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

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STUDY ON TRENDS IN TECHNOLOGICAL DEVELOPMENT IN THE PETROCHEMICAL INDUSTRY *

Prepared by

Mohammed H. Al-Shukri
UNIDO Consultant

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1. INTRODUCTION

Owing to a number of factors, the petrochemical industry has experienced, in a relatively short time an exceptionally rapid growth, fostering vast technological innovations, producing many varieties of consumer products and playing a significant role in international trade.

Moreover, between the 1940's and 1960's, the petrochemical industry became one of the largest industrial sector, providing an outstanding variety of chemical intermediates used for the manufacture of plastics, fibers, synthetic rubber and many other end products, offering many choices of substitutes for the traditional natural products at advantageous prices.

Tracing the evolution of petrochemical development it would be very difficult to select any single reason or factor which could be responsible for such a remarkable growth pattern and accomplishment in technological development. However, this spectacular progress may be attributed to a combination of favorable circumstances, including large demand, availability of abundant supplies of low cost feedstocks and many innovations besides other traditional industrial supporting factors.

During the period from its birth in the 1920's, rising to its glory prior to 1973, the petrochemical industry had witnessed a number of distinguished phases of growth and technological development.

Therefore, it is the objective of the present study to analyze the technological development of the petrochemical industry from its early days and throughout its different phases, identify the factors, motives, forces and incentives for such development reviewing the accomplishments already achieved, analyzing the impact of the oil crises on the industry in general and on the technology trends in particular and finally drawing from these certain findings and conclusions regarding its future prospects in both developed and developing countries.

However, in attempting to study any field of activity within the petrochemical industry, no matter how precisely defined and how narrowly bordered it is inevitable to overlap events and introduce other aspects which are seemingly irrelevant to the particular topic which forms the core of the study because of the industry's enormity, its involvement with numerous related activities and its international scope.

2. EARLY DEVELOPMENT OF THE PETROCHEMICAL INDUSTRY

2.1 Historical Background

The petrochemical industry dates back to the 1920's and 1930's when petroleum fractions were used by American companies to produce chemicals previously made from coal, molasses and wood. Several chemical and oil companies started to produce alcohols, ketones, ethylene glycol, vinylchloride, styrene and other chemicals from the olefins present in the overhead streams originating from refinery thermal cracking operations. The first production of ammonia from natural gas and the commercialization of steam cracking technology for the production of ethylene, propylene and butadiene from petroleum-derived hydrocarbons also occurred during this period.

Although the petrochemical industry is considered an American phenomenon, created by oil and chemical companies in the United States in the 1930's and 1940's, the technical origins of this industry are found just as much in Europe as in the USA. However, the petrochemical industry at that time was to a large extent made in the United States mainly because of the abundance of inexpensive gaseous and liquid petroleum feedstocks, suitable technology, large market and incentive for rapid development occasioned by military needs in the 2nd World War, which were followed by a consumer oriented boom that developed after the war was over. However, much of the technology, came from Europe and particularly from Germany which had built up a formaldehyde chemical industry over a 100-year period.1/

Many of the products that later became the most important "petrochemicals" were first made in Germany between 1900-1930, but from feedstocks other than petroleum. Phenol was commercially produced in 1901 by F. Raschig (Germany), ethylene in 1913 by Griesheim-Electron (Germany), ammonia by BASF in 1913, vinylchloride in 1930 by Wacker (Germany) methanol in 1923 by BASF and many others (Ref. 1/, p. xvii).

1/ Spitz P.H. "Petrochemicals, the rise of an industry", 1988, p. xi, xvii.

Although, after the end of the 1st World War the organic chemicals industry made substantial headway in Britain, France, USSR and the United States, leadership in innovation and commerce remained with Germany until the beginning of 1940. The discovery of the Texan oil fields in the United States in the 1920's, what 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. In the meantime, US chemical companies recognized the value of reactive petroleum-derived hydrocarbons and came up with a number of industrially significant processes to produce the originally coal-tar-derived chemicals more inexpensively in much larger quantities. Europeans in the meantime concentrated on synthesizing molecules from available coal-derived feedstocks, which largely involved aromatic chemicals.

Moreover, while many developments were taking place in the United States where crude oil destillates and natural gas were amply available at very low cost, the petrochemical industry also owes a great debt for its uses of chemical technology originally developed in Europe, such as the hydroforming of naphtha fractions to produce BTX aromatics, hydrogenation technology in general and the application of low-temperature separation technology using refrigerated cycles.

In order to support the 2nd World War efforts, many processes were developed and many plants producing chemicals and resins were constructed. After the war, demand for new material rapidly rose and a real development of the industry started where many technological advances had occurred in most of the petrochemical areas.

Efficient processes for larger plants were commercialized, providing great improvement in economics of manufacture "economy of scale", and the number of participants increased in each industry segment creating a highly competitive atmosphere which was quite different than prevailing before the war. As a result, petrochemical prices declined while prices of other goods were rising and the profitability of manufacture of bulk petrochemicals and commodity plastics suffered accordingly. However, there were no obvious signs of slowing development in petrochemical process technology in all respects until the early 1970's.

In conclusion, the petrochemical industry had witnessed during the mid-fourties to 1970 many phases of technological development. In the earlier period the initiative came primarily from the availability of a new type of raw materials (oil and gas) and the demands of the market place (war materials and consumer goods). In the later phase, technology development was spurred by a combination of technological opportunities (such as advances in catalysis) and economic incentives. Thus, the petrochemical industry has grown within relatively short time from a tiny base within the chemical industry before the 2nd World War to one of the most important industries in the world, operating more than one thousand complexes in different regions with an approximate output of US$ 350 billion.

From early 1970 until about mid 1980 the industry was seriously affected by two oil shocks, and a general economic recession prevailed in the world after the second oil crisis in 1979. The glorious rise of the petrochemical industry had turned down to low demand/growth and poor profitability, consequently the industry ran through a serious cutback in research and development activities. In order to adjust itself, the industry followed a series of restructuring processes which will be reviewed in this study, resulting in a relative state of stability today. Demand lately showed reasonable growth, profitability is rising up and research and development revived.

One of the most important features of the petrochemical industry today is the increasing awareness of environmental effects of the industry which would have a significant influence on future development, a case that was somewhat overlooked during the early phases.

The objective of the present study is to study the impact of emerging technologies on the future development of the petrochemical industry at both ends: the feedstock required for the production of basic and intermediate petrochemicals on one end and the consumer products on the other. The industry's impact on the environment and quality of life is given special treatment since it is considered to be of special importance in view of the present pollution hazards.

2.2 <u>The need for new materials</u>

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.2/.

In the early period, the urgent requirements for the production of high octane gasoline blending components and for synthetic rubber brought about a surge of new process development activities and the construction of a large number of plants producing petrochemical intermediates for the US war effort. Major new thermoplastic resins were also produced at that time to serve the war needs, such as polystyrene and polypropylene, based on the already existing advances in the field of high polymers in the 1930's.3/ However, the real technology development came primarily as a result of the availability of a new type of raw materials, like oil and gas, and the demands of the market place. By the end of the war, a large and diverse petrochemical industry was in place providing the market with various synthetic substitutes for natural materials.

In the decades following the 2nd World War a tremendous growth occurred in demand for new materials which allowed not only the old chemical companies to move rapidly into the production of petrochemicals but also attracted a large number of new producers who were not easily able to enter the new industry during the war period because of the closely held technology. This combination of demand and availability of raw materials created a fertile environment for process development in the 1950's and 1960's. Therefore, at an early period of the petrochemical industry, technological advances were pulled by both demand and raw materials availability. During the later phase until the early 1970's, technology was promoted by other factors such as economic incentives (energy conservation) and technological opportunities (new products application).

2/ Arni, V.R.S. Emerging petrochemical technology: implication for developing countries, UNIDO/IS.350, p. 7

3/ Spitz, P.H. Technology trends in petrochemicals manufacture. Twelfth world petroleum congress, Houston, 1987, p. (23) 4

2.3 Availability of raw materials

In order to have a clearer picture of how the availability of raw materials initiated the origin of many petrochemical process developments and technological advances, an examination of the historical background has been found on many occasions to be a useful prerequisite.

First of all, the pattern of the industry's development has varied according to the geographic regions of the United States, Europe and Japan as a result of the differences in availability of various raw materials in each region, particularly from the petroleum refining industry. For example naphtha, which, at present, could not commonly be seen as a "by-product" in Europe, was abundant there in the early 1950's as a result of the European policy to construct refineries on the continent which were slated to the maximum production of middle distillates (diesel oils) and fuel oils (for power generation). This structure yielded large volumes of naphtha for which there was inadequate demand. Thus, apart from an alternative use as boiler fuel, naphtha presented itself as a potential feedstock for the chemical industry if it only could be economically cracked to ethylene.

European companies, such as Hoechst and BASF were already operating inefficient and size-limited "whole-crude" crackers in order to obtain ethylene; they were attracted to naphtha which was selling at a low price and ethylene was first produced by naphtha crackers. This also marked the beginning of the shift from acethylene, which was the major feedstock for PVC, vinyl acetate, acrylonitrile, etc. (Ref. 2/, p. 42)

In Japan, the situation was not much different from that at the time in Europe, since their energy was based on imported crude and their refineries were oriented in the early post-war years to the production of heating oils with better access to low-cost light crudes. Such a configuration yields large quantities of the co-product naphtha for which there was, again, inadequate demand as gasoline.4/

In the United States, the situation was quite different from that in Europe and Japan. Low cost crude enabled the United States to support an

4/ Second worldwide study on the petrochemical industry, process of restructuring, ID/WG.336/3, p. 261

energy-intensive high octane gasoline market, resulting in the co-production of large volume of butane and propylene, in association with high-octane gasoline blending stocks in fluid catalytic crackers (FCC). In a contemporary development in the United States natural gas liquids (NGL) and condensate, but more important their ethane component, became a surplus commodity as a result of energy industries exploiting low priced and associated natural gas from rich fields in the South. Thus, a major feedstock for ethylene, the building block for the petrochemical industry became more available (Ref. 4/, p. 260).

