with steam fed separately.

Methods of gas clean up are proprietary to the firms and differ considerably. However, there are no "unproven" technologies utilized which are particular only to coal and not to, say, heavy residues.

Both the processes are best suited to hard coal, but the Shell Process is, in principle, more flexible in terms of using brown coal and lignite.

Published information on capital costs is admittedly sketchy, because the product gas has different end-uses and different types of coal can be employed.

Shell Oil provide[181] an investment level of $120 million (mid-1977 dollars) for a plant located in the United States with a clean syngas output of 4 million NM^3 per day.

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[180] Gas composition for bituminous coals

Unit: per cent volume (dry basis)

	Shell-Koppers	Texaco	BGC-Lurgi (Slagger)
Hydrogen	29	38	28
CO	64	46	61
Carbon dioxide	4	12	3
Methane	-	4	8

[181] "Technical and Economic Prospects of the Shell-Koppers Coal Gasification Process" van der Burgt, M.J., + Kraayveld, H.J., 175th ACS National Meeting Anaheim California (United States) March 16, 1978.

As said earlier, both processes are in wide use in respect of feedstocks other than coal. The experience of the firms' extends to 300 units and more.

Both Shell and Texaco are trying for early commercialisation of their technologies. Shell AG has obtained FRG's approvals for land (in Saxony) to establish a 2000 TPD (coal input) demonstration plant, due for completion in 1985 (end-application: 'Syngas for Methanol'). Mobil Oil AG appear to be interested in the Texaco Process for a plant of 3000 TPD located in FRG, and or start-up in 1987 (expanding to 20,000 by 1989) with syngas targeted for conversion to SNG.

III. NATURAL GAS

Introduction

Presently, about 70 countries of the world have major exploitable reserves of natural gas. Of these, 65 countries can be classified as developing, and they own about half of the reserves. The gas is in fairly good 'geographical scatter' permitting scope for regional balances in supply-demand. However, almost all of the gas that is marketed is consumed by a handful of advanced countries. It is interesting to note, in this context, that in so far as natural gas is concerned - as opposed to other fossil fuels - there are more 'supplier countries' than 'buyer countries'. Most of these supplier countries transport this gas, overland and across the seas, in distances measurable in thousands of miles, so as to serve as low cost alternatives for electric power (or as in Japan, as a source of electric power).

While with conventional technology there is only a modicum of chemical feedstock values in natural gas, with emerging technology it can be viewed as a most viable 'carbon carrier', with immense significence to developing countries.

Usage and Applications of Natural Gas

In commercial terminology, natural gas is a composite term for a gas that contains methane, natural gas liquids (NGL) - which can be easily separated from it - and 'impurities' as carbon dioxide, nitrogen, etc. It emerges (unassisted) from 'dry gas' wells that yield only methane or methane with NGL. It also emerges 'associated' with crude, in crude oil wells. It is then referred to as 'associated gas'.

All extracted natural gas is not commercially employed. When obtained in associated form, it is often wholly flared on grounds of having inconsequential value. At other times the gas may be reinjected into the wells so as to maintain pressure (to assist greater recovery of oil). In cases it might also be employed for generating steam, etc. (local energy source) for gas and crude processing.

The American Gas Association has estimated that of 1.71 x 10^{12} cu. metres of gas produced worldwide in 1977, 5-4 per cent was reinjected into the wells, 12.2 per cent flared (or lost in extraction) and 82.5 per cent usefully consumed.

While natural gas, as methane, is undoubtedly a major chemical feedstock used in the production of ammonia (70 per cent N, worldwide, is gas-based), methanol (virtually 90 per cent gas-based), 'oxo' and chlorinated chemicals, and is besides, a syngas source for'direct reduction' and 'inert atmospheres',(metallurgical processes) its energy/fuel uses vastly predominate[182/].

The use of natural gas as energy can be classified into three forms:

(a) domestic/institutional cooking and space heating;

(b) industrial heat-generation or heat-using systems - boiler fuel, cement production, etc; and

(c) electrical power generation.

Its importance has grown over the years - mostly in the industrialized countries - as infrastructures to move the gas developed and as environmental legislation created the need for non-polluting sources of heat ('clean heat'). Consequently, it now contributes a significant part of the energy-mix of the industrialized countries as illustrated

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[182/] Illustratively: Natural Gas usage in Western Europe (1978)

	per cent
Power stations	19
Industry (energy)	29
Industry (non-energy)	2
Household and commercial	27
Transport (pipeline support)	15
Other uses	8
	100

Source: Europe's International Gas Trade, Kardaun, G. and Lambers J.H. (Nederlandse Gasunie), Hydrocarbon Processing, Dec. 1980.

in Table 18[183] below:

Table 18

Share of Natural Gas in Regional Primary Energy Balances

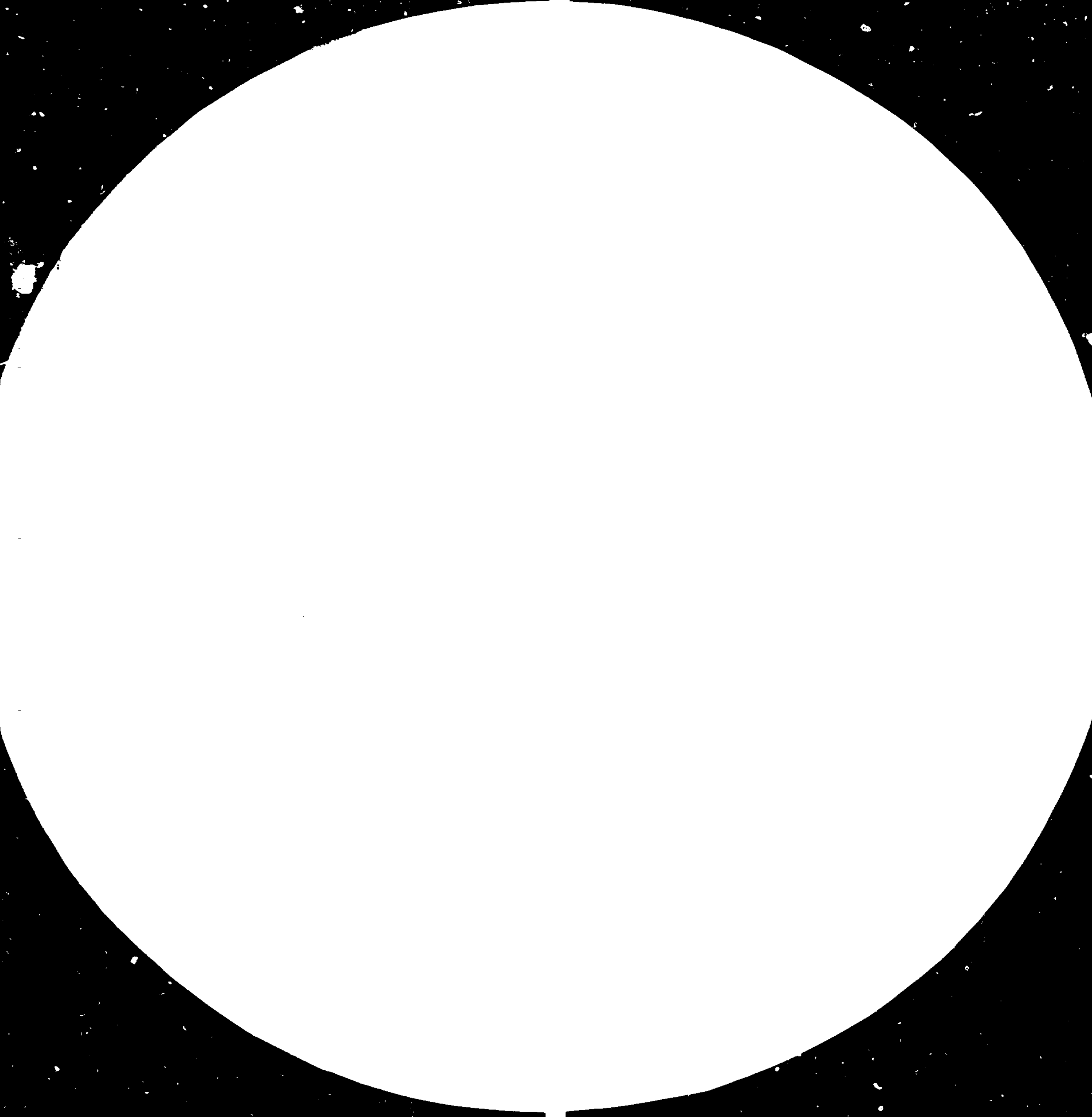
Units: Million tonnes oil equivalent; per cent share of all energy

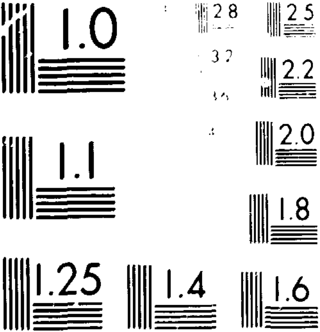
	1956		1976	
United States	249.3	26.8%	516.4	28.4%
W. Europe[184]	5.5	1.0%	167.3	13.3%
Japan	0.21	0.4%	10.9	3.1%

The importance of natural gas as an energy source needs to be appreciated. In the first place, it can be readily piped under pressure and transmitted over long distances without perceptible transmission losses (unlike 'distribution losses' in electric power transmission). Secondly, unlike electricity, it can be readily and safely stored in large quantities (typically, in 'salt domes' or in depleted oil wells). Thirdly it can be recovered from gas and oil wells with minimum loss (only 17 per cent of its energy is lost in converting it to a liquid for transport, as LNG). Fourthly, it is a 'clean form' of energy unlike fuel oil, its historical competitor in price.

183/The Development of the International Gas Trade, Ait Laoussine, N.(Sonartrach) Chemical Engineering and Economic Review. October 1978, p.7

184/Netherlands - 50 per cent of total energy
United Kingdom - 18-20 per cent
FRG - 16 per cent
France - 12-13 per cent
Italy - 16-17 per cent




1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

A very significant facet of natural gas usage as energy is shown by the following two illustrations :

(1) in 1979, the West European natural gas grid carried twice as much energy as electric power transmission lines; and

(2) the 1200 mm (30 bar) pipeline system of Europe can transmit 20 times as much energy as the largest high voltage modern power transmission system with three 380 KV conductors supported on each tower[185]. Thus, usage of natural gas in Europe or in the United States (whose gas pipelines exceed 250,000 miles) is, in effect, a substitute for electric power generation and transmission.

Sources of Natural Gas

Although natural gas reserves are widely distributed, over 50 per cent of the reserves are, by present reckoning[186], concentrated in three geographical regions (Table 19) which are, also, the most industrialized.

Table 19

Distribution of Natural Gas Reserves (1977)

Unit: 10^9 Cubic metres

Region	Proven reserves	per cent of world	Marketed production	R/P
United States + Canada	7580	10.7	656.8	11.5
Latin America	3070	4.3	50.0	61.4
W. Europe	3870	5.5	179.4	21.6
Eastern Europe + USSR	26360	37.4	402.9	65.4
Africa	5870	8.3	27.2	215.8
Middle East	2037	28.9	41.5	490.8
Asia + Oceania	3480	4.9	50.5	68.9

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[185] 'Gas-Energy of the Future', **Brecht**, C. (Ruhrgas AG), Hydrocarbon Processing, November 1980, p. 76-0 (see also Figure VI).

[186] Perspectives on Natural Gas and LNG **in the 1980s**, **Tsumura** A., (Japan Petroleum Development Corporation), Chemical Engineering and Economics Review June/July 1980.

According to Shell International Gas[187] proven world gas reserves in 1979 stood at 69,385 x 10^9 cubic metres (with useful consumption at 1359 x 10^9 cubic metres, thus giving a R/P ration of a fairly comfortable 51 years). The forecast also indicates a additional probable reserves at 96,000 x 10^9 cubic metres.

About 88 per cent of the world's consumption of natural gas is domestically based and the balance imported, as LNG (3.5 per cent) or through pipelines (9.5 per cent). The following is the distribution in international trade:

		per cent
Dutch gas (Groningen fields), only to W. Europe	-	27
OPEC supplies[188]	-	16
USSR supplies to Eastern and Western Europe (USSR gas contributes about 15 per cent to the gas imports of West European countries)	-	21[189]
Canada (to the United States)	-	16
Other supplies (to W. Europe and to Japan)	-	20
		100

187/'World LNG Trade: Present Status and Long Term Prospects', Peebles, M.W.H., (Shell International Gas) Chemical Engineering and Economic Review, Nov. 1977.

188/Whereas the OPEC group of countries owns more than 50 per cent of the world's crude reserves, it controls only about 23 per cent of gas reserves:

Unit: Billion Barrels of oil equivalent

	OPEC		NON-OPEC	
Proved	140	36%	249	64%
'Possible'	270	20%	1130	80%
	410	23%	1379	67%

Source: Sonartrach (Algeria)

189/USSR production is said to be growing at 7-9 per cent per annum. According to 1981 CIA Report (quoted by Times of India, October 1, 1981) USSR gas production in 2000 will amount to nearly 25 million barrels/day (oil-equivalent). By 1985 its income from gas sales to W. Europe is estimated at $11.2 billion.

Almost all of the LNG now goes to Europe (France and Italy primarily) or to Japan, but the United States will emerge as a very substantial market as existing contracts with Algeria become operational. The most important piped gas market (exported gas) is presently Europe.

In terms of overall consumption of natural gas, United States and the USSR dominate[190]

	per cent
USSR	- 24
United States, Canada, and Mexico	- 49
W. Europe	- 15
Rest of the World	- 12
	100 (=123 x 10^{10} cu. metres)

In terms of trends, the USSR is in the most **privileged position,** with an enviable R/P ratio of 65 years (some estimates, 90 years) and near 40 per cent of the world's **proven** reserves. In its desire to minimise dependence **on the Middle East, European continental buyers** are expected to lean more and more on Soviet gas whose contribution to the West European supply grid already amounts to some 15 per cent.

The position in the Unites States appears bleak on the surface with a R/P ration of 11 (if Mexico and Canadian reserves are excluded), way down from 16/1 in 1966 (and 46/1 in 1946). However, with the phasing out of gas price controls, which prevail till 1985, Unites States industry is expected to search and find new sources. Already, there is feverish activity in the 'Rocky Mountain' States for 'geopressured natural gas[191] (several thousand metres deep), and elsewhere for 'tight gas' which is held in sandy formations. All of this activity has presently led to the phenomenon of the 'natural gas bubble', a sudden upsurge in availability and supply.

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[190] Source: Peebles, op. cit.

[191] Under United States law, only corporations of a certain size are required to publicly disclose their reserves. Smaller companies often conceal their discoveries to take advantage of price movements.

As regards Western Europe, one of its principal supply sources - the Dutch Groningen fields - is expected to decline after 1985. Hence Europe is expected to look more and more to Algeria (which has the world's fourth largest resource) to supplement present imports from USSR. (Contractually, Algeria has presently made most headway with the United States).

Japan is a potentially large market for natural gas (as LNG) which is imported to meet electric power generation needs (environmentally acceptable fuel). However, because of the country's geographical position in relation to natural gas sources, LNG imports now form under 3 per cent of its total energy needs. According to the Japan Petroleum Development Corporation forecasts[192/], developing countries in 1990 are expected to produce 21-26 per cent of the world's production but consume only 12-13 per cent, exporting the remainder [193/].

Production of Natural Gas (and Natural Gas Liquids)

Natural gas from 'dry gas' wells is usually very rich in methane, low in other hydrocarbons, and contains inerts. However, that from crude oil wells (associated gas) can contain up to 35 per cent of C_3-C_5 hydrocarbons. Natural gas from associated wells[194/] constitutes about 25 per cent of all production.

There is very little processing for 'dry gas' production except when it has to be liquified (when moisture and carbon dioxide have to be removed). When the gas has a certain level of higher hydrocarbon constituents, its mere compression and cooling liquifies some of them; the hydrocarbons resulting from this operation are termed 'condensates'. The condensates, in the United States, are often combined with natural gas liquids (NGL) for steam-cracker feeds.

[192/] Perspectives on Natural Gas and LNG in the 1980s.

[193/] Methanol, ammonia, reduced ore, etc, made with, or assisted by, natural gas can, of course, also be exported.

[194/] Natural gas is both dissolved in crude and exists in the 'gas cap' above the oil. Most often, it is the dissolved gas that is extracted.

Associated gas, as said earlier, is natural gas with higher hydrocarbons, up to C_5. It is gas that has stayed dissolved in the crude in the latter's geological formation. On release of oil field pressures, after the oil is brought to the surface, the gas separates from the crude (typical rate: 18-20 cubic metres/barrel of crude). This gas can now be processed by various means to extract the C_3-C_5 hydrocarbons. This removal gives rise to the byproduct, LPG (which is transportable only under pressure). The natural gas that remains after this extraction step can very well have all of the ethane and some of the propane in it (it is very often piped that way and causes no problems). However, by various alternatives downstream operations as compression, solvent extraction, turbo-expansion or cryogenic separation, it is possible to extract almost all of the ethane (and higher hydrocarbons) in natural gas. The term 'natural gas liquids' is applied to ethane-propane mixtures[195/] so derived, to distinguish it from LPG ('liquified propane gas'), which is rich in propane and butane.

Technological Implications

In a recent UNIDO study[196/] it was indicated that 18 developing countries, who own 70 per cent of the world's oil resources, were flaring associated gas equivalent to 2.5 million barrels/day of oil (1978). This happens to be somewhat close to the current consumption of petroleum liquids and NGL by the United States petrochemical industry.

A comparison, such as this, had it been made in the early 1970s, even after the oil price rise, would have seemed rather far-fetched or specious since at that time the technology that was known, or anticipated greatly limited the application of natural gas (methane) to ammonia, methanol, carbon black and SCP (single-cell proteins), materials peripheral or external to the petrochemical industry. Natural gas had its 'petrochemical linkage' only through feedstock components co-present in its extraction - NGLs and LPG, which, in the case of the United States alone, were exploited for the production of ethylene and propylene.

[195/] NGL may have C4,C5 and higher constituents. When such are substantial, NGL could be valuable for gasoline admixturing.

[196/] The industrial uses of associated gas (Progress Report), UNIDO/Gulf Organization for Industrail Consulting/OAPEC Joint Study, 31 May 1980.

As discussed under 'Methanol' and 'Syngas' in the previous sections, new technologies now bring natural gas - directly, as a source of syngas, and indirectly, as a source of methanol - dramatically into the mainstream of the 'petro' chemicals industry, providing scope for a great deal of value-adding downstream products. Even the mere transformation of methanol into 'M' gasoline (see section on Methanol) is a methodology of converting a 'flare gas' or 'cap gas' into a highly valuable liquid commodity: gasoline naphtha.

It would be thus quite meaningful to compare the economics of LNG, the 'energy alternative', with the 'chemical alternative' the composite of 'syngas/methanol/M-gasoline'[197]. This is presented below:

Implications of the Energy Alternative (LNG)	Implications of the Chemical Alternative (Syngas/Methanol/ M-gasoline)
Large levels of investment in production facility - a billion dollars and over for smallest sized economic facility	Modest levels of investment of about $150 million for an economically-sized product facility - 1800 tonnes per day (methanol); about $50 million for conversion to M-gasoline.
Need for considerable infrastructure (for exports) as ships with cryogenic holds ($150 million for smallest economically sized ocean going vessel); expensive low-temperature storage facilities at shipping sites are necessary; again, expensive facilities at reception points are required for 'gasification' of LNG into pipelines	Existing infrastructre for petroleum crude and distillates is suitable for storage and transportation of methanol; as also at its reception points. Methanol converted to 'M' gasoline at producer point can, of course, even more readily be handled by the existing petroleum infrastructure. Methanol can be converted to ethylene at almost the same investment and production levels as that involving petroleum naphtha.

Contd...

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[197] While M-gasoline is an energy-carrier, like LNG, the mediation of syngas or methanol as intermediate gives it a 'petrochemical' coloration.

Implications of the Energy Alternative (LNG)	Implications of the Chemical Alternative (Syngas/Methanol/M-gasoline)
A LNG production facility needs 'dedicated' back-up wells with sufficient reserves to last for a minimum of 25-30 years. 'Gas-gathering' infrastructure for LNG production is thus complex and expensive.	Only modest levels of gas gathering needed, if at all. Methanol production at site of largest wells is often an economic proposition and avoids the 'gas gathering' alternative. Methanol from various production points can be pooled at lower costs than gas-gathering.
A LNG facility takes 7-8 years to materialise.	Gestation period 3-4 years at maximum for methanol or 'M' gasoline.
Firm long-term contracts are essential for establishing facility; dependence on one or two buyers over a long term has obvious disadvantages.	Methanol and 'M' gasoline can be traded as commodities on short contracts and spot sales, as per standard methanol and gasoline practice.

The basic disadvantage in converting natural gas to methanol is that about 40 per cent of the energy in feed natural gas is not available for export (i.e. is a 'process loss'). In LNG, on the other hand, the loss is only 18 per cent or so. This consideration, which favours LNG, has merit only if gas availability at a particular geographical locale is such that it is economic to convert it either to methanol or to LNG. (i.e. 'netback'[198] for LNG is greater than for methanol). However, if conversion to 'M' gasoline, to ethylene, or to a 'syngas chemical' provides a better netback, the chemical alternative would likely be favoured. This alternative, of course, is provided by emergent technology and thus should be taken into account in the planning perspective.

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[198] Netback is the net fund flowing to the producer after he deducts, from the c.i.f. price, ocean transport cost shipment loss (evaporation) process conversion loss and capital-related charges in distribution.

IV. NON-CONVENTIONAL HYDROCARBON

Introduction

Over the last 50 years, the industrialized countries have attempted to develop, and in most cases have developed, technologies that would enable them to use any one of the several hydrocarbon sources - as coal, shale oil, tar-sands, etc. - on the basis of its strategic availability, relative prices or convenience. The driving force has most often been Governmental intervention (technology stock-piling). In commercial terms, however, most of the technologies remain unutilized if exception is made for some that were employed during the Second World War.

Several reasons account for the technologies remaining 'on the shelf' the four most significant are:

(a) major discoveries of conventional energy sources as that of Saudi oil in the post-war period (1951), the Hassi R. Mel gas fields in Algeria (1956), the Alaska North Slope (late-1960s), North Sea oil gas (1963)[199], and the Siberian gas fields in USSR (1965/66), etc.;

(b) rising living standards in the industrialized countries which took workers 'out of the mines';

(c) societal development of environment consciousness and product safety; and

(d) 'internationalisation' in the use of resources particularly of the low-priced resources of the developing countries, combined with strategies to save domestic resource (e.g. the Mandatory Oil Import Programme of the United States).

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[199] In 1955, 89 per cent of United Kingdom's energy was coal-derived. In mid-1970s it dropped to less than 25 per cent. In 1950-1951, 71 per cent of gas used in pipelines was coal-derived (excluding producer gas, water gas, etc.). In 1964-1965, this dropped to 41 per cent and by 1971-1972, was wholly eliminated.

Source: Prospects for Conversion of Coal to Gas and Chemicals in Britian, Gibson, J., et al, Chemical Economy and Engineering Review, February 1974.

With the rise in the price of oil in 1973 there has been, for the first time since the war, a renewed drive in the market-economy industrialized countries to examine alternative energy sources and technologies. The reasons lie not only in declining international resources (of the most accessible energy forms), or of national-strategic assessments as availabilities, but very significantly - and directly - in the prices of imported energy as related to those of substitutable national and regional resources. There is certainly more coal than there is of oil or gas in the industrialized countries (including, in this instance, Australia, Canada and South Africa) for principal reliance to be placed on it[200/]. Thus, most of technological effort has been to utilise it.

200/Recoverable Reserves and Coal, Oil Gas (1976)

Unit: Million Tonnes oil equivalent

	Coal	Oil	Gas	To
Unites States and Canada	200000	18000	6000	2260
Europe (E+W)	67000	5000	4000	76000
USSR	232000	26000	36000	294000
Middle East	...	129000	29000	157000
ROW + Middle East	132000	160000	30000	323000
	631000	209000	79000	920000

Adapted from "Planning for coal in 1980s" Mahendru, R.G,, (Coal India), Hydrocarbon Processing, October 1978 p.58-C. (Note: Reserves position is assumed as at beginning 1976, since source data is not specific). (Canada's resources, in 1976, were about 10 per cent that of the United States in oil and gas, and 5 per cent in that of coal).

ROW = Rest of the World. 'ROW+Middle East' can be taken to represent, approximately, LDC segment of world resources (although it would include Australia, S. Africa and Japan). In terms of percentages, it is: Coal 21 per cent, oil 77 per cent; gas 39 per cent; developing countries segment of all resources 35 per cent.

The incentive to exploit tar-sands and oil-shale has become significant of late. National resources put some of the industrialized countries - the United States, Canada and the USSR - in very favourable positions. The oil-shale deposits of the United States are said to place the country, in fact, far above OPEC in total oil potential.

There are two reasons which make the acquisition of such technology almost irrelevant to the countries of the developing countries domain:

(a) The poor geographical spread of the resources among the developing countries - in tar-sands only Venezuela is exceptionally well placed while in respect of oil-shale only Brazil and China have reasonable reserves; and
(b) As will be shortly discussed, the impracticality of internationally trading in tar-sands or oil-shale because of the physical structure of their deposits.

Nevertheless, the resources themselves are significant to developing countries as sources of oil-like materials, with the potential they afford of some day reversing the present directions of flow of energy materials between industrialized countries and the developing countries.

Collectively for the developing countries, they are best placed in gas and oil in terms of geographical spread of resources and ownership, with gas the far less exploited. Both gas and oil are facile materials compared to coal and the 'entry fee' for being in the 'business of oil and gas' is far lower than for being in the business of coal.

One surprising facet of the substitutive technologies is that while developed from the perspective of energy usage (transport fuels, mainly) they have almost consistently shown, ever since the invention of Fischer Tropsch synthesis in the 1920s, greater relevance, economically and technically, to their use as chemical feedstocks. That is, the 'molecules mix' in the new materials has resembled that of well-understood petrochemical feedstocks than that of the energy materials as gasoline. Hence, in many cases, their first commercial or semi-commercial use has been, or is expected, in the context of chemicals.

In this document, the term non-conventional hydrocarbon-feedstocks is applied to the products of substitution technologies with the objective of indicating that they are oil-like derivatives of 'upstream technologies'; they seek to maintain, as intact as possible, methods of processing, conversion, distribution and marketing which exist in current refining and petrochemical infrastructure. In other words, the products being derived from tar-sands, shale oil, and that from coal, generally resemble the constituents of petroleum refinery fractions such as naphtha, diesel, heating oils. Syngas and methanol while 'non-conventional hydrocarbon-feedstocks' have been given separate coverage in this study because of their considerable importance to developing countries.
In this section, only oil-like non-conventional-feedstocks are discussed. However, because of their relative lower significance to developing countries, the coverage on them is rather brief.

Characteristics of the Non-conventional Feedstocks

Tar sands are sands containing very viscous hydrocarbons, and unlike the situation with petroleum, the oil (tar) in the sands does not come 'gushing out' from its geological location. It has to be arduously extracted. The term 'tar sands' is synonymous with others as 'oil sands', 'oil belts' etc. According to Shell Oil, there are some 3 trillion (3×10^{12}) barrels of oil in the world's tar sands,most of which are located in Venezuela (North Bank of the Orinico River), the USSR, Canada (Alberta) and the United States. The tars are located both at the surface of the mines and at depth. The Canadian 'Athabasca' reserves, for example, lie between 0 to 500 metres (estimated the equivalent of 600 billion barrels of petroleum).

Surface deposits are treated with hot water to separate sand and the heavy oil with the latter then extracted into naphtha and centrifuged to separate out residual sand. For deep deposits 'in-situ' methods are practised, with high pressure steam melting the tar and compressed air driving the tar out to the surface.

The following data enables a quick comparison of tar sand oil with that of petroleum crude:

	Heavy oil (tar sands)	Crude oil (typical)
API Specific gravity	5-10	10-40
Pour point, °C	10-30	below -15°
Sulphur, per cent (wt)	3.5 - 5.0	0.05 - 3.5
Atmospheric disillate, volume, per cent	below 20	40-60

The heavy tar-like character of the oil makes it difficult to work with, but presents no new problems of technology. To make tar into a petroleum-like material it needs to be hydrogenated (conventional technologies are applicable[201]).

One of the major problems with tar-sands is the high sulphur content of the recovered heavy oil. It is very expensive to reduce. Even the oldest types of fuel oils (of conventional refining) did not have more than 3-5 per cent. The cost of removal, is thus, very high[202]. The oil is highly aromatic and is consequently a good feedstock for gasoline. However, Canadian firms now use the oil for "petrochemicals production".

201/It needs to be only recollected that modern petro-chemistry had its beginnings in 'coal tar'.