The 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 tubular processes for LDPE production. The technology-base for the exploitation of ethylene in the United States was, however, largely European. Thus, the United States ethylene-based industry developed rapidly, increasing ethylene consumption from about 115,000 tons in 1940 to 4-5 million tons by the mid 1960's. (Ref. 2/, p. 44).

2.4 Impact of surplus feedstock on new development

As a result of the availability of surplus feedstock, naphtha in Europe and ethane in the United States, both at a very low price, a major change in technology had occurred. European companies, who used to crack whole crude in order to obtain ethylene, shifted to naphta and the size of crackers began to increase rapidly. European chemical companies benefited from this shift to naphtha cracking, not only from the angle of low-priced feed offered to them, but also from the significant gain 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 supporting its greater adoption as a basic industrial raw material.

Thus, vast economies were achieved in the production of basic, or "first generation" petrochemical raw materials.

While acetylene, as was mentioned before, was, since 1940, the major feedstock for volume chemicals such as PVC, vinyl acetate, acrylonitrite, polychloroprene, acrylics, trichloroethylene, etc., ethylene became a strong competitor to acetylene through the 1950's and 1960's. Consequently, the rapid growth of downstream petrochemicals has raised the rate of growth of the chemical industry about three times faster than the rate of the aggregate industrial growth.

As for propane/propylene and butanes/butenes technologies, however, major and unique contributions have emerged from American industry, thus enabling it to compete with its energy counterparts for raw materials. Further American contributions to petrochemical technology are Sohio's ammonoxidation of propylene to acrylonitrite, 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.

2.5 Development maturity

The development of the refining and energy industry during the 1950's and 1960's offered an opportunity of cheap hydrocarbon by-products to the petrochemical industry, which developed at a rate of 5 to 7 per cent points over and above the growth rate of GDP, providing the market with highly attractive substitute, on economy performance basis, to traditional materials and products.

During this period the outstanding development of products/processes was accomplished. Most of these early technological developments originated in Western Europe and the United States and were quickly diffused in the market economy developed countries. The industry had achieved a high degree of maturity and no new major breakthrough was expected either in products or processes within medium term. Any development would principally be directed towards improvement of processes and operation conditions.

2.6 The role of the market and economy of scale-shifting scene

The petrochemical industry was the fastest growing sector within the chemical industry. During the period 1950-1970 the world export of chemicals increased tenfold while the total world export increased by only half as much. Organic chemicals export increased during the same period 24 fold (in value), of which the export of plastics grew 32 times.

Due to the continuous decline in the unit value of organic chemicals, as a result of cheap oil prices, technological development, and economy of scale, the volume of the world export of plastics increased 76 times. The pattern of trade flow in petrochemicals reflected, to a great deal, the patterns of their production, i.e. high concentration in the developed regions. (Ref. 4/, p. 12-13)

The location of petrochemical feedstock sources in the past (1950's and 1960's) tended to coincide with that of petrochemical markets. Crude oil being easy and cheap to transport and reserves of natural gas were first exploited where proximity to a large market enabled the gas to be distributed by pipeline. It was in the most industrialized areas (United States, Europe, and Japan) that this growth of energy product markets first married up with that of the petrochemical market.

The decentralization of the locations of the world petrochemical industry, outside the main three industrialized areas, began prior to the first oil shock in the late 1960's with the first wave of investment in several developing countries, slightly changing the scene of the world structure of the petrochemical consumer markets.

The first developing countries to set up their own petrochemical industry were those which had both a refining industry and high local demand for petrochemicals like the Latin American and largely export-oriented countries such as the newly industrialized countries in South East Asia. Such countries first invested at the downstream end of the petrochemical industry (synthetic fibers, plastics, rubber) then tried to work back upstream to replace the intermediate products they had to import. Examples are the ethylene steam crackers built in Mexico in 1966 and in Brazil and Korea later on. 5/

5/ Energy aspects of structural change in the petrochemical industry, OECD, Paris, 7 June 1984, p. 103

3. DEVELOPMENT IN THE 1950's, 1960's AND EARLY 1970's

The period prior to 1973 may be described as the golden era of the petrochemical industry. This period was marked by rapid growth of markets, technological innovations, appearance of giant plants, and a rush of new entrees into the industry. The combination of these circumstances and the ample availability of feedstocks provided an exceptionally fertile situation for process development in the 1950's and 1960's.6/

Petrochemical production showed, between 1960 and the early 1970's in developed regions a rate of growth varying between 10 per cent and 17 per cent per annum (ethylene 17 per cent, propylene 16.5 per cent, benzene 13 per cent, and butadiene 10 per cent), while total industrial production rose during this period by only 5.6 per cent and chemical production by 9 per cent a year. In terms of volume, production went up for ethylene from about 3 million to 24 million tons, for propylene from 1.6 to 12.4 million tons, for benzene from 2 to 11 million tons, and for butadiene from 1.1 to 3.7 million tons. This spectacular progress was due to the combination of favorable circumstances, which were basically:

- Rapid general economic growth sustained by a large number of innovations and accompanied by major shifts in pattern of demand primarily towards the chemical industry which is one of the industrial sectors to have shown the largest expansion during the 1960's.

- Technical and economic factors whereby the petrochemical sector featured prominently in the growth of the chemical industry. Research and development in the petrochemical sector, or downstream of this sector, made it possible to multiply the uses of products derived from processing hydrocarbons and therefore created the technical conditions for including new demand, which could be met in the context of general economic growth or substitute demand. The availability of abundant supplies of relatively low-cost raw materials made it economically possible to develop demand of this kind on a large scale. Owing, above all, to the relatively low level of prices of chemicals, substitution of the synthetic products of organic chemistry for natural products was, in particular, very high.

6/ Chemical and engineering progress, July 1988, p. 26

In general, ethylene production showed the largest growth in the developed countries as a whole with an annual rate of 17 per cent (35.[illegible] per cent in Japan, 22.5 per cent in Western Europe, and 11.5 per cent in the United States). Growth of propylene production was almost of the same order, while overall growth of benzene production was slightly below the rate of ethylene and propylene. Demand for butadiene rose less rapidly than demand for the other three products (at an annual rate of 10 per cent). The lowest rate of growth in butadiene was in the United States 5.2 per cent compared with the rate of growth in Japan 23.4 per cent and in Western Europe 17.7 per cent .7/

In general, the growth of the industry, because of its replacement of traditional material, was very high in Europe, the United States, and Japan, compared to the general indicators of economic growth.

Table 3.1. Growth rates 1965-1973

				Unit Per cent	
	Economy	Total Energy	Oil Products	Ethylene	Plastics 1960-75
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

3.1. Breakthroughs in technology

New technology in almost every petrochemical product area was developed during the period of the 1950's and 1960's by operating companies, engineering contractors and research organizations. These years were the most fertile for technological innovations in the industry, particularly in the development of processes for the production of the first generation products, ethylene, propylene and aromatics, chemical intermediates such as ethylene oxide, acrylonitrite, acetaldehyde, the fiber intermediates, and most important, the polymer materials (high density polyethylene, polypropylene, suspension PVC and the elastomers, etc.), providing the market with highly attractive substitutes on a cost/performance basis for traditional materials and products.

7/ The petrochemical industry - Trends in production and investment to 1985, OECD, Paris, 1979

Technology innovation during this period was particularly characterized by the scaling up of plant sizes, simplified processing steps, and greatly improved specification in the action of catalysts, their efficiency and life. (Ref. 4/, p. 273)

Table 3.2 Presentation of the evolution of typical sized production units from 1955 to mid seventies for same significant products in 1000's tons (Ref. 2/, p. 29)

Products	1955	1960	1965	1970	1976
Ethylene	20	50	150	300	450
Styrane	10	30	50	150	450
Vinyl chloride	30	50	100	150	270
Acrylonitrite	10	15	30	60	180
Ethylene Oxide	5	10	20	70	135
Low density polyethylene	10	30	50	100	100
High density polyethylene	5	10	20	60	90

The commercialization of progressively more efficient processes in larger and larger plants provided greatly improved economics of manufacture. At the same time, the increasing number of participants in each industry segment created a highly competitive atmosphere, quite different than before the war. As a result petrochemical, plastics and synthetic fiber prices declined over the entire period even while the prices of almost all other goods were rising and the profitability of manufacture of bulk chemicals and commodity plastics suffered accordingly. Nevertheless, until the beginning of the 1970's, there were actually no signs of slowing down the development of more efficient petrochemical process technology, either through the use of better catalysts or through the substitution of alternate, lower cost raw materials in a different processing sequence.8/

Among the most significant break-through technology is the achievement of Union Carbide in the development of linear low density polyethylene (LLDPE) as an extension to UNIPOL process which was developed in 1968 (producing high-density polyethylene). Commercial production of LLDPE by the gas-phase, fluidized-bed process was started in the mid 1970's. This was a real turning point in the evolution of polyethylene technology.

8/ P.H. Spitz, Technology trends in petrochemicals manufacture, Twelfth World Petroleum Congress, Houston, 1987, p. 23, 24

LLDPE had physical properties which are superior to those of LDPE. For example, LLDPE films were stronger than LDPE films of the same thickness, film producers soon converted to LLDPE where they could reduce the thickness of their products while retaining equal or enhanced strength, thus using fewer pounds of polyethylene. By 1986, world total LLDPE capacity amounted to 5.13 million tons.