202/A chemical user of sulphur-bearing fuel oil can often desulphurise flue gases at his plant to meet environmental standards. For oil tars (and shale), processing technology requires or involves dusulphurisation at the refinery.

Oil-shale has significance because of its larger reserves than tar sands (50 per cent more oil is distributed in oil-shale than in tar sands according to Shell Oil), its vast presence in the United States (most of the world's reserves; other deposits lie in China, Australia and Brazil) and its significant ownership by the oil companies.

Oil in shale (rock) occurs as 'kerogen', a complexly structured hydrocarbon, very much like asphalt. In good deposits the oil content would average 10 per cent. Kerogen is released from the rock by the supply of heat, either in-situ or in above-ground operations. It then (like the heavy oil from tar-sands) has to be hydrogenated. Again, there are no technological hurdles to using it as a commercial form of energy[203/]. Shale oil extraction has indeed been practiced for decades in Estonia. In Brazil and China there are small-sized recovery operations.

The naphtha from shale oil refining is highly paraffinic and thus leads to excellent levels of ethylene and propylene in conventional steam-cracking.

Coal Liquefaction: Germany, Britain and the United States - in that order - have made the largest efforts (in a time span of some 50 years) to 'liquefy' coals for use as fuels. Only in war-time Germany did the technologies reach 'commercial' status, the direct and indirect methods of coal liquefaction yielding some four million tonnes of transport fuels a year at peak effort.

Highest thermal efficiency is obtained in direct liquefaction technologies - which is, of course, critical to good economics. In all of the developed processes, the objective is to maintain, as intact as possible, the high 'resonant energy' in the polynuclear aromatic structure of coal. That is, the 'aromatic rings' of the coal should maximally transfer to the 'coal liquid'[204/]. While such transfer does take place

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[203/] There appears to be some reservations on the utility of shale naphtha as gasoline on the grounds that it could give rise to unknown 'emissions' problem.

[204/] For usage as 'unleaded' high-octane gasoline, again, a high aromatic content is desirable.

in the strong presence of hydrogen, it is best achieved in low-ash. low-sulphur coals which are expensive, as they can be alternatively used for direct burning, even in environmentally protected areas.

Investments in direct liquefaction are large as the processes involve both high temperatures and high pressures, and scale requirements entail large production units. Besides, very large quantities of hydrogen are required, which often have to be supplied from an ancillary operation. Two of the modern ('second generation') hydrogenation technologies are those of the oil companies - Exxon (Electron Donor Solvent) and Gulf (Solvent Refined Coal Process SRC-II). Hydrocarbon Research Corporation has also developed its 'H-coal Process'[205], one version of which is oriented to gasoline and petrochemicals, and the other to fuel oils.

Indirect liquefaction technologies, on the other hand, have their economic significance in their ability to use virtually any type of coal, hard or soft, and with high levels of ash and sulphur. Thus coals which would be unsuitable for direct burning on environmental grounds would be acceptable to the processes. Because of this 'unsuitability' they are also available at low cost (see later). In all of the well-developed indirect processes coal is first converted into synthesis gas and the gas is then catalytically converted to a liquid.

The most modern variant of the indirect technologies has already been discussed under 'METHANOL' (Mobils 'M' Gasoline Process). A competitive process, the modern version of Germany's Fischer-Tropsch process - South Africa's Sasol II Process - has also been discussed under 'METHANOL' and 'SYNGAS'. Methanol, in itself, of course, can also be considered a liquefied product of coal.

In these indirect technologies, the destruction of the aromatic rings - by the depolymerisation of coal's condensed rings followed by 'ring-opening' and 'fission' reactions (leading to the gasified products, carbon monoxide and hydrogen) - requires that part of the energy in coal

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205/Now licensed to China.

be diverted to these molecular changes. Subsequently, energy is again required to make the syngas molecules grow into larger hydrocarbon fragments. Hence, the thermal efficiency of the indirect technologies is low - about 45 per cent in Fischer-Tropsch and 50 per cent in Mobils M-gasoline process-as against 60-75 per cent in the direct liquefaction processes.

Coal has a low hydrogen level (H/C molal ratio = 0.7 to 1.1) and hence to liquefy it, either hydrogen has to be raised, hydrogenated (viz. to 2.2 to approach naphtha; it is 1.9 in crude) or its carbon proportion reduced (by oxidation[206/]).

Economic Aspects

As discussed elsewhere in this document, corporate attention in the industrialized countries is not so much directed, at present, to availability factors in oil as much as it is to price. It is recognised that several state-of-art technologies (some owned by the concerned corporations) are already available for using resources as coal, oil-shale or tar-sands which are not price-linked to oil (unlike natural gas). Consequently, the actual utilization of any of these alternative feedstocks, with the current pricing of oil, is critically related to entrepreneurial assessment that oil, has become dearer and will stay dearer than alternative resources.

The survey finds that corporate investment will first take place either in the FRG or in the United States. For reasons discussed in Section I, it is unlikely to take place elsewhere[207/]. With the United States having most options - accessibility to several alternate materials - it appears, as the most likely location.

[206/] To convert coal to methane (H/C = 4.0) a great deal of hydrogen has thus to be added to coal.

[207/] Sasol's election of Fischer-Tropsch technology in the early 1950s is not 'oil price' motivated. New Zealand's 'M' gasoline project is not based on non-conventional pseudo-feedstocks. While there are several development consortia evaluating specific alternatives as SRC-II and Exxon's EDS, the only exercised commercial choices in new technology lie in the coal gasification area.

Theoretically, the current price of oil is at the point which makes a new feedstock option possible in the United States. This is quite evident from the following data[208].

	Price per barrel of oil equivalent (1979 US$)
Liquid fuels from coal in the United States	$30-37
Liquid fuels from imported coal in Europe	$30-34
Liquid fuels from oil sands***	$15-25
Liquid fuels from shale	$15-35

*** Already commercial in Canada.

This data is based on the following coal prices:

	Price per barrel of oil equivalent US$ (1979)
Indigenous coal in the United States	$3-5
Imported coal in NW Europe	$8-14
Indigenous coal in Europe	$10-15
(As reference, LNG imports into Europe)	($10-25)

Such prices have led Shell Oil (and other companies) to forecast substantial production levels for 'coal-liquids' and shale oil in the United States[209].

	Unit: 000 barrels/day crude oil equivalent	
	1991	2000
Coal liquids	320	1355
Shale oil	540	1000

The 'cross-over point' to new technologies is also dictated by levels of new investment required[210]. For 'economic-sized' projects, the

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[208] Data from the Chemical Times (India) September 3/79 quoting European Chemical News which updates Shell's "World Energy Prospects". The indicated ranges are in conformance with other estimations, although the latter do not treat all technologies in such a unified manner.

[209] Reynolds, W.W. (Shell Oil) 1980; op. cit. President Carter's synfuels programme calls for 500,000 bbl/day by 1987 and 2 million bpd by 1992.

[210] The survey, as noted in Section I, has indicated that Oil companies rate production from shale to come on-stream earlier than coal, tar-sands following both (in the United States).

the following data of Exxon[211] and Fluor[212] are indicative:

	Oil shale	Tar sands	Coal liquefication
Plant size	50,000 bbl/day	150,000 bbl/day	58,000 bbl/day
Investment (billion US$)	2-3	3-4	4-5

With the largest of current private sector projects (cited elsewhere) below $1.5 billion in fixed investment, entry into these new areas of technology will, therefore, constitute an (unusual) 'order-of-magnitude' jump[213]. (For illustration, a conventional petroleum refinery of 100,000 barrels/day would be below $700 million at the present time.

Such investment levels would strain even the largest corporations - the oil corporations (who, incidentally, own 70 per cent of the United States coal and have very substantial ownership in shale)[214]. Hence the most probable manner in which new investment is expected in the form of producer-consortiums[215]. This is not likely in the United States situation. (The patterns of such association and organizational/ Governmental problems have been dealt with in Section I).

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[211] "Project Execution - Challenges to Contractors and Operators", Crosby, C.R., (Exxon Research). Paper presented at the "Colloguium-Frontiers, Chemical Industries, 1985-2000" Amsterdam, May 21, 1981.

[212] In 1980 dollars, the estimated cost of a Sasol-type coal-liquids plant in the United States (Wyoming), designed for gasoline, jet-fuel and diesel, (58,000 barrels/day) is $3.6 billion. ("Coal Conversion Today" Sterbenz, P., Quoting J. Robert Fluor, Chairman Fluor Corporation, Hydrocarbon Processing July 1980, p. 68).

[213] While investment levels in shale and tar sands are considerably lower than in coal, the cost of infrastructural support must be considered for their commercialisation. Coal already has a well-developed infrastructure.

[214] E.g. Gulf, Chevron, Mobil

[215] In the manner in which utility companies have entered the coal gasification area. See SYNGAS,this Section and Section I.

In FRG (dealt with also in Section I) the most appropriate organizations for exploiting coal liquids - the only accessible non-conventional resource within the FRG is coal - are the utility companies. This is because of their large ownership of coal reserves and operating status[216]. However, they have not been forthcoming despite their keen participation in several multi-agency pilot plants (heavily funded by the Federal Government to the extent of 75 per cent[217]) oriented to coal liquefaction.

The locales in which new investments will take place will, expectedly, influence choice of technology. This is not merely a truism. It is a significant indication in the context of the modern period when internationalization of energy resources is a very strategic consideration for major energy importers. Thus, it is expected that if the energy needs of FRG and Japan are to be met from investments in the United States - say, in coal - the corresponding project will have a different resource-product-market orientation (hence, technology) than if met from coal resources in FRG or Australia.

This will also occur in the pseudo-petroleums (tar-sands, shale oil) despite the high mobility expected of the technologies[218]. That is, oil shale and tar sands will have to be worked at their site. Unlike coal, which is a good carbon-carrier, shale rock has only 10 per cent oil. Similarly, tar sands oil is too sulphurous to be economic after transportation. Consequently, while the technology may become mobile (cross national frontiers) the hydrocarbon resources may not be.

216/URBK, BASF and Huls of the chemical companies group also own brown coal and hard coal resources. BASF and Huls are apparently not working their mines. Soft coals are virtually reserved for generation.

217/Indeed, government and industry are presently working together in 21 liquefaction projects.

218/The Shell (NV)-Koppers, Texaco-Ruhrchemie, British Gas-Lurgi transnational "process packages" (combining respective historical experiences in oil and coal for the non-conventional hydrocarbons) constitute one illustration of the mobility of the new technologies. The British Petroleum and Mobil investment in New Zealand for 'M' gasoline is another. Development consortia in the United States involving German, Japanese and United States firms, and Japanese/American experimentation in Japan on Exxon's EDS technology, constitute yet other illustrations.

Chemical feedstocks from non-conventional hydrocarbons

The processing (refining) of the non-conventional hydrocarbons, including 'coal liquids' can yield both gaseous and liquid hydrocarbons (viz. C_1-C_3 saturated hydrocarbons and distillates of various boiling point ranges) or only liquid hydrocarbons. Whereas the gas streams can be directly and conventionally processed (ethane and propane crackers), it may not always be possible to routinely feed the "naphtha" and "gas-oil" fractions to conventional steam-crackers.

Just as petroleum naphthas of the present day typically have a compositional mix reflecting the crude they are derived from - i.e. paraffinic, aromatic or naphthenic - the naphthas of the pseudo-petroleums will reflect their origin. However, it is expected that they (the naphthas, etc.) would be blended at the refinery to conform to conventional chemical feedstock specifications. Blending could be between various 'synthetic' naphthas or between conventional and synthetic naphthas.

As will be explained in the following section, a paraffinic naphtha is preferred for olefins production and naphthenic naphtha for reformer feedstock (aromatics). Consequently, straight naphthas's and light gas oils from shale oils will be better materials for olefins[219] while those from tar-sands would be more suited for aromatics.

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[219] Comparison of steam-cracker yields - Hydrogenated shale oil cut vs. petroleum naphtha

	Shale oil cut (244-975°F)	Arabian light (430-750°F)
AOI		
API	34.3°	35.1°
C/H Ratio	6.52	6.44
Yields, wt per cent		
- ethylene	22.93	24.13
- propylene	13.09	14.05
- C4's (note 1)	9.05	9.32
	45.07	47.50
Methane/hydrogen	15.25	11.51
C5-liquids	36.98	40.99
	100.00	100.00

Note 1: 44-55 per cent butadiene, both cuts

Source: Spitz, P.H and Gomi S., "Petrochemical Industry Development: Facing the next Transition". Chemical Economy and Engineering Review, March 1980.

In the case of coal liquids, a great deal of variation occurs in the composition of naphthas since the degree to which polyaromatics in coal are 'depolymerised', and the degree to which the depolymerised materials are hydrocracked (to lighter products), are dependent partly on the character (grade) of the coal employed and very substantially on process operating conditions (temperature, pressure, depth of hydrogenation etc). In principle, it is possible to tailor make a 'naphtha-constituent' - a naphtha moiety - in the pseudo-petroleum by proper chemical control).

One of the most interesting 'coal liquid' technologies, from the viewpoint of the petrochemical industry, is Gulf's SRC-II (Solvent Refined Coal)[220] which is being operated in two pilot plants in the United States. The process yields four streams:

(1) a gaseous stream;
(2) naphtha;
(3) light fuel oils; and
(4) heavy fuel oils.

Typically, 70 per cent of the product stream is liquids and the balance 30 per cent gases (methane, ethane, propane, butane)[221]. A 90,000 barrels/day (fuel oil equivalent) plant - the size of contemporary refineries - yields sufficient ethane/propane to feed on steam-cracker rated at 500,000 tonnes per year ethylene. Besides, the naphtha stream can also be hydrotreated to act as a supplementary feedstock for olefins.

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[220] SRC-II is a development on SRC-I. In the latter the objective was to remove ash from coal (and the sulphur associated with the ash) by extracting the organic matter that is coal in a solvent. Filtration followed by evaporation (distillation) of the resulting solution left behind an ash-free carbonaceous residue, ready for burning in powerstation boilers. The process is still beset with problems of filtering the ash.

In SRC-II, the ash is creatively used as a catalyst to hydrogenate dissolved solids using an external source of hydrogen. The solvent is then removed by distillation.

[221] "Make Petrochemical feedstocks with coal liquefaction". Harris, G.A., et al (Gulf Research and Development Company). Hydrocarbon Processing May 1980, p.152. Mr. Hariss, among others of Gulf, was interviewed during the survey.