Table 3.3 Production capacity of LLDPE compared with other polyethylenes in 1986 in thousand tons/year

	LDPE	HDPE	LLDPE	Total
USA	3,175	3,252	1,916	8,343
Canada	305	318	762	1,385
Central and South America	1,128	468	280	1,876
Europe	7,141	3,883	811	11,996
Middle East and Africa	511	365	439	1,315
Far East and Australia	2,775	2,119	761	5,655
World Total	15,036	10,405	5,129	30,570

Source: Hydrocarbon technology international 1987

In the 1960's, terephthalic acid (TPA) was introduced by AMOCO as raw material for polyester manufacture and later on the pure terephthalic acid, replacing the DMT (dimethyle-terephthale). This route offered many technical and economical advantages to the polyester fibers industry. By the mid 1970, about 25 per cent of the world polyethylene-terephthalate (polyester) has been switched to use terephthalic acid TPA and by 1985 TPA use in the manufacture of polyester exceeds the use of MDT worldwide.

3.2 Creation of a truly global industry

While the petrochemical industry and its technology were concentrated in the developed countries and were held in the hands of a limited number of companies new patterns were set in the dissemination of technology in the second phase of their development (mid 1950's-1970) . Some firms decided to license their processes to others, very often including competitors, so that they could put higher returns on their research investment from a combination of manufacturing profits and licensing fees (royalties) than from exclusively internal use, although some operating companies continued the traditional industrial policy of using internally-developed technology only for their own benefit.

Moreover, good technology was also available from engineering firms, and therefore, manufacturing technology could be obtained from either operating companies and/or from research and engineering firms. Consequently, new technology has been broadly licensed. Hence, the industry was globally extended in spite of the fact that the increasing competitive environment brought a very low profit margin. Another factor which contributed to technology dissemination is that the exclusive internal use of new technology may not always be realistic for a large volume of products (such as ammonia, methanol, ethylene, etc.)

For products such as ethylene, propylene and butadiene, technology was basically concentrated in the hands of engineering companies which were eager to multiply the number of production units. In the area of most petrochemical intermediates (with exceptions such as acrylonitrite), effective patent protection was not feasible because specific utility (as with pesticides or pharmaceuticals) could not be claimed or because a variety of dissimilar production routes could be developed.

At the same time, privileged production through patent protection was not available for products such as polyethylene, styrene or PVC because their development had been government-funded or because they constituted public disclosures following the end of the Second World War.

Similarly, because of the anticipated costs of patent infringement suits, many companies continued imitating or copying technologies which were otherwise under the protection of viable patents (polypropylene).

In addition to other factors such as cross-licensing of patents (ICI and Dupont) technological diffusion occurred to the extent that it was not prohibited under the aegis of free enterprise economies within the developed market economy countries. (Ref. 4/, p. 262-263)

Thus, apart from the areas of far downstream products such as special plastics, pesticides, and pharmaceuticals, etc., upstream technologies such as those pertaining to naphtha cracking were available from engineering firms because the latter did not have a competitive interest in production, and technologies for intermediates became potentially licensable because of technology diffusion.

On the side of petrochemical producers, until 1973 a border line could fairly be realized between the market interests of oil majors and the chemical majors, even though some oil majors (such as Exxon and Shell) were very active in the chemical industries of Europe and the United States. In Europe, firms such as Hoechst, Bayer, ICI and Solvay were confident enough to avoid upstream integration, both with respect to refinery products and naphtha cracking. In the United States, too, firms such as Union Carbide, Dupont and Monsanto were prepared to depend on long-term supply contracts of ethane, propane and naphtha, but, compared to Europe, had integrated to the extent of having self-sufficient facilities for propylene and ethylene through ownership of gas and naphta crackers.

Before the seventies, demand exceeded production in most petrochemicals and commodity plastics and the number of producers was very limited (industry concentration by regions). Furthermore, in developed countries the industry was characterized as resource-rich, and in the user applications mostly as mature. This is compelling the companies into globalization using economies of scale if possible, integration, competitive technology and new products, new applications and advantageous secure feedstocks.9/

In fact the process of globalization is still ongoing due to the fact that, the petrochemical industry is particularly well-suited to the process of globalization as demonstrated by the growing inter-relationship between commercial groups across the international borders. To a large degree, petrochemical companies and groups follow a business strategy that co-ordinates an integrated operation throughout the world. They operate on basis of material of regional demand and they marshall raw materials, locate manufacturing plants, and supply customers according to the world-wide dictates of their market.10/

Today, decisions are mostly made on the basis of global considerations rather than what might benefit a single, home base. More particulars could be cited for the process of globalization of the petrochemical industry, because

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9/ Restructuring process in the petrochemical industry in 1980-1983, UNIDO

10/ James E. Fligg, US Perspective on petrochemical industry in Asia. Presentation at the Oil Dialy/International Herold Tribune Petrochemical Conference, Singapore, 16 June 1989 it lends itself to these processes, like globalization in trade and research and development, etc.

Another aspect of the industries globalization as a post 1970 phenomenon are the investments in foreign countries. The total foreign investment of the United States chemical industry was increasing during the seventies from US$ 2.9 billion in 1973 to about US$ 7.1 billion in 1979.

The largest share comes from European Companies (71 to 74 per cent). In a recently published estimate almost half of the people employed in the US chemical industry are working for foreign-owned concerns. At the same time US companies are making significant investments in other countries, as well as undertaking joint ventures with non-US partners.

Japanese chemical firms as well have taken steps since 1973 to establish themselves overseas in joint venture processes with Saudi Arabia's, Iran's, South Korea's, Alaska's, Canada's, and Singapore's petrochemical establishments.

4. ENERGY CRISIS: IMPACT ON THE PETROCHEMICAL INDUSTRY - 1970's and 1980's

The petrochemical industry which had long been one of the leading sectors in industrial development as described in Chapter III, entered a new, less favorable phase of its development in the 1970's, when deterioration in the conditions vital to its growth worsened further. The combination of several different causes, the increase in feedstock prices because of the two world oil-shocks, the slowdown in general economic growth, the saturation of major end-use markets and the associated emergence of new producers, especially in oil-exporting countries brought an era of poor profitability, low demand growth and slow rate of innovation.

The high oil and gas prices caused petrochemical prices to increase at a rate much faster then the general inflation rate. These higher prices, in turn, have caused petrochemical output to trail the growth in gross national product (GNP), and several recessions have also negatively affected petrochemical markets.

The lack of expanding markets meant less opportunity to use new technology, and the erratic nature of the markets meant higher risk in the development of new technology. Furthermore, many petrochemical products were getting more mature. As a result, there was a substantial slowdown in both product and process innovation after 1973 (see Figure 4.1). The main feature of the petrochemical industry associated with the oil crises in 1973 and 1979 and the world economic recession in early 1980's will be analyzed in more detail in the following sections of this study.

Figure 4.1 New process development in each decade of a product's life from the year of the product's introduction through 1974

Source: Chemical Engineering Progress, July 1988, p. 26-27

4.1 Shift in cost structure - increasing importance of feedstocks and energy cost in total cost structure

Although feedstock constitutes one of the most important elements for the development of the petrochemical indstry, this element was less evident during the earlier stage of the industry's development because of the limited demand for feedstocks in the total energy pool on the one hand, and the extremely low prices they commanded on the other hand. However, with the sharp increases in prices of oil and its derivatives the principal sources of raw material and energy for the petrochemical industry have, since 1973, completely changed the situation. After 1973, serious attempts were made to encourage a counter-movement toward coal utilization and other possible energy sources in order to reduce dependence on crude oil and its derivatives. The industry was no longer confident of obtaining its feedstock and energy requirements at the right price and quantity and still remain able to operate with a reasonable profit margin. Thus, the petrochemical industry was not easily able to transfer the increases in the cost of its inputs to the prices of its output (products) without affecting a serious drop in demand.

The tight supply of crude oil and subsequently naphtha, the main feedstock in Western Europe and Japan, also created a state of possible competition and a conflict between the two main sectors using naphtha, i.e. the motor fuel sector and the petrochemical industry.

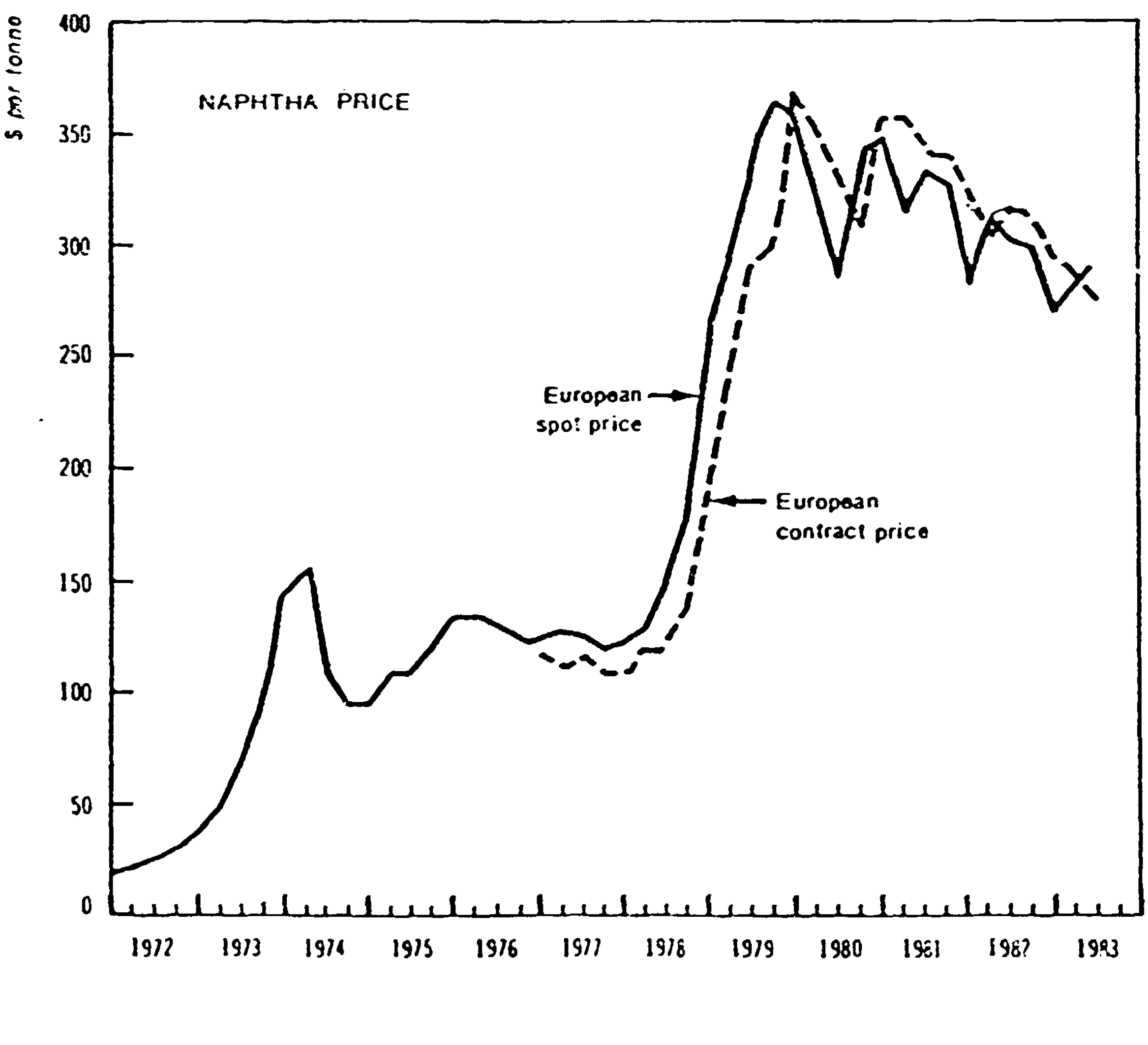
Such a situation intensified the search for alternative sources of feedstock and greater flexibility which would make possible the shift from one source to another depending on availability of supply and price differentials. (Ref. 4/, p.17)

The impact of world price increases in crude oil has not been the same in all countries and for all feedstocks. In the United States and Canada, oil and gas regulations buffering the pressure from the world energy market while in Japan, on the contrary, the pressure increased because of the priority given to consumption of domestic products in the framework of policy designed to avoid imbalance between supply and demand of petroleum products.

4.2 Naphtha prices

In the past, naphtha prices in Europe used to be about 1.3 times those of crude oil in times of price stability (before 1973). In 1973/1974, however, and again in 1978/1979, the figure rose to about 1.8-2.2. This was caused by a steep increase in crude oil prices and by crude shortage. Naphtha supplies were then insufficient, or at least it was feared they might be so. In the United States, where naphtha has less of a role of a petrochemical feedstock, naphtha prices were consistently below those in Europe and Japan, and the gap was particularly wide at the time of the oil shocks in 1973/1974 and 1979/1980. In mid 1980, for example, the average United States' price was about 50 dollars per ton below the average price paid by European producers, equivalent to an advantage of over US$ 100 per ton of ethylene. (Ref. 5/, p. 53) However, most of the naphtha in the United States is consumed on the captive market of the integrated oil companies, thus the open market has a minor role compared with the situation in Europe.

Figure 4.2 Naphta price development



4.3 Natural gas condensate prices (LPG and ethane)

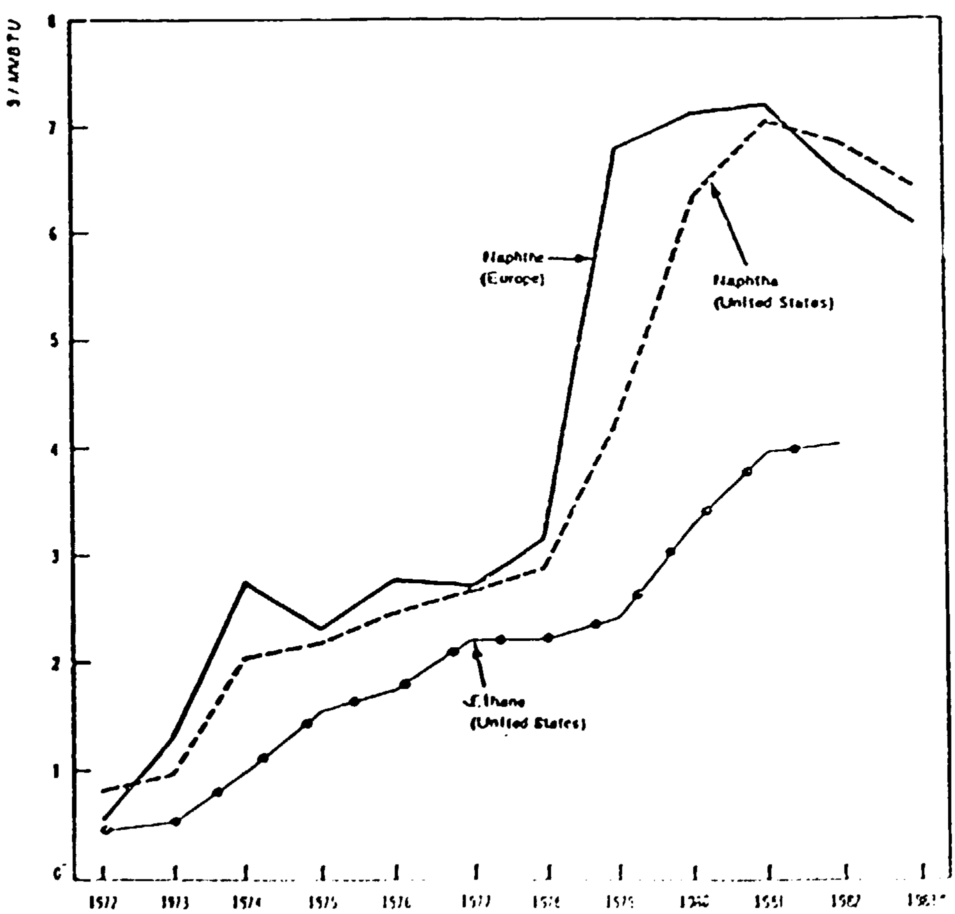
Natural gas condensate prices are almost as decisive for the overall economics of petrochemical production in the United States as are naphtha prices for petrochemical profitability in Europe and Japan. More than

12o-thirds of ethylene production in the United States is based on the use of condensates, especially ethane.

Ethane prices have always been much lower, in energy equivalence, than those of liquid refinery fractions, and the gap was widened at the time of the two oil shocks when it reached US$ 3 per million BTU which is about 40 per cent lower per BTU than the figure for naphtha. While the rate at which ethane prices increased was lower than that for oil products, it was, nevertheless, high (more than an eight fold increase between 1972 and 1981).

In fact, the feedstock price increases have badly shaken the entire petrochemical indstry. Everywhere, the industry was caught between the need to pass on the price increases downstream to safeguard financial viability and the difficulty of doing so to a sufficient extent in a time of economic depression. Figure 4.3 shows the relative trends in feedstock costs in Western Europe and the United States.

Figure 4.3. Relative trends in feedstock costs in Western Europe and the United States



4.4 Fall in profitability and decline in growth

Even before the oil crisis in 1973, there were, in fact certain signs of change in the favorable situation which the petrochemical industry had enjoyed during the 1960's. The first indications were associated with the market saturation for many petrochemical products, yet owing to the high level of general economic activity during the very early 1970's, its effect was not so noticeable. With the first and second oil crisis and the economic recession that followed, however, the situation was more pronounced.

Gradual saturation of the main markets coupled with slower general economic growth resulted in much slower demand. For instance, between 1974 and 1980, the aggregate output for the main petrochemicals (olefins, aromatics, plastics and synthetic rubber) in the top European countries (France, Germany, Italy, and the United Kingdom) rose only by an average of 1.5 per cent, a very low figure compared with the industry's growth during the 1960's which was over 10 per cent. Nevertheless, this rate of growth was still slightly better than that of the total industrial production over the same period (1.4 per cent). Trends in Japan and the United States exhibit, to a lesser extent, the same pattern.

Many causes of this process lie on both the supply and demand sides. On the supply side, there was the fact that many basic petrochemical technologies had matured in the 1970's, and the benefits to be gained by increasing plant size and energy saving procedures almost reached the limits. On the demand side, there was the narrowing of the field of potential applications, whether in terms of new uses or the replacement of other materials in existing markets because of their intensive exploitation during the previous 10-15 years.

Profits during the 10-12 years following the fist oil crisis lagged behind those of the earlier period (mid 1950's to early 1970's). In fact, the early 1980's was particularly disastrous. Profits of major US petrochemical manufacturers fell to half of their 1973 level, and estimates of losses of the European petrochemical industry in 1981-1982 ranged from US$ 5 billion to US$ 7 billion. In addition, a new factor increasing the gloom of the industry in industrialized countries was that countries rich in oil and gas resources began to manufacture petrochemicals primarily for the export.

Consequently, low profits, market maturity, and reduced demand for petrochemicals have, for some years, greatly dampened manufacturers' enthusiasm for the introduction of new process technology. For example, one of the international studies on the level of process innovation in the petrochemical industry listed nine petrochemical product innovations of commercial significance during the 1960's and a mere two in the 1970's. Another study confirmed these findings, naming nine important product innovations between 1961 and 1973 and only two between 1973 and 1982. (Ref. 6) p. 26).

The serious cut-back in process development activities was an inevitable consequence of the fact that the many companies involved were unwilling to dedicate scouting research money to new petrochemical process technology at a time of uncertainty. Thus much of the research budget was switched to process improvement and product development.