Concluding Remarks

Except for a few developing countries (coal in India, tar sands in Venezuela, shale in China and Brazil), the possibility for most developing countries to use emerging United States technologies related to non-conventional hydrocarbon feedstocks is remote. However, on a regional basis, it may be possible for some developing countries to obtain "chemical-oriented" distillates from better-placed developing countries or from countries as Australia, particularly if there is consortium-type of investment. But even for countries with shale, coal or tar-sand resources, investment requirements, for production facilities and infrastructures, are likely to be extremely heavy. Methanol would be a far more economic petroleum substitute for petrochemicals.

V. FEEDSTOCKS FROM NEW PETROLEUM-PROCESSING CONCEPTS

Introduction

As discussed in Section I there is a growing tendency in the industrialized countries to 'stretch' petroleum (by making 'light-end' products) so that two sectors of its use, transportation and petrochemicals, can be maximally serviced. In such orientation new variations of otherwise well-proven refinery processes - such as fluid catalytic cracking (FCC), hydrocracking and others - will become increasingly adopted. Properly concepted and managed, the processes have the capability to increase supplies of conventional petrochemical feedstocks. They would be relevant to developing country planning.

A historical tendency has worked to keep the 'refiner' and the 'chemist' apart. This has contributed to the narrow vision that refinery processes mostly serve the fuels-user. Today, however, factors such as the growing adoption of cataclytic processes, with their strong chemical-engineering nature (high temperatures and pressures) and a better need to understand the chemical structure of refinery streams, are leading to a strong and active technological interface between the petroleum-processing and chemical industries. Contributing to this interface, which is also becoming international in character, are such things as the 'backward integration' of chemical companies into refining, and the forward-integration of oil companies into traditional organic chemicals and plastics.

For developing countries, both oil-importing and oil-independent, there could be advantage in planning integrated chemical-fuel, or chemical-fuel-energy refineries, since, in most developing countries, the petroleum industry and the 'first generation' chemicals industry are in the public sector. The degree and complexity of integration would, perforce, depend on whether the chemical usage of the carbon atoms in crude, or the heat content in the chemical constituents of crude, is sought to be maximised.

A particular feature of new refining technologies is that they can very effectively use 'bottom of the barrel' fractions. It is hence conceivable that an oil-importing developing country can import these fractions - which tend to be low cost - and convert them, as it wishes, to chemical, energy or fuel uses. The following discussion is, in part, directed to exploring such alternatives.

It is significant that, unlike downstream chemical industry, which tends to be proprietory and product-specialised, and therefore introvert, the refining industry, like upstream chemical industry, is extrovert, comprising of technology which is highly mobile and transferable. Consequently, developing countries would be in a ready position to acquire them.

As this report relates to petrochemicals, it is useful to examine refinery streams as compositions of chemical constituents and the segregations and conversions they (the chemical constituents) undergo in refinery processing. Both chemical and petroleum literature increasingly reflect the need for this understanding. Most of today's petroleum conversion technologies are of United States development. Since they were developed in the context of the American market-place, an appreciation of their development is desirable and this is also attempted in the following section.

A Chemical View of Refinery Processes

Because of its predominant usage as fuel, petroleum was not an important 'chemical material' till the late 1960s when a series of factors combined together to warrant such attention: the increasing use of naphtha as a petrochemical feedstock and the need to develop new sources of it; public concern with the quality of the environment and the need to abate toxic and ecologically-damaging emissions from automobiles and factories; the need to utilise more effectively the coal tar-like 'heavy end of the barrel' whose share of production was increasing the urge to improve the design of refinery processes, etc.

In the United States, where petroleum got its commercial start, it primarily served the requirement of the transportation industry, predominantly the automobile. The United States chemical industry evolved unrelated to petroleum; first based on coke and later (post-war) on natural gas liquids (NGL) obtained in the course of processing natural gas ('heating gas'). But with the development of fluid catalytic cracking (FCC) processes, byproducts propylene and butylenes became attractive new feedstocks sources for the chemical industry (actually to the 'chemical arms' of petroleum companies). While this led to a sort of linkage between the industries, the quantities of C_3's and C_4's produced were so large, compared to the level of chemical demand, that processes were developed by the petroleum companies to convert them to gasoline supplements (the 'alkylation', 'polymerisation' and other technologies), thus seeing C_3's and C_4's again as fuel precursors. Separately, the chemical industry, interacted with the petroleum industry in relation to aromatics, obtaining supplies from naphtha reforming processes to make up for declining supplies from the coke industry. Here, too, refinery technologies (thermal and catalytic reforming) produced such large volumes of aromatics that they promoted high-octane gasoline markets.

A more abiding interaction is now emerging between the industries as the chemical industry's demands for feedstocks, mainly naphtha, cannot be met by the oil companies unless they generate more naphtha, and in excess of automobile needs[222/], without corresponding increases in crude oil throughout.

To appreciate the contributive value of these interactions, it is desirable to view the refinery as accomplishing three principal functions:

(a) The simple physical separation of groups of components (see Figure XII) in petroleum through distillation, with boiling point ranges of the distillation cuts suited to various applications;

(b) The chemical transformation (molecular rearrangement) of low-value petroleum cuts to upgrade them (e.g. the FCC and catalytic reforming processes); and

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[222/] The situation described here holds particularly true for the United States. In W. Europe, the petrochemical industry feeds the gasoline market with aromatics via 'pyrolysis gasoline' made in naphtha crackers.

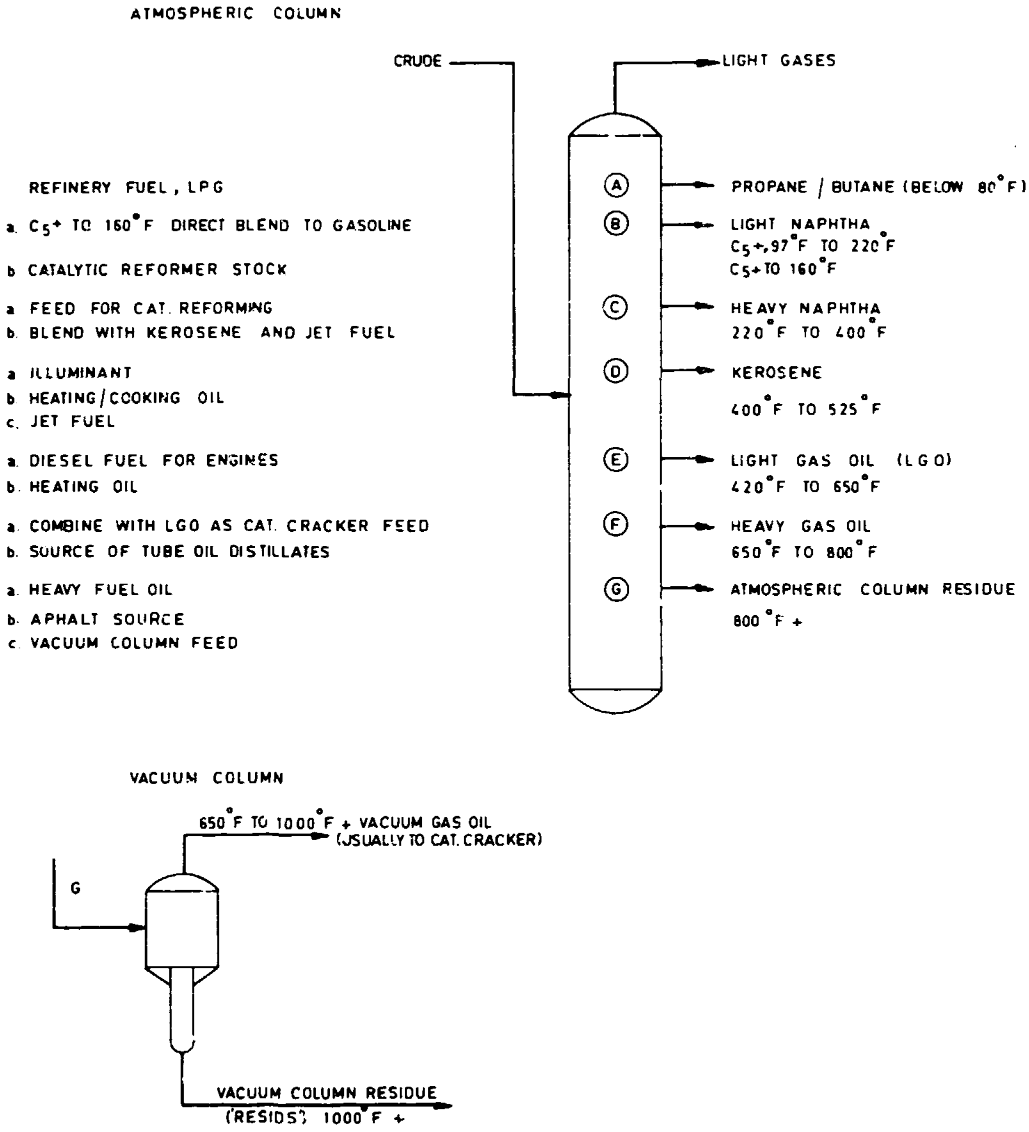

FIG. XII PETROLEUM FRACTIONS FROM ATMOSPHERIC COLUMN AND VACUUM COLUMN DISTILLATION

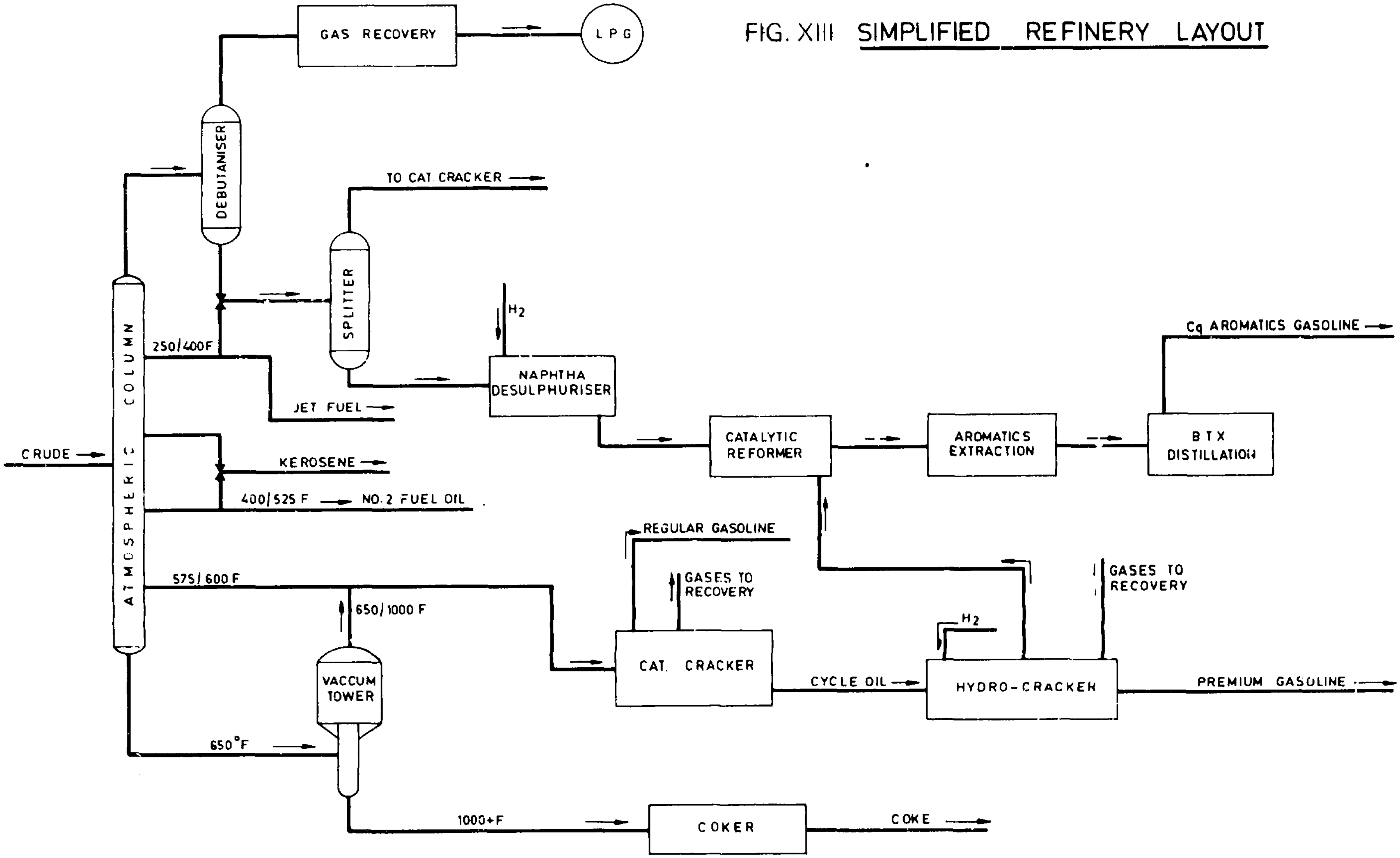

FIG. XIII SIMPLIFIED REFINERY LAYOUT

(c) The physical and chemical extraction, or the removal, of constituents from refinery streams so as to obtain higher market values for what is left behind (the raffinate) or what is recovered, the 'product'; an example of the former is any of the dewaxing technologies[223/]; and example of the second type is the extraction of aromatics (BTX) from thermal or catalytic reformates for use as chemical intermediates.

Most refinery processing involves combinations of the above processes (see Figure XIII). For example, vacuum gas oil (VGO) from an operation of type (a) could be hydrocracked in an operation of type (b) and then a distillate fraction of the hydrocrackate fed to an FCC unit to yield a superior gasoline.

Operations of types (b) and (c) are generally called 'refinery conversion processes', and presently most of such conversion is carried out in the United States.

Classification of Crudes

The spread of distillation cuts (yields), the degree to which distillate molecules can be chemically rearranged, etc. depend on the crude oil type. Crude oils fall into four categories, or combinations thereof:

(a) Paraffinic;
(b) Aromatic;
(c) Naphthenic:
(d) Asphaltic;

Sub-classifications are made on the basis of gravity (the heavy and light crudes), sulphur content ('sweet' and 'sour' crudes), metal content ('metallic'), etc.

Paraffinic crudes are those rich in linear and branched long-chain paraffins, with carbon numbers ranging up to C_{60}. Aromatic crudes are those rich in BTX precursors: the alkyl aromatics with long side chains, the tetralins, tetralins with side chains, polynuclear aromatics, etc.

[223/] Although they would not strictly fall under this classification, desulphurisation and demetallisation processes may be included.