4.5 Shift in strategy

The petrochemical industry is one of the most energy-intensive industries. About two-thirds of the energy consumed by the industry (commonly natural gas, natural gas condensate and oil products) is used as feedstock for synthesizing various compounds and the remainder as a source of energy required for various processes, whether in the form of heat and steam or electricity for automotive power or electrolysis purposes.

It is, therefore, quite obvious that the rising cost of energy is of substantial impact on this industry. The increase in oil prices has radically changed the structure of the petrochemical industry in the main 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 increased cost of hydrocarbon and energy feedstocs together with other factors, mainly the market situation for bulk products, poor profitability, new environmental concerns, the increase in capacity and the imminence of new industry in developing countries occurring in the 1970's and early 1980's caused traditional producers to reappraise their petrochemical operations.

The issue of feedstock and energy cost have then attracted most of the attention of the industries. The trends were directed toward the search for cheaper sources of feedstock and energy (shift from naphtha to natural gas, possible use of alternative feedstock such as the return to coal or to feedstock of bio-origin materials, etc.), improving yields particularly by using new catalysts of higher activity and longer life, energy saving, shift to special products, and other measures which are often referred to as "industry restructuring".

4.6 Response of technology to new development

As was mentioned before, the main emphasis in technology development was directed towards developing alternative feedstocks, feedstock flexibility, energy saving measures and improvement of existing processes, as a response to the increase in oil prices, decline in demand and subsequent decline in profitability. On the other hand, while specific innovating firms have patent protection in essential processes and catalysts, there exists a pluralization of competing technology sources in individual products such as HDPE, LDPE, VCM, PVC and others. These technologies are owned by producing companies and thus the presence of the competitive market constitutes the principal motivating force for diversity of technology ownerships. Thus, the diffusion of technology in the market economy countries has mostly been through imitative development rather than through licensing. This characteristic enables each developer of the same product (or nearly the same) to add some superior qualities to it and thus capture certain consumers or segments of the market. An example of this is the latest development of linear low density polyethylene (LLDPE).

In the main petrochemical products (petrochemical building blocks), ethylene, propylene, benzene and synthesis gas, the technology was not expected to change much either in feedstock used, process technology, or scale of plants. Competitiveness may be more related to catalyst improvements, utility savings, integration and utilization rates rather than new plant design.

The most outstanding new development in technology is the conversion of methanol to olefins, aromatics and gasolines, which had attracted the attention of oil and chemical companies as well as producers in developing countries.

Besides the improvements in process technology, there have been gradual improvements in the mechanical performance of equipment and materials which, in turn, improved the efficiency in production and increased the scale of the plant, an example of which is the improved furnace design in olefins production permitting much higher conversion of feedstock to ethylene, the use of large centrifugal compressors in ammonia production, and the application of bi-metalic catylists and moving bed furnaces in aromatics production.

4.7 Feedstock promoted technology development and the shift towards alternative resources

Except in countries with ample hydrocarbon reserves, petrochemical producers were greatly concerned with the supply of feedstocks and energy after the sharp increase in oil prices in the 1970s and the consequent shortage and uncertainty of the feedstock supply. Strategies have been changed in the use of petrochemical feedstocks. Dependence of hydrocarbons that are particularly valuable in the motor fuels market, especially naphtha and gas oil, was lessened, and thoughts towards building flexible steam crackers to handle light feedstocks were considered (Naphtha & LPG, naphtha and NIG, etc.) especially in Western Europe.

This situation has promoted increased attention to the development of new feedstocks which could be summarized, but not limited to, the following technologies:

- technologies for utilizing "heavy end of the oil barrel" such as hydrocracking;

- production of synthesis gas from heavy oil fraction such as partial oxidation with concurrent development of downstream technologies for the production of oxygenated hydrocarbons as well as the olefins; such efforts also comprise the utilization of tar sands and oil shale which are particularly abundant in the United States and Canada;

- the direct cracking of crude and heavy residues for the production of ethylene (UCC-Kureha-Chiyoda high temperature steam infection process, the Lurgi and BASF sand and coke based cracking processes);

- direct liquification of coal through a diversity of hydrogeneration technologies (British Gas Corporation, Lurgi Kelloggs, Institute of Chicago, etc.);

- indirect liquification of coal resulting in higher alcohols, methanol, etc. depending on the process route;

- biomass - based technologies for the production of oxygenated hydrocarbons, principally ethanol;

- biogenetic mechanism for the direct production of petrochemical intermediates, such as ethylene and propylene oxides, ethylene glycol, etc. (Standard Oil, Monsanto, Dupont).

In practice, all these technologies, with the exception of those where the end-product orientation of which is methanol or the biomass/biogenetic processes, aim at obtaining feedstocks, which are identical to, or closely resemble those in current use and for which well-practiced technologies exist.

Among all alternative feedstocks, methanol has begun to show the promise of naphtha in practically all applications: as transport fuel (gasoline), as fuel and as petrochemical feedstocks. Methanol could be produced from a wide variety of sources, that makes it particularly important for the non-oil producing countries.

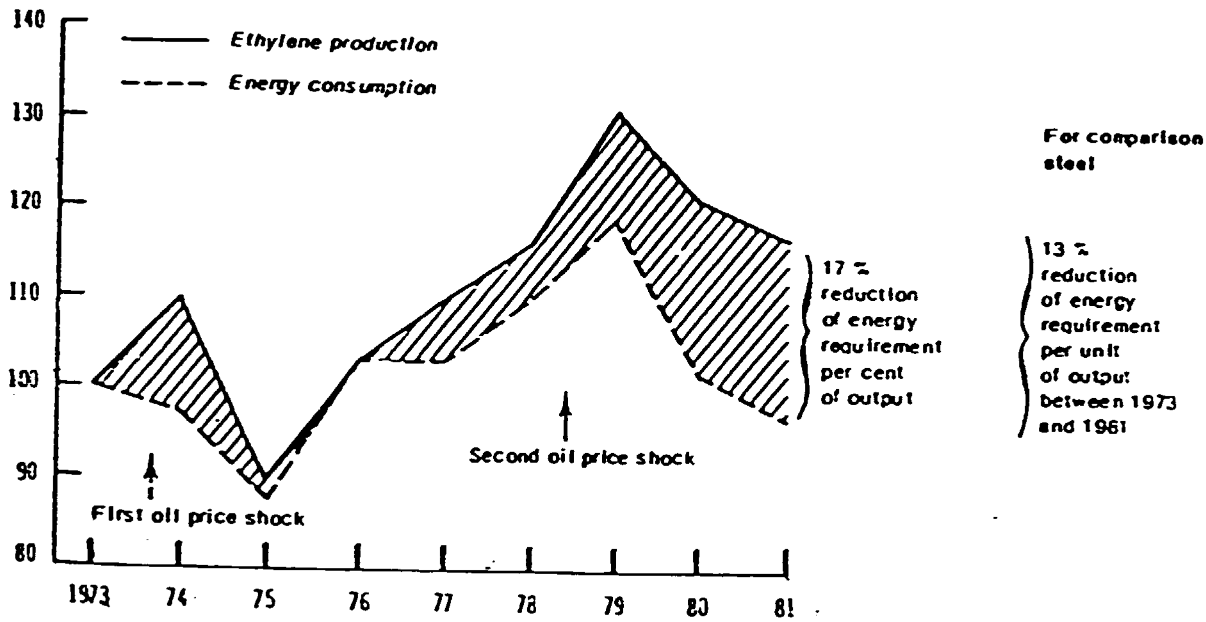
4.8 The promotion of energy saving technology

Petrochemicals are among the most energy-intensive products. The impact of the two oil price shocks was more or less confined to prices rather than the physical availability of the energy. Thus, the petrochemical industry met its requirements for energy, but at a higher cost. The combination of high energy and feedstock cost, slower economic growth, and consequently poor profitability of the petrochemical industry which prevailed after the oil shocks of the 1970's have created new trends in energy conservation in the industry. Measures were taken towards more rational use of energy and, to a certain extent, the industry successfully adjusted to the changed conditions in the relative availability of the various energy products by changing the kind of feedstocks used. The lack of adequate statistics made the analysis of trends in specific energy consumption by the petrochemical industry in the main production area rather difficult. Figure 4.4 illustrates the energy saved since 1973 throughout the OECD area. Moreover, it compares trends in ethylene production which was selected as indicative of the entire sector with those in total energy consumption (including feedstocks)by the petrochemical industry as a whole.

by the petrochemical industry as a whole.

The Figure below shows that the overall reduction in energy consumed per production unit was about 17 per cent between 1973 and 1981.

Figure 4.4 OECD petrochemical industry evolution of energy consumption (including feedstocks) and of production (100 = 1973)



Source: Energy aspects of structural change in the petrochemical industry, OECD 1984

Among the specifically energy related measures in the total energy conservation trends are:

- "housekeeping measures aimed at reducing energy losses without any major changes in existing process, such as, but not limited to, control leaks and heat losses, and others.

- process improvement - this line involves redesign of petrochemical processes to reduce feedstocks, fuel and energy consumption per unit of production. One example of this approach is the production of methanol where the original high pressure process was superseded by a low pressure process introduced in 1967 with a saving of 12 per cent in energy used for feedstock and fuel. The process flow was completely redesigned in 1974 to improve thermal efficiency and a further saving of about 11 per cent was achieved. After the second oil price shock, the distillation section of the process was redesigned to save heat energy, and further 6 per cent reduction in total energy usage was achieved. Another example is polyethylene where a new polymerisation process (linear low density polyethylene) which requires much less energy than previous processes, has recently been introduced and has spread rapidly.

- A similar approach has been taken for all the common large scale petrochemical processes, and much of the industry's capital expenditure since the late 1970's has been on replacing or improving plants for higher efficiency in the use of energy sources as feedstock and fuel. It should, in particular, be noted that computer control of processes has been extensively introduced.

- Another approach adopted was the total energy concept in the plant where waste energy was recycled for internal use.

4.9 Emerging role of oil/chemical companies

By the virtue of their control over hydrocarbon supply, the major oil companies emerged into the petrochemical industry as the largest beneficiaries from the post 1973 crisis. Due also to their high cash-flow position they were able to, enter into joint ventures with the major chemical companies which were seeking feedstock security and establishing their own new production facilities in the field of downstream operations, mainly basic, intermediate and some commodity petrochemicals.

The oil companies in Europe have initiated the primary petrochemical and main thermoplastics markets in the 1970's. Table 4.3 illustrates the share of oil companies in the total production capacity of European petrochemical markets.

Table 4.1 The oil companies' share of total production capacity in Europe in per cent (%) 1970 to 1980 (Ref 5/, p.95)

Year	ethylene	ethylene oxide	styrene	VCM	PVC	P.P	LDPE	HDPE	P.S
1970	50	23	24	9	16	29	28	20	-
1975	53	31	49	12	21	34	28	26	10
1980	60	42	51	19	21	39	41	29	18

In the United States, the oil companies' penetration into the petrochemical industry was growing rapidly as a sequence of OPEC's actions. Also, due to the fairly profitable chemical industry, the oil companies' penetration into petrochemicals become deeper. (Ref. 2/, p. 103)

Table 4.2 Petrochemical Company Penetration into US Petrochemical Industry a/

	Unit: Percentage of total capacity		
	1974	1978	1980 (estimated)
Plastics			
LD Polyethylene	39.5	43.3	45.9
Polypropylene	54.1	64.1	62.1
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
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

a/ The Myths and the realities of the oil companies' aggressive move into the chemical business, First Boston Corporation (United States) Oct. 1977.

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

- They had to compete with companies which are their raw material suppliers (naphtha, olefins, aromatics).

- 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.

- If the chemical companies wanted to maintain their traditional independence (from the oil companies), they would have to move further downstream into specialized products or they would have to seek feedstocks outside the control of the oil companies.

To the oil companies, the petrochemical industry, as was mentioned before, has attractive aspects for the following reasons:

- Commodities constitute the bulk of the industry's scales, which require for their marketing many merchandising techniques (rather than close technical support of clients as required by special products) with which they are more familiar.

- Oil producing nations, particularly the Middle East, realize that involvement in petrochemicals manufacture could give them access to oil (crude entitlements) besides opening up a world market to them.

- In an alternative energy industry they could co-produce materials such as syngas or enthane which had increased valorisation as chemical industry feedstock rather than as energy.

In Japan, the situation is completely different. 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, were largely absent in Japan. International oil majors (Exxon, Mobil, Caltex) are joint-venture subsidiaries of Japanese oil companies, notably Nippon Oil, Japan's largest oil company. But none of the majors is associated with ethylene production. The strong competition has prevented oil-chemical ventures backward integration and scale rewarding.

However, the Japanese government has created a pricing and distribution structure for naphtha which eliminates, to some extent, the need for oil chemical associations such as those of BASF-Shell and Bayer-BP in the Federal Republic of Germany.

Pricing of naphtha in Japan, under the "oil law" is on 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.

Since 1973, Japan's "big three": Mitsubishi Petrochemical, Mitsui Petrochemical and Sumitomo Chemical, have taken steps to enter joint-ventures overseas. Mitsubishi with chemical and oil companies entered a joint venture with SABIC-Daw Chemicals in Saudi Arabia, Mitusi entered a joint-venture with the National Iranian Oil Company, and Sumitomo with the Government of Singapore and a few private companies to produce basic and commodity petrochemicals.

Japan's petrochemical industry thus suffers serious deficiencies in respect to research and development capabilities caused by severe inter-firm competition which reduced the possibility of creating financial surpluses for long-term research as well as their own tendency to license out proven technology rather than experiment with "home grown" technology, and consequently any improvement they make will become the property of the licensors.

Therefore, Japanese firms have moved to sponsor research in private organizations in areas other than Japan such as the United States. Also, and under the guidance of MITI, Japanese Chemical firms, with a defensive attitude, have agreed to form research consortia such as chemistry groups whose objectives are to develop (non-oil) routes to commodity petrochemicals.

Finally, 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 defensive measures, the chemical companies subsequently developed some specialty lines and general chemical business.

4.10 Trends in locations towards feedstock and energy sources

Until around the late 1960's the effect of the factors governing the location pattern of petrochemical industry such as feedstocks costs and availability, enterprise strategy, government policies, technological features of processes, production cost structures, the nature and structure of markets and the cost of transport for products and feedstocks etc., was to concentrate all petrochemical segments in OECD countries.

Table 4.3. Share of OECD in the World Petrochemical Output in 1970
(Ref. 5/, p.102)

Primary Products	Per cent (%)	End products	Per cent (%)
Ethylene	90.3	Thermoplastics	89.5
Propylene	94.8	Synthetic rubbers	77.2
Butadiene	87.2	Synthetic fibers	86.4
Benzene	83.2		

Apart from the relative early development of production capacities in East European countries, decentralization (outside OECD) of the locations of the world petrochemical industry began prior to the first oil shock, in the late 1960's and early 1970's, with the first wave of investment in several developing countries. To a large extent, this trend arose out of the same rationale that had previously governed the swarming of petrochemical activities throughout the OECD area from their initial American and European centers, as local energy and petrochemical markets reached the scale that warranted investment.

The first developing countries to set-up their own petrochemical industry were those which had both a refining industry and high local demand (e.g. Latin America) or largely export-oriented such as the newly industrialized countries in South East Asia.

The 1973 oil crisis opened the door to a new type of investment in many oil and gas rich countries based on turning their national energy resources into the form of processed products, often intended for export. A number of projects of this kind came up during the few years after the first oil shocks, but it was only after the second increase in oil prices in 1979 that many of them really developed.

This new investment, significantly intensified the redeployment of petrochemical activities away from traditional production centers, and certain segments of the industry were redeployed towards primary feedstocks and energy sources, mainly natural gas. In many oil-producing countries (especially in the middle east) programmes for recovering associated gas were launched, the gas being used as a fuel or raw material for chemicals (methane for producing ammonia or methanol and ethane for producing ethylene) or exported in the form of LNG or LPG.

The development of ethane-based production capacities outside traditional production areas is considered one of the dominant feature of structural change in the petrochemical industry during the 1980's. As a result, major export centers for ethylene derivatives, Middle East/North Africa and Alberta, Canada emerged.

Table 4.4. gives an approximate picture of capacity growth of ethylene during the 1980's in areas other than traditional petrochemical production centers and Figure 4.5 indicates the changing distribution of Western World ethylene production name-plate capacity (1980-1990). (Ref. 5/, p. 117-118)

Table 4.4. Ethylene production capacity in million tons

Regions	1975 a/	1983	1990
Canada	-	1.8	3.0 - 3.7
Middle East/North Africa	0.06	0.5	2.4 - 3.5
Latin America	0.74	2.4	3.6 - 4.4
Asia	0.54	1.4	3.2 - 4.1
Remainder of Africa	-	0.15	0.6

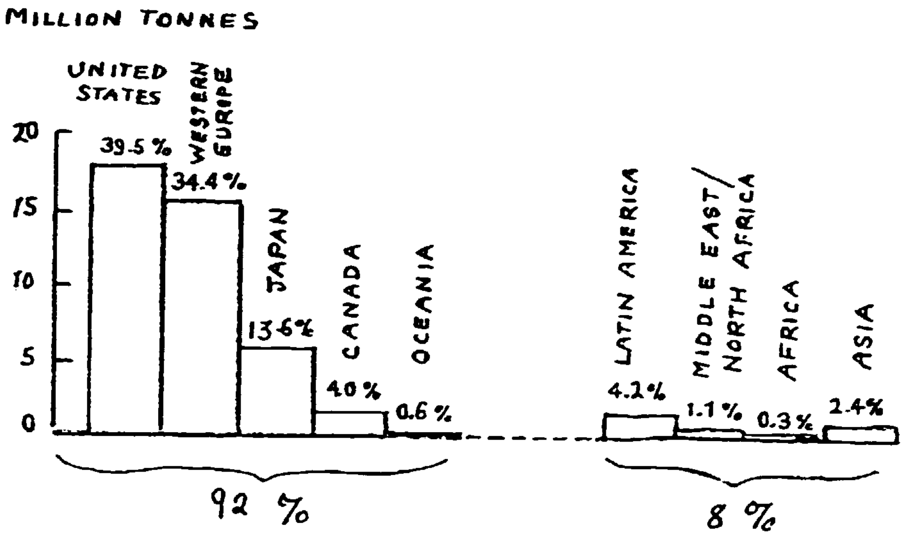
a/ Current world situation in petrochemicals, UNIDO/PC.126, 14 Nov 1985, (Annexes)

The share of these countries in the total world ethylene production capacity in 1970 was estimated at 1.8, in 1975 reached 3.9 and in 1983 approached 11 per cent and the forecast for 1990 indicates that ethylene capacity in the above-mentioned developing regions would be about 25 per cent.12/