(while the crude oils, in themselves, contain less than 3 per cent or so of 'native molecules' as benzene, toluene and the xylenes). Naphthenic crudes are those rich in cycloparaffins (naphthenes) such as cyclohexane and cyclopentane and C_5/C_6-fused rings. Asphaltic crudes contain asphaltene, a complex of polycondensed ring compounds with extensive sulphur bridges (i.e. sulphur is held in a tight aromatic matrix). Aromatic crude oils are often associated with asphaltic components.

Crude oils do not contain olefins (ethylene, propylene, etc.) or diolefins. However, because gas is often associated with oil, 'gaseous' hydrocarbons up to C_5 would be found dissolved in the crude oil.

A crude oil is selected in terms of its cost (at the gate of the refinery), its distillation behaviour (the relative yields of the principal distillates), the appropriateness of the distillate mix to market-mix, and the problems that it might pose in terms of its inorganic constituents (nitrogen, sulphur, metals) in conversion processes, etc. Fundamentally, of course, the refiner would like to dispose of all products to a value-maximising manner.

Chemical Classification of Distillates

The chemical constituents of petroleum are distributed among the various atmospheric column distillates graded by their boiling points.

First, light hydrocarbons yield a gas fraction (see Figure XII[224]). The lightest liquid cut is 'Light Naphtha' (also called straight-run naphtha or virgin naphtha). It can be used as petrochemical naphtha or alternatively sent to the gasoline pool as blend stock. The next cut is 'Heavy Naphtha' which can be catalytically reformed (see later), blended into kerosene or jet fuel, or blended with light naphtha for chemical feedstock.

224/Methane, ethane and some propane, would normally be burnt for meeting part of the refinery's heat requirements. Propane and butane, but largely propane, would be recovered (liquefaction under slight pressure) as LPG for 'bottled gas' sale. Normal butane would be recovered for blending into gasoline in order to raise its volatility.

In composition, light and heavy naphthas reflect the origin of the crude oil - i.e. in themselves are paraffinic, aromatic or naphthenic. Paraffinic naphthas are particularly rich in n-paraffins. Light paraffinic naphthas predominantly have C_6-C_7 paraffins tailing off into C_8, with a good proportion of straight-chain isomers. They are excellent steam-cracking stock[225/]. Heavy naphthas, with paraffins up to C_{10}, however, contain substantial amounts of branched chain paraffins, naphthenes and alkyl-aromatics. They yield considerable liquid products ('pyrolysis gasoline') in steam cracking.

Aromatics and napthenic naphthas are not suitable for the steam-cracker (olefins production). They are relevant to the petrochemical industry only in terms of their being potential substrates for catalytic reforming (production of aromatics). They are also not good gasoline stock because they have a low octane number (see later).

Gasoline naphthas, as will be seen later, are obtained by combining various refinery processes (including catalytic reforming).

[225/] Steam-cracker feedstock is usually specified for a high n-paraffin content. N-paraffins crack more readily than iso-paraffins and yield more ethylene than propylene.

In order to meet octane ratings[226/] a most important need in gasoline - the naphtha must have high concentrations of two sets of components:

(a) Long chain branched paraffins;and

(b) Mononuclear aromatics, particularly with side chains.

Naphthenes can substitute for aromatics if compensated by isoparaffins. The objective in much of refinery processes is to bring about such compositions. However, the final suitability of a naphtha is determined by the empirical tests dictated by practice.

Kerosene, light gas oil, and heavy gas oil constitute the 'middle distillates' which are very important in developing countries - and continue to be important to Europe and Japan. Kerosene, depending on its boiling range and composition, is a heating oil, an illuminant oil or a jet fuel. Light gas oil is diesel oil if its, 'cetane number' is acceptable; otherwise, it is a fuel oil. Heavy gas oil is a fuel oil.

[226/] Octane Numbers: The octane number measures the antiknock quality of a gasoline fraction in spark-ignition engines. A highly branched paraffin, iso-octane - 2, 2,4 trimethyl pentane - is taken to have Octane = 100. Normal neptane is taken as zero. A sample of gasoline is tested in a octane-rating machine and matched with synthetic mixtures of the "Zero" and "100" octanes. When such a mixture has the same antiknock value as the sample, the octane value is simply established.

There are two octane numbers, RON (research octane number) and 'MON' (motor octane number). MON is a severer test for antiknock evaluation. Unspecified, the octane number is an average of MON + RON.

Higher octane numbers permit higher engine compression ratios. With higher compression, fuel economy is better. High octane contributors are mononuclear aromatics with side chains, branch n-paraffins and napthenes.

The addition of tetraethyl lead (TEL) upgrades octane number of gasolines (octane booster) by several points. Standard test is to add 3 cc TEL to one US gallon of gasoline but required octane may be reached with lower addition.

With the virtual banning of 'lead' as an additive,toluene and xylenes concentrations in gasoline have to be upgraded. The isomerisation of n-paraffins also helps.

Premium gasolines have octane numbers over 100. A straight-cut naphtha would have a typical value of about 65.

In the middle distillates the primary constituents are long-chain n-paraffins (C_{13}+), napthenes with long side chains and fused ring compounds (polyaromatics). Kerosenes need to have vaporisability and good burning characteristics. Diesels must have a high cetane number[227/] for use in compression ignition engines and a low pour point[228/] for usage in low temperature environments. Fuel and furnace oils must be suitable to the 'burning mechanism' (industrial boilers, powerplant boilers, cement plant burners, marine boilers, etc.), and where environmental legislation exists, meet sulphur specifications.

Sulphur 'concentrates' in heavier distillates and in the industrialized countries the distillates must meet stringent environmental specifications.

The last fraction in atmospheric column distillation is the residue called atmospheric column residue, or 'reduced crude'. In the past this residue was often blended with heavy fuel oil. It is rich in polynuclear aromatic liquids but usually has a high sulphur content.

[227/] Cetane Number: A short ignition delay is required in compression-ignition engines (diesel engines) to ensure smooth start. The cetane number measures this. Like octane number rating, n-C_{16} paraffin is given a 100 rating (high ignition quality i.e. low delay) while a highly branched chain paraffin, called HMN, is given a rating of 15. Sample diesels are tested in standard engines against synthetic mixtures and matched.

Cetane Numbers for diesels may be anywhere from 35 to 65 depending on usage of the engine (mobile, stationary, truck, farm tractor etc). The order of decreasing cetane numbers is: n-paraffins; olefins; napthenes; branched paraffins; aromatics. It is the reverse order for octanes. Straight cuts (atmospheric colum distillation) have maximum of n-paraffins and napthenes. Hence they make very good diesel fuels.

[228/] Pour point requirements may be as low as - 15 per cent or lower. Chemicals, like n-paraffins which are waxy, and settle out, have to be removed by dewaxing processes.

Refinery Conversion Processes (General)

The objective of the following discussion is to provide a basis for the next chapter 'Bottom of the barrel processing', which examines the potential links between the refinery and petrochemical industries, in the context of developing country requirements.

It is expected that processes now widely employed in the United States, and being adopted by Europe, Japan and the Middle East, will also be the ones which will first find their way to the developing countries. It is thus worthwhile examining the rationale which led to the development of the various conversion technologies.

The United States processes responded to an economic environment in which the following spread of prices existed in stable relationship for several years:

		Prices (1965): ¢ per million Btu
Natural gas	-	15
Domestic crude	-	56
Propane	-	45 (in bottles)
Gasoline ("Regular")	-	84
Foreign crude	-	43 (certain levels of import mandatory)[229]
Natural gasoline	-	71
Butane	-	52
Kerosene	-	69
No.2 Fuel oil	-	60 (Fuel oils freely importable)

It is quite obvious that refining objectives would gravitate to maximizing the yield of gasoline and of the liquid products.

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[229] Under United States laws designed to conserve United States domestic crude reserves, it was mandatory for oil companies to import crude in fixed proportion to production. While low-cost fuel oil could be freely imported, imports of other fractions were inhibited by tariffs. Obviously these are highly simplified versions of the actual situation.

Whereas in Europe and Japan refineries were being designed to maximize 'middle distillates', the objective in the United States refining has traditionally been to convert fuel and furnace oils coproduced with gasoline and other fractions[230] into higher value products.

As the following Table (Table 20) shows, the yield of fuel oils is generally very high:

Table 20

Atmospheric Distillation Yields of Typical Crudes

	Arabian Light	Iranian Heavy	Indonesian Minas
Gasoline/naphtha(vol. per cent)	23-25	20	12.5
Kerosene (vol. per cent)	13	26	23
Gas oils (vol. per cent)	13	—	—
Heavy fuel oil(vol. per cent)	48	52	64
Sulphur,(weight per cent)	3	3	0.1
Heavy metals,ppm (weight)	36	320	17

---

[230] Straight forward crude distillation provides little scope for altering proportions of the various petroleum cuts as they are boiling-point related. Flexibility arises only in terms of broad and narrow cuts (boiling point range). However, certain types of crudes favour one fraction over the other and are chosen on this account.

As the (atmospheric) gas oil fraction is reached, and heavier fractions are met with, a series of problems develop:

(a) Sulphur concentrates into heavier and heavier fractions;

(b) The boiling point spread of chemical components narrow appreciably;

(c) The molecular complexity of the chemical components increase very considerably, incorporating heavy metals into their structures;

(d) The 'freezing point' ('pour point') of the fractions increase so that many cuts would be solid at ambient temperature;

(e) The viscosity of the heavier cuts tend to be pitch-like (some cuts are indeed pitch) difficult to pipe and transport; and

(f) Because of coke-promoting propensities of sulphur and heavy metals, processing of the heavier cuts through further distillation leads to 'cracking', and more significantly, coking[231/] (usually above 300°F).

Where recovery of the atmospheric column bottom products (i.e. reduced crude) is considered valuable, vacuum distillation is resorted to (see Figure XII). Reduced crude, (boiling point at 600°F or so) would be distilled under vacuum so that distillable products with boiling points above 1000°F can be recovered. The vacuum column yields two products - the overhead vacuum gas oil product (VGO) and a bottoms-product, vacuum column reside ('resids' for short)[232/].

[231/] While coke has value in certain applications, if markets exist, its most direct markets are as anxillary fuel for power station boilers and as gasification stock ('blue gas', etc).

[232/] Unit: Vol. per cent

	Heavy Arabian Crude	Venezuelan Crude
C_4 and lighter	3.3	0.6
Naphtha	19.0	4.5
Middle distillates	22.5	12.0
VGO	25.2	42.8
Resids	30.0	45.0

The most direct use of VGO is as a blending component, for stationary turbine fuels. As can be expected, it comprises principally of polynuclear aromatic compounds. However, its most common use is as a feedstock for catalytic crackers.

The bottoms product of the vacuum tower - 'resids' - can go directly:

(a) for the production of asphalt, which is rich in asphaltene, a coal-like material in composition and physical structure;
(b) for the production of coke - the 'delayed cokers[233];
(c) as furnance oil, viscosity permitting; or
(d) it can be further processed in thermal and catalytic processes.

Because of the very large and profitable gasoline market in the United States, a whole series of processes were invented (in the United States) which had the potential to convert almost any stream of the refinery to high-quality gasoline.

Refinery Conversion Processes (Technology)

If two preparatory processes - hydrotreating and desulphurisation[234] are laid aside as being supportive or ancillary to the mainstream of refinery conversion processes, the critically important components of the modern day refinery are the following five processes:

(a) Catalytic cracking (the FCC process);
(b) Hydrocracking
(c) Isomerisation;
(d) Alkylation;
(e) Catalytic Cracking (the FCC process).

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[233] The delayed cokers took advantage of 'coking crudes' accessible to United States industry. The resulting 'petroleum coke', if low in sulphur, is a valuable feedstock for the manufacture of electric furnace graphite electrodes and of aluminium industry anodes.

[234] Hydrotreatment processes (mild and deep hydrotreatment) use hydrogen in catalysed operations to saturate unsaturated compounds as the olefins and aromatics and to remove nitrogen, oxygen and sulphur as ammonia, water and hydrogen sulphide. The desulphurising processes are specific to sulphur removal with minimum impact on the structure of molecules and their distribution in the submitted streams.

The first two, as said earlier, are treated in greater depth in a later section.

Of the next three processes two are not important to the chemical industry - isomerisation and alkylation. Both processes work to maximise the proportion of branched chain paraffins in a mix of hydrocarbons[235/].

Catalytic reformation accomplishes many things and it is important to both the petrochemical and refining industries. Its prime function is to maximize mononuclear aromatics and branched chain paraffins. The process operates multi-dimensionally:

(a) It splits off alkyl side chains from ring compounds;
(b) It dehydrogenates napthenes to aromatics;
(c) It causes paraffins to undergo 'dehydrocyclisation -- leading to the formation of ring compounds;
(d) It isomerises straight chain paraffins to branched chain compounds, etc.

For the petrochemical industry, the catalytic reformate is a source of aromatics, and several processes have been developed (as Shell's Sylpholane and UCC's TETRA Processes) to extract the aromatics[236/]. For the refining industry, the reformate is a key blending stock for high-octane gasolines. Catalytic cracking and hydrocracking contribute a great deal to winning values from high boiling point residues of the atmospheric column bottoms. While hydrocracking was once a major method of obtaining gasoline, FCC now can compete with it in practically all aspects.

235/Isomerisation converts long-chain n-paraffins to branched chain isomers. In alkylation, short-chain hydrocarbons are interacted with branched structures to obtain branched chain paraffinic structures. Both processes, of course, contribute to upgrading octane number.

236/The raffinate of this extraction process is often an adequate steam-cracking stock.

The most important feed to the FCC unit is VGO, but hydro-treated resids can also be fed. The limits on feeds, more for FCC than hydrocracking,are set by sulphur and heavy metals levels. In the FCC, sulphur and the metal promote coking which, by inactivating catalysts, increases regeneration ("burn off") costs. Thus, such feeds must be desulphurised and demetallised which increases costs.

The hydrocracker is a good desulphurizing tool and can withstand a 'metallic' feed. However, it is an expensive process because of its requirements of hydrogen[237/]. The hydrocracker is sought as a means of converting resids ('residual cracker') in which sulphur and metals have accumulated.

In practice FCC units and hydrocrackers treat a great deal more distillates than just the difficult fractions.

'Bottom of the Barrel' Processing

For numerous reasons, there is international effort to use more of the 'bottom of the barrel'. Technology which accomplishes this is well established in the Unites States. It is also now being rapidly employed in Europe, and is getting a foothold in Japan. Some of the processes used have relevance to developing countries, both oil-independent and oil-importing.

The reasons creating this attenation are:

(a) Most of the available incremental oil production is of the heavy variety carrying the implication that the'bottom of the barrel' segment will be much larger than what was obtained with traditional oil (e.g. Arabian Light);

(b) It is OPEC's policy to supply crudes in the proportion of lights to heavies as its reserves; as of March 1978, Saudi Arabia, for example, indicated that it supply oil in the ration of 65/35: light/heavy[238/];

[237/] In the United States, catalytic reformers acted as a source of hydrogen for hydrocrackers.

[238/] In 1976 the ratio of light crude to world reserves was 31.7 per cent; however, its consumption was 37.7 per cent. For heavy crude, the corresponding numbers are 48.7 per cent and 41.7 per cent.

In terms of sulphur content it may also be noted that while OPEC has only 15 per cent of the world 'sweet' crude, it supplies half of United States needs, the United States being its biggest customer.

(c) Most industrialized countries intend to hold petroleum consumption to levels of the late 1970s in terms of long-term planning even though absolute petroleum consumption [illegible] increase in the interim[239/]; strategies call for maximising petroleum for transportation and petrochemicals, with other current uses of petroleum (fuel oils primarily), eventually substituted by nuclear energy, natural gas, coal, etc. This leads to 'stretching' of petroleum and would involve the conversion of heavier petroleum fractions to lighter materials;

(d) OPEC countries are building very substantial refining capacity[240/] and can be expected to become net sources of heavy residues; consequently, unless European or American refining capacity is reduced in some proportion to OPEC's new capacity, new applications for the 'bottom of the barrel' products will have to be found.

Thus, to rephrase a comment by UOP: the problem in refining technology is becoming one of producing a slate of products which are progressively becoming lighter (i.e. the demand pattern) from crudes which are progressively becoming heavier. In attempts to reach solutions, residues increase and uses have to be found for them.

239/Britain's gasoline demand, after an intervening 'hump' is expected to reach 455,000 barrels/day in 2000, only slightly higher than 440, 000 barrels/day in 1980. Naphtha supplies from atmospheric column distillation is expected to reach only 240,000 after meeting petrochemical demands. It is Britain's plan to generate the difference by cracking fuel oils, vacuum gas oil, etc. (Source: Chemical Weekly (India) December 30, 1980 p.89 reporting on talk by Sir Nevil Macready of Mobil United Kingdom to the International Association of Energy Economists).

240/OPEC capacities:

1980	- 6.25 million barrels/day
1984	- 9.50 million barrels/day
(1974	- 4.00 million barrels/day)

OPEC's 1980 capacity was about 9.3 per cent of world capacity (67.3 million barrels/day) excluding capacity in centrally planned economies. In 1984, OPEC is expected to have 12 per cent of world capacity (on same basis). Source: Chemical Engineering, May 4, 1981. (USSR's refining capacity is estimated at 18 million barrels/day).

Technology for processing 'bottom of the barrel' products, often collectively called 'black oil processes', involves using the following 'fractions' of atmospheric column and vacuum column distillation:

(a) Atmospheric column bottoms;
(b) Vacuum gas oil;
(c) Vacuum column bottoms (resids).

Black oil processes also handle products which are produced (or co-produced) in one or other of the component refinery processes, viz. cycle oils, deasphalted oils, etc. (The processes also operate on distillate oils of atmospheric column distillation (as naphthas or kerosenes) or on streams from other refinery conversion processes. They are then part of strategies for optimizing the product slate of a refinery).

Black oil processes attempt to do one of three things:

(a) Breakdown heavy products to light products for which there is conventional demand, typically gasoline;
(b) Reduce sulphur levels of refinery streams, as gas oil, fuel oil, et. so that environmental requirements converning their combustion can be met, or in other cases, to meet limits set by downstream refinery processes; and
(c) Make the best of a 'bad bargain' by turning the carbon in petroleum to coke, pitch, etc.(which can be seen as an indirect path to converting viscous materials to gaseous fuel or to liquid energy products as methanol).

Of the various established processes, two are quite relevant from the point of view of their ability to supply feedstocks: to the petrochemical industry, particularly in an 'integrated refinery' or a 'chemicals refinery,: catalytic cracking and hydrocracking. In fact, these are two of the three important refinery conversion process in use presently (see Table 21).

Table 21

Comparison of Refining-mixes of Japan, FRG and the United States (1976)

Unit: per cent

	Japan	FRG	United States
LPG	6.1	2.5	1.9
Gasoline	11.4	16.6	41.5
Naphtha	12.4	3.9	3.7
Kerosene/jet fuel	9.3	1.8	6.9
Gas oil + distillate fuel	14.8	39.0	21.1
Fuel oils	41.8	19.3	19.0
Other	4.2	8.2	5.9
	100.0	100.0	100.0
(Atmospheric column feed)	(5.9 million bpd)	(3.08 million bpd)	(17.6 million bpd)
Catalytic cracking[241]	5.8%	13.1%	28.2%
Hydrocracking	0.2%	0.3%	5.2%
Thermal cracking			
- visbreaking	0.0%	4.9%	1.1%
- delayed coker	0.9%	1.5%	5.4%
- fluid coker	0.3%	-	0.7%

Of the two, catalytic cracking is the more important for petrochemicals However, new developments in hydrocracking technology, and new concepts in the use of conventional hydrocrackers, promise a place for hydrocracking in chemicals manufacture. Unlike the thermal processes (e.g. visbreaking and the 'coking' processes), the catalytic and hydrocracking processes use very specialised and expensive catalysts in sophisticated capital-intensive plants. Both have their origin in the United States in the mid-1960s. The catalytic process, the modern version of which is Fluidised Catalytic Cracking (FCC zeolite cracking) is currently employed internationally for some 8 million barrels per day throughput, whilst hydrocracking capacity is about one million barrels[242] per day.

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[241] Percentages are on atmospheric column throughput
Source: Chemical Engineering + Economic Review, April 1981, p.14.

[242] "What world crude analyses imply", Carter C.P. (The Chase Manhattan Bank, New York), Hydrocarbon Processing, September 1979 p. 103. (Most of the capacities listed above are in the United States).

The FCC Process

The FCC process was initially developed to produce high octane gasoline using heavy feeds as virgin and thermally cracked gas oil, atmospheric and vacuum column distillates, coker gas oil and deasphalted oils[243/]. The process selectively removes hydrogen from co-produced paraffinic materials to provide an environment for the cracking of polyaromatic rings to mononuclear aromatics. In this process of hydrogen deprivation, olefins are produced (Table 22), predominantly C_3 and C_4. If the feedstock was fed hydrotreated, e.g. hydrotreated vacuum gas oil (VGO), ethylene yields would improve.

Table 22

Product Distribution (Typical) from FCC (Gasoline Optimised)

		Feed: Light Arabian VGO
C_2's	-	3.4 wt%
C_3's	-	6.7
C_4's	-	10.8
Gasoline	-	47.0
Light cycle oil	-	17.9
Coke	-	5.5
Others	-	8.6 (incl. H_2S)
		100.0

C_3's Composition:

Propylene	-	75% (wt)
Propane	-	25%

C_4's Composition:

Isobutane	-	34%
n-butane	-	10%
iso-butylene	-	15%
Butene-1	-	13%
Butene-2	-	28%

Source: "Petrochemical Intermediates from C_3/C_4 olefins", Persak, R.A., et al (UOP) Chemical Engineering Economic Review, July 1978, p.25.

[243/] The coker is an inexpensive means of treating atmospheric column bottoms to maximise oil production. It is a thermal process whose byproduct is coke. Deasphalted oil is oil that has been solvent extracted from vacuum column residue. Both coke and asphalt 'concentrate' sulphur.

Apart from naphtha-cracking (steam-cracking), the FCC is the sole source of the higher olefins. In the Unites States, it is the major source[244]. It needs to be realised, of course, that the yield of a FCC unit will depend on the nature of the feed, cracking severity and catalyst selection.

Whereas conventional FCC is oriented to maximisation of gasoline and of the liquids/gases ratio, new versions of the process provide the option to maximise olefinic LPG[245]. This is illustrated in Table 23.

244/Before the olefins can be employed in downstream process, FCC gases have to be cleaned up and concentrated for the desired fractions. The most economic and convenient method of accomplishing this is to pipe the FCC stream to the recovery (fractionation) system of a naphtha steam-cracker set up provided access and adequate capacity are available. Integrated petroleum-chemical producers are best placed to do this.

(While names of the specific units were not provided, two "area examples" were quoted to the author of this report during the survey. FCC-cracker integration was said to be practiced between oil and petrochemical companies in Claymont, Delaware (United States) and Lake Charles, Louisiana (United States). For developing countries, this type of integration should be more readily achievable.

245/"Petrochemicals from the FCC Unit", Vermillion, W.L., and Niclaes, H.J., (UOP), Hydrocarbon Processing, September 1977, p. 193.

Table 23

FCC Yield Structure, LPG maximised

	Feed: Kuwait Vacuum Gas oil 9000 M^3/day	
	Case A(Max.LPG)	Case B(Max.Gasoline)
Fuel Gas (NM^3)/day	630	469
Liquids (M^3)/day		
C_3 LPG	1659	1086
C_4 LPG	1902	1469
Gasoline) Fuel oils)	5075	7215
Fuel Gas Composition		
Hydrogen	11	13
Methane	42	37
Ethane	15	17
Ethylene	18	15
C_3's	6	7
Inerts	8	11
	100	100
C_3 - LPG, Vol.%		
Propylene	75	77
Propane	25	23
C_4 - LPG, Vol.%		
Butylenes	59	61
Butanes	41	39
Olefins potential		
Ethylene, tonnes/year	48,300	29,700
Propylene	221,100	148,500
Butylene	232,500	189,300

While FCC catalysts are being developed to be more metals tolerant[246/], demetallisation of feed, or choice of a low-metal feed (essentially, the choice of crude) is necessary. FCC catalysts are also sensitive to sulphur and hence a hydrotreated feed is often required. But such treatment also helps to increase the ethylene yield.

Hydrocracking

Hydrocracking, in its traditional form, is not useful for production of petrochemical feedstocks. As Table 24 illustrates, the FCC process is a far better approach. However, the concepts of the hydrocracking process, and modifications thereof are developing which make its consideration as a source of feedstocks worthwhile.

Table 24

Typical Yields from Cracking Processes[247/]

Unit: Fuel Oil Equivalent per cent

	Hydrocracking	FCC
C_2 and lighter	2.0	4.0
C_3's	2.0	13.4
C_4's	3.3	20.2
Naphtha	58.2	61.3
Distillate	52.7	12.7
Residue	—	4.6

[246/] Vanadium, followed by iron, are 'catalyst poisons' occupying active sites in catalysts and acid centres in zeolites. Metals promote coke formation which reduces catalyst activity, while increasing its costs of internal regeneration.

[247/] Source: "What World Crude Analyses Imply", Carter, C.P. (Chase Manhatten Bank, New York), Hydrocarbon processing, Sept. 1979.

Like FCC, hydrocracking is a catalystic process but has a 'fixed bed' configuration. It is used mostly to work on streams that resist cracking by other means. As its name indicates, the process both hydrogenates and cracks (heavy molecules). Unlike FCC, it requires a source of hydrogen (external supply). The process does several things - it cracks polycondensed aromatics, it saturates aromatics to naphthenes, it encourages ring-opening reactions, it splits off side chains from aromatics and naphthenes, etc. Under catalytic direction, the resulting paraffin chain fragments recombine to form branched chain isoparaffins. Because of the hydrogen environment, no unsaturates are formed, further, because of this environment there is very little of residue in the process. Coking is not a problem since polyaromatics (which condense to coke) are destroyed. Catalyst selectivity can be such, however, that aromatic rings are not overtly saturated.

Hydrocracking is also a sulphur removal process (sulphur ultimately appearing as H_2S). Thus, the hydrocracker can be a route to preparing low sulphur feeds for FCC.

While maintaining a satisfactory level of aromatics, the hydrocrackate capitalises on its high paraffin isomer level and naphthene content to make an excellent gasoline. It yields a high liquid/gas ratio as well as a large volume of liquid products. The FCC, on the other hand, makes a better quality aromatic gasoline.

New Approaches in Hydrocracking

There are two new approaches which try to make the hydrocracker concept fit the demands of petrochemicals.

Hydroconversion

This is a promising development by Linde AG[248/] by which feeds such as vacuum distillates, deasphalted oils and cycle oils [249/] can be fed to the steam-cracker (naphtha-cracker). If they were to be fed directly to

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248/"Hydroconversion Upgrades Heavy Olefin Feedstocks" Kreuter, W., et al. (Linde AG). Hydrocarbon Processing, June 1979, p. 109
Dr. Kreuter was interviewed during the survey.

249/Cycle oils are fractions that remain unconverted in FCC.

to the steam cracker, two types of problems arise:

(a) The high levels of polyaromatics in the feeds would lead to excessive coke formation in the tubular furnaces of the steam-crackers, reducing throughput and leading to processing difficulties in downstream equipment; and

(b) The low H/C ratio in such feeds would be inadequate to yield high olefins conversion.

The second of these problems can be very readily solved by submitting the feed to the hydrocracker and then feeding the hydrocrackate to the steam cracker. However, conventional hydrocracking, as said earlier, leads to a high yield of branched chain paraffins as a consequence of polyaromatics destruction ('isomerisation'). The branched paraffins, of course, do not efficiently crack to olefins but result instead in the production of LPG and lower saturated hydrocarbons.

Linde's hydroconversion technology, which is being piloted, is said to employ catalysts which selectively crack polyaromatics and naphthenes with less 'isomerisation activity', while requiring minimum levels of hydrogen consumption. The net result is that a hydrocrackate is obtained which "shows gas oil-like behaviour but naphtha-like yields of ethylene" in steam-cracker operation. At the same time, excellent 'middle distillate fractions' become available (see Table 25).

Table 25

Product yields in Hydroconversion

	Feed: Light Arabian Vacuum Gas Oil Unit: weight per cent
C_1-C_4	0.30
Light gasoline	0.76
Heavy Naphtha (80-180°C)	6.38
Kerosene (180-230°C)	5.84
Gas oil (230-340°C)	24.92
Treated Steam-cracker feed	59.70
Losses, ammonia, hydrogensulphide	2.10
	100.0

The M-B-E Hydrocracking System

Hydrocarbon Research Inc., United States (HRI) have reportedly developed the M-B-E system of thermally hydrocracking naphtha, kerosene and other liquid distillates (including oil) to simultaneously yield methane, benzene and ethane (MBE) with the latter then serving as a steam-cracking feed. The developers claim that it is possible to achieve better ethylene yields from a given naphtha or gas oil feedstock by their process than by today's direct steam cracking of the hydrocarbon feedstock[250/]. The product mix as shown below meets the olefins-aromatics spectrum of conventional light distillates cracking (Table 26).