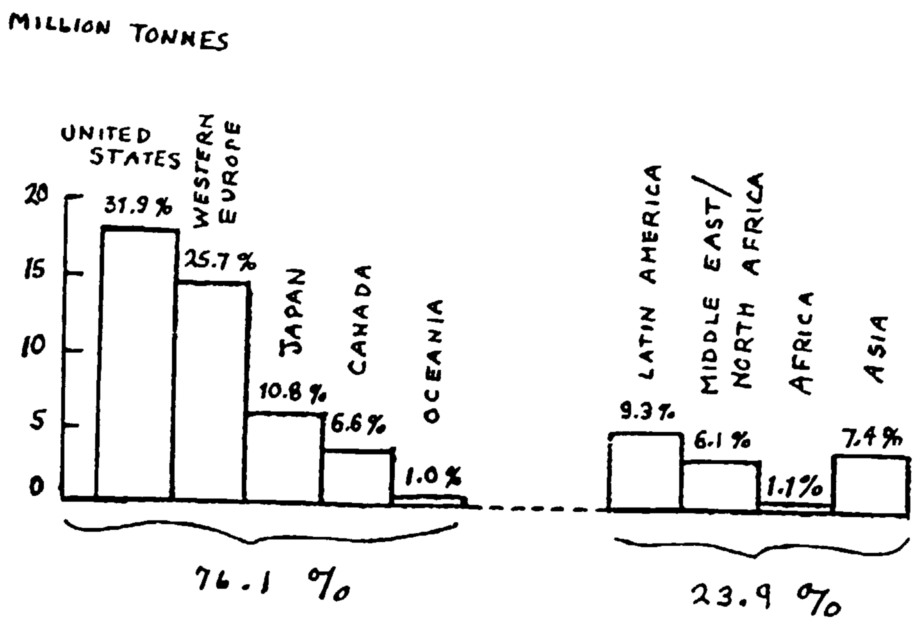
12/ Current world situation in petrochemicals, UNIDO/PC.126, 14 Nov. 1985, (Annexes)

Figure 4.5 <u>The changing distribution of Western world ethylene production name plate capacity</u> **(million tons)**

1980 - 1990



1990



4.11 The shift towards alternative resources

The attempts of the industrialized countries in adjusting themselves to the high prices and availability of hydrocarbons, did not stop at locating or developing regional access, but they were as well very much concerned with probeble shifiting towards alternative feedstock and energy. Thus, a need for new feedstock technology had also risen.

To the petrochemical industry, the non-petroleum hydrocarbons that were considered as possible replacement feedstocks, are coal, oil shale, tar sand and biomass. Reserves of these hydrocarbons are relatively large and the processes are mainly determined by extraction and processing costs, but coal is considered the most attractive of the alternative petrochemical feedstocks because firstly, it has the largest known reserves and a wide geographic distribution unlike tar sands and oil shale and secondly it has been produced for hundreds of years and the technology and infrastructure for its exploitation, processing and transportation already exist in most parts of the world, particularly in Europe. Coal is also produced at very low cost.

Although the present paper is devoted to the trends in technological development in the petrochemical industry, the close interrelation with energy sources leads to overlapping in many cases, where energy requirements and its alternative sources are discussed as well.

It is a fact that technical and economic efficiency is increased when coal is used jointly for energy production and petrochemicals. Petrochemical feedstock volumes are very small in relation to those used for fuel.

The other important area of modern research relates to alternative petrochemical feedstocks is the capability to convert methanol and synthesis gas to ethylene and propylene. The commercialization of this technology depends on methanol having a sufficient price advantage over existing feedstocks, particularly naphtha.

The conversion of methanol to ethylene may only be economic if methanol is produced on a large scale and it should find a market as a fuel by obtaining conventional gasoline from methanol. New Zealand and Argentina have a significant "M"-gasoline programme.

In the United States, any major methanol production would be based on coal, and the main problem for a coal-to-methanol development is the scale of investment needed for an economic size unit which would generally require the formation of consortia.

In Western Europe, the only country with the possibility for methanol from coal production is the Federal Republic of Germany. It has large reserves of coal, and the use of methanol as a fuel would reduce the reliance on imported oil. The other possible feedstock for ethylene and propylene is synthesis gas which again is normally derived from coal and it is the same as the case of methanol, for syngas to be a major energy source. The role of syngas as an energy is limited by high investment cost and pipeline distribution as well as technological problem relating to variation in the grade of coal.

Until recently, there was no really viable technology for ethylene and propylene production from syngas, there was not even a theoretical impediment to its development. In fact, the Fischer-Trapsch process, currently used in the Sasol Oil from coal plants in South Africa produces ethylene as a co-product with hydrocarbons. Shell oil's forecast revealed that by the year 2000, 8 per cent of the world's ethylene will be syngas derived. (Ref. 2/, p. 17-20)

In Japan, where the natural resources are limited, measures have been taken for the longer term, such as:

- synthesis of petrochemicals utilizing methanol and synthesis gas as feedstock (C_1 chemistry),

- conversion of barrel bottoms, including vacuum residue, to feedstock for olefin plants,

- increasing utilization of refinery by-product,

- diversification into high-technology fields such as electronics and biochemistry.13/

13/ A. Yomijama, Restructuring the petrochemical industry in Japan, Twelfth World Energy Congress, Houston, Texas, 1987

4.12 The refinery/petrochemical complex

The petrochemical industry, due to its technological structure, lends itself to integration, particularly vertical integration. The concept of refinery/petrochemical complex is an outstanding embodiment of vertical integration from the raw materials (hydrocarbons) to petrochemical feedstock (product of refinery) to basic, intermediate and finished petrochemical products in such a closed production cycle, where maximum benefit could be made of by-products

The 1973-1979 oilprices increase, the subsequent increase in feedstock prices, and the uncertainty of supply enhanced rapid involvement of major oil-companies into the production of petrochemicals taking advantages of their control over hydrocarbon resources. In the meantime and as a defensive policy, most of the major chemical companies moved further upstream to the hydrocarbon sources, alone or in joint ventures with the oil majors to secure their feedstock supply. Thus, several developed countries have created integrated/hydrocarbon/petrochemical national companies.

There are many potential links between the refinery and petrochemical industries. In the industrialized countries, there was a growing tendency to stretch petroleum (by making light-end product) so that two sectors of its use, transportation and petrochemicals, can be maximally serviced. Well proven refinery processes such as fluid catalytic cracking (FCC), hydrocracking and others were increasingly adapted. These processes have the capability to increase supplies of conventional petrochemical feedstocks.

Today, factors such as the growing adoption of catalytic 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 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.

Many examples could be cited to illustrate the inter-relation between refinery operation and the potential links to petrochemical industry. The main refinery processes, if we exclude hydrotreating and desulphurization, are:

- catalytic cracking,
- hydrocracking,
- isomerization, and
- alkylation.

Isomerization and alkylation are not so important to the petrochemical industry because they contribute mainly to upgrading the octane number, while catalytic reformation is important to both petrochemical and refining industries. Its prime function is to maximize mononuclear aromatics and branched chain paraffins.

The process operates multi-dimensionally:

- it dehydrogenates naphthenes to aromatics,
- it causes paraffins to undergo "dehydrocyclization" leading to the formation of ring compounds,
- it isomerizes straight chain paraffins to branched chain compounds,
- it splits off alkyl side chain from ring compounds, etc.

Thus, for petrochemical industry, the catalytic reformation is a source of aromatics. Several processes have been developed (as Shell's Sylpholane and UCC's TETRA processes) to extract aromatics. The raffinate of this extraction process is often an adequate steam cracking stock.

For the refining industry, the reformation is a key blending stock for high-octane gasolines.

Catalytic cracking and hydrocracking contribute a great deal to gaining values from high boiling point residues of the atmospheric column bottoms.

4.13 <u>Shift towards specialties</u>

To improve economies of operation, most of the petrochemical companies moved further downstream into the specialty products field where higher value-added and new market horizon could be accomplished as well as minimizing the volume of feedstock needs. Moreover, an era of so-called engineering and high performance polymers had vigorously entered the petrochemical market and experienced a relatively above average growth rate. Details on this new wave of polymers will be further discussed in subsequent fractions dealing with the industry's outlook.

5. REALIGNMENT OF THE INDUSTRY

5.1 Process of restructuring

Technology process has been a key-factor in the remarkable resilience of the petrochemical industry to changes in the conditions of the world market. The increases in feedstock costs were gradually but effectively neutralized by corresponding increases in total product yields and reductions in specific energy consumption in cracking operations. Likewise, the gradual maturity of a number of downstream petrochemicals has sparked a new generation of products. New plastics and other petrochemicals (rubbers and fibers) have all appeared in the world market with substantial advantages in production costs, improved performance and technical characteristics. A major innovation is constituted by the introduction of engineering plastics and high performance polymers, a trend which will be analyzed in more detail in the next sections. In the synthesis of polyolefins, technological development activities were related to the introduction of more versatile technologies; for example, processes capable of producing a wider variety of polymer grades. Other technological improvements were in lines of increasing catalyst activity and life span and the use of common co-moromers.

A further example of modifications in production technology is typified by the improvements in the production process for polypropylene and the displacement of LDPE by LLDPE. Three new processes for production of polypropylene have been commercialized in the last five to six years, and have resulted in reductions of total capital costs and significant yield increases, etc.. Other features of this restructuring process are that the large oil majors have asserted their presence in the petrochemical industry, mainly because they were losing their role in the management of oil; and that the chemical majors have been re-directing their investments to reduce the effect of competition in mature products and to insure new bases for their cash flow. Thus, chemical majors apparently have had new technological strategies in order to obtain a high degree of independence from oil companies in terms of access to raw materials and energy; such as the use of raw materials which could be acquired without involvement with oil companies, the most important being coal and methanol. The other strategy which could be described as "structural strategy" involved obtaining independent access to oil.

For example, Dow Chemical has acquired reserves to the extent of 600 million tons of brown coal and was constructing a 200,000 barrels/day refinery at Freeport, Texas. Monsanto, likewise, owned 30 million barrels of oil reserves and 600 billion cubic feet of natural gas and operated a 32,500 barrels/day crude plant at Conoco Oil's Louisiana refinery. Du Pont had completed the largest take-over (merger) in the United States history by its acquisition through majority control of Conoco Oil, a resource-rich oil company. It has also formed the Syngas Company in association with United States Chemicals to make syngas from heavy petroleum fractions.

The process of restructuring also opened a number of opportunities for international co-operation aimed at achieving a better co-ordinated global supply of petrochemicals, taking account of the needs and potentials of the countries concerned, and optimizing the use of resources which were wasted or left untapped, etc.