Table 26

Thermal Hydrocracking Yields

	Kuwait Kerosene	Venezeulan Kerosene
Feeds:		
Kerosene, wt. per cent	100.00	100.00
Hydrogen	9.00	9.00
	109.00	109.00
Products:		
Benzene	10.52	16.77
Methane	55.57	52.75
Ethane	41.70	39.57
Hydrogen sulphide	0.24	0.24
Other aromatics	0.97	1.45
	109.00	109.00

250/"Make Ethylene Feed from Distillates" Lehman, L., and Vergara M., (Hydrocarbon Research, INc.) Hydrocarbon Processing, July 1977, p. 126.

Sources and Uses of Naphtha

Naphtha, whether it ultimately serves as gasoline, steam-cracker feed, etc. is, today, available from a variety of refinery operations (ans some non-refinery operations) as shown below:[251]

Unit: Million Short Tonnes

	Total	Virgin naphtha	Cat. Cracker	Thermal process-	Condensate[252]	Coal tar
United States	332	162	120	10	37	3
Rest of the world	596	481	80	10	18	7

The content of light naphtha in crude can be anywhere from 5-25 per cent, depending on source. Its constituents may range:

aromatics	6-22 per cent
naphthenes	20-50 per cent
paraffins	40-75 per cent

It would typically have a research octane number in the 1960s. Catalytically cracked naphtha derived from VGO is about 50 per cent olefinic (diolefins, etc.) and has to be hydrogenated. The hydrogenated stock is a good catalytic reformer stock. Thermal naphtha also tends to be olefinic. Condensate naphtha is highly paraffinic and is a viable steam-cracker feedstock. Coaltar naphtha is usually aromatic but it could also be paraffinic.

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[251] "Naphtha: Supply Demand, 1977-1985", Carter, C.P., (Chase Manhattan) Hydrocarbon Processing, September 1978, p.237.

[252] Natural Gas Condensate.

Naphtha demand levels for 1977 and forecasts for 1985 are presented below:[253/]

Unit: Million Short Tons

	Gasoline	Petro-chemical	Other Fuel	Process Loss and change	Total
1977					
United States	312	23	14	15	354
Rest of the world	400	119	10	39	578
	712	142	24	54	932
1985					
United States	314	42	14	16	387
Rest of the world	507	164	11	63	745
	821	206	25	80	1132

Showing quite evidently the large role that the United States plays, and will play, in the international use of naphtha.

The demand for petrochemical naphtha is seen as follows:

	Steam cracking	Aromatics	Other petro-chemicals	Total
United States	3	15	5	23
Rest of the world	44	35	40	119

[253/] Naphtha: Supply/Demand - 1975/85 - Carter, C.P., op., cit. (Figures are believed to exclude production and usage of the centrally planned economies.)

'Heavy Bottoms' and 'Residues' as Feedstocks in Developing Countries

Developing Countries may be able to utilize heavy bottoms and residues as low cost sources of hydrocarbons. Surpluses of materials of such character become available in situations such as:

(a) Disposal/export of crudes after 'hydroskimming' - that is, the exploitation of crude for its lightest hydrogen-rich components; potential sources would be the oil-rich countries;

(b) Disposal/export of residues and bottoms by refineries such as those established in the Carribbean, Singapore and other places basically on grounds of transportation logistics;

(c) 'Byproduct' of refining heavy crudes imported on considerations of freight, foreign exchange; etc.

(d) Byproduct of conventional refining of indigenous crudes wherein fuel demands of the market-place are readily met by light and middle distillates production, etc.

The residues and heavy bottoms could arise from various operations such as vacuum distillation, solvent deasphalting, thermal cracking, etc. and through uses of differing kinds of crudes - 'metallic' crudes, high-sulphur crudes, asphaltic crudes, etc. Thus, the utility of the residue or heavy bottoms would be dependent on its source.

Irrespective of source, the developing country would be able to utilize the residues, and such like byproducts, in partial oxidation syngas processes (Texaco, Shell and other gasification processes) which have been widely practiced in the industrialized countries for several years. Without catalysts being poisoned or coked they are open to operating on feedstocks, and can even accept composite feeds such as asphalt or pulverised coal distributed in heavy oils. For feeds with sulphur, which is the most likely situation, economic penalty arises from the degree of desulphurisation needed in downstream processing, before gasified product can be used in synthesis etc. (see SYNGAS).

However, for use as steam-cracker feed or FCC feed (for C_3's/C_4's) it would be necessary to treat the residues and bottoms in hydrotreating processes, or to demetallise and hydrocrack them to raise the H/C level and reduce the sulphur level.

For countries without coal, 'bottom of the barrel' products would most often be the lowest cost sources of hydrocarbons. Even in circumstances of indigenous coal, the use of residues/heavies may be an economic alternative in terms of capital requirements.

The survey shows, however, that a most attractive proposition for developing countries is to integrate refinery and petrochemical operations, even if this is only a long term goal (perspective integration).

International transport of vacuum column residues does pose both shipment and safety problems, although it is commercially transported. Like No. 6 fuel oil, vacuum residue can be shipped solid, but more often warm viscous transport might be necessary. For trade between developing countries in typical regions, the problem is greatly reduced. Solid residues poses safety problems because of a process called 'lensing' it has been known to explode.

VI. ETHYLENE

Introduction

In almost all of the processes discussed in this section, propylene is a co-product with ethylene. The term 'ethylene' can be generally read, in the technical passages, as a "stand-in"both for itself as well as for propylene.

Ethylene production has grown, as presented in the data below, from a relatively modest tonnage, of about 700,000 tonnes worldwide in 1950, to something of the order of 50-55 million tonnes today:

Unit: Million Tonnes[254]

	1950	1960	1970	1980
North America	0.64	2.5	7.9	19.9
Western Europe	0.03	0.7	5.9	18.4
Japan		0.08	3.0	5.8
Eastern Europe			1.1	5.4
Other countries		0.02	0.8	5.0
	0.67	3.30	18.7	54.6

While historical growth rates in the industrialized regions are indeed impressive (17 per cent 1950-1970; 12 per cent thereafter), they could be quite modest to the anticipated growth (in demand)

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[254] The figures between 1950-1970 are "demand" figures; that of 1980, "capacity".

in the developing countries (Tables 20 and 21 below):

Table 27

UNIDO Forecast of Developing Country Demand for Ethylene[255]

Unit: Million Tonnes

	1975	*1990*
Africa	-	0.30
N. Africa	-	0.80
W. Asia	-	2.65
Asia	0.25	3.80
China	0.30	1.40
Latin America	0.60	5.00
	1.15	13.95

Table 28

Forecast of International Ethylene Consumption[256]

Unit: Million Tonnes

	Consumption in year 2000	*Capacity needed*	*Capacity added by 1.1.1986*
Developing Nations	15.8	17.3	5.6
North America	29.1	12.9	2.6
W. Europe	21.0	6.8	3.1
Japan	13.5	7.1	0.9

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[255] *"Second World-Wide Study on the Petrochemical Industry: Process of Restructuring (UNIDO) ID/WG.336/3, May 19,1980) p. 50*

[256] *"The Changing Pattern of Petrochemical Feedstocks to the year 2000 and Beyond', Reynolds, W.W. (Shell Oil) op.cit. Dr. Reynolds was interviewed during the Survey.*

Shell's data base:

GDP growth:		
	N. America	2.8% per year to 2000
	W. Europe	2.8%
	Japan	5.0%
	Latin America	5.7%
	Middle East	5.9%
	Africa	5.5%
	Asia	5.6% (including Australia)

Petrochemical Consumption Growth Rates:

Unit: %

	1980-1990	*1990-2000*
N. America	4.2	3.6
W. Europe	2.8	2.8
Japan	5.0	5.0
Latin America	9.4	8.6
Middle East	15.0	12.1
Africa	11.4	10.1
Asia	11.1	8.7

The capability of individual developing countries to meet national demand for ethylene from domestic production, particularly of countries which are petroleum deficient, is contingent on the following factors:

(a) The 'naphtha balance' in terms of the country's refining pattern (i.e. its surplus or deficiency after meeting demand for gasoline and/or middle distillates);

(b) The financial strength of the petrochemical industry to:

   (i) afford the high price of naphtha;
   (ii) wean it away in competition from its use as gasoline; and
   (iii) survive international competition for naphtha supplies.

While in developing countries the demand for motor fuel may not usurp, or very strongly compete with that of petrochemical naphtha in the short run, it should be noted that its present division between the automobile and petrochemical industries in the European countries and in Japan is one to one. Just as in these countries gasoline usage spurted after a slow start, it can do likewise in developing countries. The expectation is that the rate of consumption of gasoline will rise steeply in the developing countries in line with the standard of living[257].

Inter-product competition for naphtha is not the only dimension for developing countries. There is also an international dimension. As discussed in Section I, most industrialized countries with the exception of the United States are heavily reliant on imported naphtha because demand is in excess of domestic levels of production (in turn, because refinery configurations in the countries are oriented to middle distillates, mainly heating oils). Should, thus naphtha production in a developing country be inadequate to meet both chemical and gasoline demands, the country will have to compete for it in the international market-place with rich nations[258].

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[257] Motor gasoline growth rates:

United States	1.7%
W. Europe	2.7%
Middle East	8.0%
Africa	8.0%
South America	5.0%
Asia	3.5%

Source: "What World Crude Analyses Imply". Carter, C.P., op.cit.
Data for United States from Chem.Systems (United States)

[258] About 15 countries export naphtha, principally to the United States, Europe and Japan. The international trade is approximately 12 million tonnes. (Source: UNIDO Second World-wide Petrol-chemical study op. cit.p 226).

These factors not only work to restrain developing country accessibility to world naphtha but also to raise its price.

Operating costs of processes which employ naphtha as a raw material could also pose problems for developing countries. With the recent multi-fold increase in the price of naphtha, there has been a drastic reversal in the proportions of variable and fixed costs in the manufacturing cost of ethylene. Thus, for instance, between 1972 and 1980 the share of variable costs (principally feedstock costs) for a steam naphtha-cracker has risen from about 45 per cent to near 85 per cent today[259/]. Consequently, dependence on naphtha as feedstock also presents a high risk for developing countries in situations of underutilized capacity.

Thus, for these reasons, should technology not be able to provide viable alternate raw materials to naphtha, oil-deficient developing countries will be prevented both from enlarging their individual 'materials pools' through the production of plastics and from achieving a redistribution of their overall materials-mix consistent with well recognized price-performance-economy values in the plastics sector.

There are, fortunately, several promising technological developments, some relevant to developing countries. They can be broadly classified under two categories, those based on:

(A) low-cost hydrocarbons which are already in international trade; and

(B) non-conventional materials, only some of which are presently traded.

The following table classifies the two categories of development based on the feedstocks use.

A. New Technologies of ethylene production with conventional hydrocarbons.

1. Vacuum gas oil (VGO)
2. Vacuum column residues ('resids')
3. Heavy distillates
4. 'Whole crude'

[259/] Estimated from various studies in literature, including UNIDO's data presented in the First and Second World-Wide Studies on the Petrochemical Industry, UNIDO/ICIS.83 and ID/WG.336/3.

B. New Technologies of ethylene production with non-conventional materials

1. Methanol
2. Syngas
3. Coal liquids, shale oil and tar-sand distillates ('pseudo petroleums')
4. Chemical streams in modern refinery processing concepts.

While a major deviation away from petroleum raw materials cannot be expected in the next decade or so, there is already responsible forecasting that new feedstocks will enter the world scene by the year 2000. Two such forecasts can be cited here (United States situation). The first, made 7 years ago by Chem Systems, and the second, a 1980 forecast by Shell. These are presented below:

Chem Systems Forecast (1975)[260/] year 2000(for United States)

1. LPG/naphtha/gas oil	79 - 65%
2. Coal liquids	2 - 4%
3. Syngas	5 - 10%
4. Shale oil cracking	10 - 15%
5. Other	4 - 6%

Shell Oil Forecast (1980)[261/] year 2000 (for United States)

	1990-2000 (per cent of incremental demand)	
	Scenario I	Scenario II
1. From petroleum	65%	25%
2. From coal	27%	67%
3. Imports	8%	15%

Potential access to new feedstocks and technologies should also be measured against the forecast (again, of Shell Oil) that if developing countries wish to merely achieve self-sufficiency, they would have to build 35 per cent of all new capacity for ethylene for the next 20 years.

[260/] Petrochemical Industry Development, Facing the Next Transition. Spitz. P.H., + Gomi, S. (Chem. Systems) Chemical Economy and Engineering Review, March 1980, p.7.

[261/] Reynolds, W.W. op.cit. The scenarios are discussed in other chapters of this report. They are energy-related scenarios.

Technology Options in the Production of Ethylene

When one reviews the historical development of ethylene technology, one immediately sees a sequence of continuing change in the use of feedstocks and a lack of rigidity in the usage of raw materials. Thus, in the 1930s ethylene was contemporaneously produced by several methods, the dehydration of alcohol, the hydrogenation of acetylene and extraction (recovery) from coke-oven gas[262/]. The move to petroleum-based materials began in 1942 when British Celanese, in the United Kingdom, built a plant to crack gas oil (in vacuum) to obtain ethylene for the production of ethanol and acetic acid. In the late-1940s Stone and Webster engineered and built the steam-cracker (over six gas-oil crackers were operating in the United States around about 1950).

In Europe, in the immediate post-war period, Hoechst and BASF built plants to crack whole crude - the sand, coke and pebble crackers (then called "cokers") - which were operated commercially till naphtha took over in the late 1950s. In the corresponding period, United States companies moved to the exployment of 'natural gas liquids' (ethane mostly) with Gulf Oil establishing the first NGL cracker on the United States Gulf Coast in 1960. Later, co-feed crackers, with butane and propane supplementing ethane, were put into commercial operation[263/]. This was subsequently followed by growing dependence on naphtha.

The large success of naphtha emerges from two factors:

(a) its H/C ratio, as shown below, is close to ethylene

	Light Naphtha	LGO	Ethane	Propane	Ethylene
H/C Ratio (weight)	13.5-15	13.5	20.2	18.2	14.2

and

(b) in the early 1950s, its price was similar to that of crude; indeed cheaper than crude in the European market area. (Unites States industry relied on ethane because ethane had no alternative value other than as fuel (at natural gas price) and could be purchased against a small premium over its cost of extraction. Naphtha, on the other hand, had high alternate value as gasoline)

[262/] For example, till the mid-1950s DuPont operated a coke-oven plant from which ethylene was recovered for polyethylene.

[263/] Union Carbide Corporation commissioned research work with the United States Mellon Research Institute for cracking naphtha to acetylene, then a key product of the corporation. The project was a 'failure' in that pyrolysis yielded far more ethylene than acetylene.

In the relatively stable 15-year period, between 1960-1975, European and Japanese industry shifted from their early feedstock bases to rely on naphtha as a feedstock (for ethylene) and United States industry on natural gas liquids (NGL). Around 1975, however, several factors were at work among tl the use in crude prices and restriction in its supply, indicated that continued reliance on naphtha, or NGL, as prime industry feedstocks would not be safe or practical. New technologies, for new raw materials, would be required. If a survey is made of these factors, they would, on a region-wise basis, be as follows:

In the West European region:

(a) The need to import naphtha because domestic refinery configurations were heavily slated to middle distillates;
(b) The need to rely on Middle East sources which in European political perception appeared risky;
(c) The pre-empting of naphtha supplies by its requirements as gasoline, together with upward price movements in naphtha due to tightness of supply; and
(d) The growing dependence of European chemical companies on international oil majors who acted as on-shore suppliers of naphtha (to the chemical industry) in a situtation which oil majors were making inroads into the European petrochemical market.

In the Japanese region:

(a) Practically the same reasons as in Western Europe, with the situation more serious in that sources of supply, of both crude and imported naphtha, were located at vast distances from Japan;
(b) The lower 'affinity' between Japanese chemical firms and international oil majors which posed problems of assured supplies ('feedstock security'); and
(c) Intense competition within the industry arising from domestic oil companies forward-integrated into chemicals.

In the United States area:

(a) Recognition of decline in world R/P ratio of crude, and the real or cautious interpretation that availability of NGL will decline in the region; and
(b) Near certainity that with the phasing out of natural gas price controls, the price of ethane will sharply rise to international levels.

Two supporting factors for the emergence of new feedstock technologies would be:

(a) The need for 'recapitalisation' in the ethylene industry due to the growing age of crackers[264] (implying that new capacity should be in terms of feedstocks whose ratio of cost to total production is far more reasonable than in the extant case of naphtha); and

(b) The change in the relative prices (real prices) of coal and petroleum, favouring coal, which provides incentive to develop coal-based technologies.

New Technologies Using Conventional, or Near-Conventional, Feedstocks

Consistent with historical experience in technology evolution, new technologies can be expected to follow an in-between stage of technological development: 'hybrid' technologies which would link the conventional with the new. Two economic features that support the intervening stage are:

(a) Discoveries of natural gas (and NGL) and heavy petroleums which can act to feed conventional naphtha steam-crackers with supplementary feeds (LPG, butane, atmospherical gas oil, vacuum gas oil, etc);

(b) Tendency to diversify feedstock usage, partly on grounds of feedstock security (feedstock flexibility, actually) and partly because of changed price ratios among the petroleum fractions (as overall energy strategies change traditional ratios in the use of fuel oils, gasoline, diesel, etc[265]).

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[264] The average age of ethylene plants in Japan, as discussed in Section I, is about 12 years; in the United States, over 3 million tonnes of present capacity (NGL-based) is over 14 years old.

[265] Feedstocks for ethylene (United States, 1980)

	Contribution to ethylene capacity Per cent
Ethane	37
Propane	13
N-butane/refinery gas	4
Naphtha	24
Atmospheric gas oil	16
Vacuum gas oil	6
	100

Source: Feedstock Flexibility: Cracking butanes for Ethylene, Gurecio, V.J., Chemical Engineering January 26, 1980.

Technological change in the hybrid stage is more of an engineering nature than of process chemistry[266] - modification of furnaces and transfer line heat exchangers, of separation systems to handle more gas (or liquids), etc. Some process changes, otherwise 'established chemistry', is expected to be involved in preconditioning cracker feeds to upgrade H/C ratio, reduce metals and sulphur, etc.

Except for gas crackers, which would be of a 'greenfields' nature, the survey indicates that much of this hybrid technology would be applied to lengthen the life of ageing steam crackers (largely by oil companies in the United States). The use of feedstocks, such as AGO or VGO, would, the survey reveals, also be oriented to upgrading production economics rather than enlarging product tonnage.

A span of technologies are, however, being developed which are alternatives to tubular steam-cracking (conventional cracking). Among the prominent developments are:-

(a) The UCC-Kureha-Chiyoda Advanced Cracking Reactor (ACR) technology being developed to crack premium whole crude (particular crudes), atmospheric gas oil, or vacuum gas oil, which like other technologies of its type (Dow Plasma Cracker, etc), bring the hydrocarbon into very short duration contact with superheated steam or other hot substrates (as heated pebbles, plasma, etc), directly, so that hydrocarbon chains can be fragmented with minimum formation of coke (the basic problem

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[266] The survey indicates that very little of basic change can be expected in the design of the present-day 500,000 or 300,000 tonnes naphtha steam-crackers, even though the defect in cracker technology, that less than 50 per cent of feed naphtha is recoverable as olefins (i.e. all of the carbon in naphtha is not converted to carbon in olefins) is recognized. Equally, while it seems obvious that the fractionation (olefin recovery) systems follow distillation technology of 50 years ago, no breakthrough technology for alternative separation systems has emerged. The resistance of the naphtha cracker to change is also explicit from the fact that between 1970 and today ethylene yield has moved barely from 27 to 31 per cent. While energy consumption has reduced by some 20 per cent, it has been achieved with increased investment. Compressor size, and poor 'turn down' capability of large compressors limit larger single-stream plants than in use today.

which hinders the use of heavy hydrocarbons in steam-crackers)[267].

(b) Variations on hydrocracker technologies used in advanced refineries for dealing with heavy fractions that resist cracking (into lighter oils). Important among them are the Linde Hydroconversion[268] technology (catalytic).

Hydrocarbon Research's M-B-E thermal hydrocracker technology[269] and the Heurtey (French) recycle hydropyrolysis hydrocracker working at high pressure, etc. Unlike the direct contact crackers of concept (a) these technologies give higher yields of ethylene and lower levels of acetylene, while also producing lower levels of byproducts;

(c) Catalytic cracking technologies, differing from the hydrocracker-type in that an external supply of hydrogen is not required. They resemble concepts in Fluid Catalytic Cracking (FCC) in that short contact times are obtained coincident with high reaction rates[270]. Similarity also arises from built-in catalyst de-coking (regeneration) systems, etc.; and

(d) Thermal cracking systems for the use of resids being developed by Gulf Oil and Stone and Webster (regenerative type) and by Kunugi-Kuni (KK) using high temperature fluidized beds.

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[267] Economics of the ACR

	Basis: U.S. Gulf Coast 1979 III Qr	
	UCC ACR	Conventional steam cracker
	Deasphalted crude oil	Naphtha/gas oil 50/50
Capital		
ISBL	261 million $	260 million $
OSBL	180 million $	181 million $
		Unit: ¢/lb
Cost of Production		
raw materials	23.7	26.7
utilities	4.0	3.8
operating cost	1.7	1.7
overhead expenses	6.2	6.2
byproduct credit	(20.2)	(24.4)
net cost of production	14.2	15.4

Crude Oil at the rate of $ 18.75/bbl
Naphtha at the rate of $ 21.95/bbl
gas oil at the rate of $ 22.20/bbl

Source: Spitz and Gomi, op.cit. p.7

[268] These have been described elsewhere in Section II.

[269] These have been described elsewhere in Section II.

[270] See "Feedstocks from new petroleum-processing concepts" Catalysts will, of course, differ, thus altering product-mix and selectivity.

The processes enlisted above are, it should be noted, devised for particular types of feeds and for particular product slates. Thus, as Table 29 illustrates, the yields of tar/pitch in the ACR and KK technologies is very high; consequently the technologies have merit only if pitch (or coke) is a saleable premium priced product[271/].

Table 29

Yields in New Experimental Technologies

			Yields: per cent	
	ACR	DOW	Heurtey	Kunugi Kuni
	Arabian light Crude	Crude (un-specified)	Gas oil	Khafji vacuum residue
Cracker Product Mix				
Hydrogen	2.4	NA	(1.3)	0.5
Methane	8.9	14.0	22.1	8.9
Acetylene	4.2	2.3	-	0.2
Ethylene	31.8	25.2	32.9	14.4
Ethane	1.7	1.9	-	2.3
Propylene	6.1	8.3	19.2	7.6
C_4's	3.5	6.6	-	4.3
Steam cracker naphtha	10.9	23.2	14.0	7.7
Fuel oil/tar/pitch	24.1	15.7	13.1	52.3
Others	6.4	2.8	-	1.8
	100.0	100.0	100.0	100.0

Source: "World Petroleum Congress and Trends in Oil and Petro-Chemical Industries", Chemical Economy + Engineering Review Oct/Nov, 1979, p. 15.

[271/] Both UCC and Kureha have large carbon and graphite product operations and hence can use by-products to advantage.

New Ethylene Production Technologies with Non-conventional Feedstocks

Three entire sub-sections of this document (in Section II) are devoted to examining prospects for the utilization of non-conventional feedstocks: methanol, synthesis gas and the non-conventional hydrocarbon. One sub-section of Section II, in addition, is devoted to examining the optimal use of petroleum crude in a fuel-chemicals refinery (which would essentially be a non-conventional refinery).

In the following classification, comparison is presented, mostly on a techno-commercial basis, of using non-conventional materials for ethylene in relation to the understood features of naphtha.

As said earlier, while ethylene has been made the sole focus of this section, it needs to be recognized that in all of the technologies discussed propylene is a co-product. Hence the technologies are relevant to countries concerned with 'propylene balance'. However, the technologies would generally not be responsive to economic demands that propylene be produced at the expense of ethylene. In most countries it is found that propylene supply, from both chemical and refinery processes, is in excess of its demand for chemical conversion.

Concluding Remarks

Technologies utilizing non-conventional feedstocks, particularly methanol, together with the technology associated with the 'chemicals refinery', offer the most attractive prospects for oil-deficient developing countries should they wish to be self-sufficient in the production of ethylene. The survey reveals that new technological patterns of working with conventional, or near-conventional petroleum materials, would be only marginally applicable to oil-producing developing countries. Technology relating to the non-conventional hydrocarbons (coal liquids, shale oil, oil from tar-sands, etc) demand very high levels of investment and require, for economic justification, consumption levels characteristic of market in developed countries. Unless developing countries participate in consortium-type investment, locating production facilities at the sites of raw materials and participate in product-sharing, there is little scope for developing countries to utilize such technology (at least, in the balance of this century).

Left solely to economic factors, only the United States is likely to use, on a commercial basis, a non-conventional feedstock for ethylene in the coming decade. This will be syngas. This technology would be almost irrelevant to the situation of most developing countries (see Syngas).

Technologies for the direct production of end-chemicals, bypassing the intermediary production of ethylene, is emerging very strongly in the United States. However, such technology does not produce the chemical monomers which can be conventionally polymerized to materials as polyethylene, PVC or polypropylene[272/]. Hence, such technologies do not afford developing countries the opportunity of bypassing dependence on ethylene.

[272/] Monsanto's new development of making styrene from methanol and toluene, and Halcon's developments of making vinylacetate and methylmethacrylate (MMT) from methanol/syngas are exceptions.

Annex I

Fossil-Fuel on a Global Basis

For purposes of comparison of data presented in the various sections of this document, the following summarises the availability and usage of the fossil-fuel on a global basis:

Petroleum:	Currently proven reserves	- 90 billion tonnes (oil equivalent) (Not billion - 1000 millicn)
	Probably reserves	- 250 billion tonnes (oil equivalent)
	Oil-inshale (estimates of probable reserves)	- 500 billion tonnes (oil equivalent)
	Current (1978) annual consumption	- 3.08 billion tonnes OOE
Natural Gas:	Proven reserves	- 68,000 billion NM^3 (70.5 billion tonnes oil-equivalent)
	Probably reserves	- 95,000 billion NM^3 (8.5 billion tonnes oil-equivalent)
	Current annual consumption	- 1400 billion NM^3 (1.45 billion tonnes oil-equivalent)
Coal:	Economically Recoverable Proven reserves	- 800 billion tonnes (615 billion tonnes oil-equivalent)
	Probably reserves	- 7000 - 11000 billion tonnes (5400 - 8500 billion tonnes oil-equivalent)
	Current estimated annual consumption	- 2.35 billion tonnes

In common units, world consumption of these three forms of energy would thus be:

		per cent
Oil	-	48.5
Natural gas	-	22.9
Coal	-	28.6
		100.0

Annex II

List of Corporations Interviewed

The Federal Republic of Germany

1. Lurgi Kohle und Mineraloeltechnik, Frankfurt
2. Wacker-Chemie, Munchen
3. Bayer AG, Leverkusen
4. Linde AG, Munchen TVT
5. Uhde GmbH, Dortmund
6. Hoechst AG, Frankfurt

The United Kingdom

7. BP Chemicals, London
8. Imperial Chemical Industries, London
9. British Gas Corporation, London
10. Constructors John-Brown Ltd., Portsmouth

France

11. Institut Francais du Petrole, Rueil Malmaison
12. ATO Chimie, Paris
13. Produits-Chimiques Ugine Kuhlmann S.A. Paris
14. CdF Chimie S.A. Paris

Belgium

15. Solvay and Cie, Brussels

Italy

16. Montedison s.p.a., Milan
17. Euteco (S.I.R.), Milan
18. Snam Progetti, Donato Milanese

Japan

19. Sumitomo Chemical Co., Ltd., Tokyo
20. Chiyoda Chemical Engineering and Construction Co., Ltd., Tokyo
21. Idemitsu Kosan Co., Ltd., Tokyo
22. Mitusi Petrochemical Industries Ltd., Tokyo
23. Association of Petrochemical Industries, Tokyo
24. Chisso Engineering Company Ltd., Tokyo

Annex II (contd.)

The United States

25. SRI International, Menlo Park, Calif.
26. Chevron Chemical Company, San Francisco, Calif.
27. UOP Inc. Des Plains, Illinois
28. Celanese Corporation, New York
29. Mobil Oil Corporation, New York
30. Chem Systems Inc., New York
31. The Lummus Company, Bloomfield, New Jersey
32. Monsanto Chemical Intermediates Company, St. Louis, Miss.
33. Gulf Science and Technology Company, Pittsburgh, Pa.
34. Exxon Chemical Company, Florham Park, New Jersey
35. Shell Oil Company, Houston, Texas