5.2 Capacity reduction, closures and plant idling

The beginning of the 1980's has seen a period of significant capacity reduction in the United States, Western Europe and Japan as the industry responded to conditions of severe overcapacity and stagnating growth in demand. As capacity expansion in the 1970's outraced demand growth, a situation of overcapacity was reached in 1980, with capacity utilization levels of 60 per cent in Western Europe, 65 per cent in Japan and 70 per cent in North America. These events forced all three of the developed regions to reduce capacity of the most affected petrochemical products, namely ethylene, PVC and low density polyethylene by restructuring. The net capacity closures between 1980 and 1983 in these regions amounted to 7,520,000 tons in ethylene, 1,550,000 tons in PVC and 2,920,000 tons in low-density polyethylene (Table 7.1). Obsolete and marginal plants were permanently shut-down while some old plants were revamped with the introduction of new technology and energy saving measures.

From Table 5.1, it can be seen that Western Europe has had the most capacity closures in volume as well as in percentage terms (20 per cent). Japan's reduction was second in volume but first in percentage (35 per cent), while the United States industry had shut down approximately 10 per cent of its ethylene capacity.

In Eastern Europe, the capacity and production figures did not change significantly between 1980 and 1983 with capacity utilization staying at about 80 per cent. In the developing countries as a whole, total ethylene capacity actually expanded during this period from 4 to 6 million tons, but capacity utilization was quite poor, approximately 60 per cent in 1983.

Table 5.1 Capacity Reduction in the United States, Western Europe and Japan, 1980-1983 a/

	Plant Closures 1000 tpa	Plant Closures % of total capacity	Plant Idling
Ethylene			
United States	1,700	10	3,800
Western Europe	3,750	21	250
Japan	2,250 a/	36	520
TOTAL	7,520		4,570
PVC			
United States	200	6	500 b/
Western Europe	860	14	
Japan	490 a/	24	
TOTAL	1,550		
LDPE			
United States	830	21	
Western Europe	1,820	27	
Japan	270 a/		
TOTAL	2,920		

a/ The plant closure figures for Japan include the planned closures up to August 1985

b/ postponed

On the other hand new ethylene capacity was expected to come on stream from petrochemical complexes which were already under construction in Saudi Arabia, Canada, and Mexico, a situation which has had the effect of changing the regional share of world capacity.14/

Nevertheless, the process of restructuring continued throughout the 1980's, and even at the relatively moderate and stable feedstock prices, some steam crackers in Europe were candidates for closures, although they could be saved by acquisition, but no producers were interested. Some of these plants are the steam crackers of CdF Chimie at Dunkirk and the Sines Complex of CNP, Companhia Nacional de Petroquimica.

14/ World changes in the structure of the petrochemical industry 1980-1983, UNIDO.PC/123, 9 Oct.1985, p. 6,8, and 19

ICI, also has made a 100 per cent withdrawal from polyethylene and has moved 50 per cent out of vinyl chloride monomer and PVC by forming a joint venture with Enichem, etc.15/

5.3 Specialization in product lines

With these new forces affecting the industry, and as another measure for restructuring, traditional producers were increasingly specializing in specific product lines, concentrating on products and activities where their strength lies instead of feeling that they must produce every product to stay in the market. More and more companies were trying to stick with what they did best, and consolidation of efforts became the order of the day. In addition, companies in the United States have turned to joining forces, as in Western Europe, restructuring has involved mergers and joint ventures to create more specialized companies and a more orderly marketing scenario.16/

The big chemical companies' main thrust was directed towards the specialty, high value-added petrochemicals, such as engineering plastics, industrial fibers, etc., abandoning slowly their dominant position in the bulk, low value added products. Research and development activities were also following the new scene.17/

6. THE SEARCH FOR NEW FEEDSTOCKS

As the petrochemical industry became almost totally dependent on petroleum-based energy and feedstocks, including natural gas, moving away from coal because of the extreme low prices and abundant availability of oil products, the situation was completely changed with the sharp increases in the price of oil and its derivatives since 1973. Upon the second oil shock in 1979, coupled with the tight supply of crude oil and subsequently naphtha (because of the competition of using naphtha in both the motor fuel sector and petrochemicals), the industry was not sure any more of obtaining its feedstock

15/ Chemical Insight No. 346, July 1986, p. 7

16/ Vervalin, C.H., Petrochemical Industry's outlook, Hydrocarbon processing, May 1986, p. 41-43

17/ The petrochemical industry in developing countries, Prospects and Strategies, UNIDO/IS.572, 24 Oct. 1985, p.47

and energy requirements at prices and quantities to keep it at a reasonable profit margin. Consequently, serious thoughts, attempts and actions were directed towards the search for alternative sources and greater feedstock flexibility which would allow the shift from one source to another depending on availability of supply and price differentials.

The alternative feedstocks for the petrochemical industry can broadly be classified into two categories: those based on conventional hydrocarbons such as natural gas and oil refinery products (light and heavy ends) and the feedstocks derived from non-conventional hydrocarbons such as those produced from coal, "tar sands", "oil shale", and from biomass origin.

For the first category, efforts were focused on:

6.1 Lighter products

Where the attitudes were directed towards access to lighter feedstocks, particularly by West European corporations, such as NGL, LPG and distillates from the North Sea oil fields, increasing imports of LPG from the Middle East and Africa and producing higher quantities of gas oil from refinery configuration (higher share of catalytic and thermal cracking). These trends would reduce the dependence of the petrochemical industry on naphtha and at the same time decrease the feedstock/fuel conflict. Thus, over the medium term, Europeans would introduce flexibility into their ethylene crackers so as to handle light feedstocks (the use of co-feedstocks, naphtha and LPG, naphtha and NLG, etc.).

Ethane is an obvious choice wherever it is available and its role will be predominant in the Middle East and other countries rich in oil and gas, while ethane is expanding in Europe, it is declining in the United States.

LPG is a very favorable alternative but its utilization will depend on its prices, as many other users compete for it. (Ref. 17/, p. 35-36)

6.2 Utilization of "Heavy end of the barrel"

There is, as well, international effort to use more of the "bottom of the barrel". The technology which accomplishes this is available and well-established in the United States, being rapidly employed in Europe and is gaining a foothold in Japan. This trend was particularly enhanced by the facts that:

- 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);

- OPEC's policy is to supply crudes in the proportion of lights to heavies as its reserves. Saudi Arabia, for example, supplies oil in the ration of 65/35 light/heavy;

- Most industrialized countries intend to hold petroleum consumption to levels of the late 1970's in terms of long-term planning, even though absolute petroleum consumption may increase in the interim, by adopting a strategy to stretch petroleum by making "light-end" products from the conversion of heavier petroleum fraction to lighter materials.

- OPEC countries are building very substantial refining capacity which would be net sources of heavy residues.

Technology for processing "bottom of the barrel" products involves using the "fractions" of atmospheric column and vacuum column distillation:

- Atmospheric column bottoms,
- Vacuum gas oil,
- Vacuum column bottoms (residues).

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 chemical refinery: catalytic cracking and hydrocracking.

Catalytic cracking is more important for petrochemicals, particularly its modern version, fluidized catalytic cracking (FCC), which is currently employed internationally and through which olefins are produced predominantly: C_3 and C_4. If the feedstock was fed hydrogenated, e.g. hydrogenated vacuum gas oil (VGO), ethylene yields would improve. In fact, apart from naphtha cracking (steam cracking), FCC is the sole source of the higher olefins (in the United States it is the major source). Whereas conventional FCC was oriented to maximize gasoline yield and the liquids/gases ration, new versions of the process provide the option to maximize olefinic LPG (Table 6.1). Because FCC catalysts are sensitive to sulphur, a hydrotreated feed is often required and, in turn, helps to increase the ethylene yield.

Table 6.1 FCC Yield structure, LPG maximized

	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	1,659	1,086
C_4 LPG	1,902	1,469
Gasoline, Fuel oils	5,075	7,215
Fuel Gas Compositon		
Hydrogen	11	13
Methane	42	37
Ethane	15	17
Ethylene	18	15
C_3S	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, tons/year	48,300	29,700
Propylene	221,100	148,500
Butylene	232,500	189,300

Developing countries may be able to utilize heavy bottom and residues as low cost sources of hydrocarbons. The residues and heavy bottoms could arise from various operations such as vacuum distillation, solvent deasphalting, thermal cracking, etc., and through uses of different kinds of crudes as "metallic" crudes, high-sulphur crudes, and asphaltic crudes.

Though, irrespective of sources, the developing countries could be able to utilize the residues, and such like by-products, in partial oxidation syngas processes (Texaco, Shell and other gasification processes) which have been widely practiced in the industrialized countries for several years.

For countries without coal, "bottom of the barrel" products would most often be the lowest cost source of hydrocarbons. Moreover, the transportation of these materials do not involve safety problems.

The second category of the non-conventional alternative feedstocks involves the utilization of coal, "tar sands", "oil shale" and biomass.

Since over 50 years, the industrialized countries have attempted to develop, and in most cases have developed technologies that would enable them to use anyone of the several hydrocarbon sources, such as coal, "tar sands" and "shale oil" on the basis of their strategic availability, relative prices and convenience but most of such technologies were somehow shelved because of the abundant availability of conventional energy sources arising from major discoveries of oil in Saudi Arabi (1951), gas fields in Algeria (1956), in Alaska (late 1960), North Sea oil gas (1963) and the Sibirian gas fields in the USSR (1965/1966) etc., as well as other factors such as rising living standards in the industrialized countries which moved workers out of the mines and increasing social development of environmental awareness.

With the rise in the prices of oil in 1973 there has been, for the first time since the war, a renewed drive in the market economy countries to examine alternative energy and feedstock sources and technologies (Ref. 2/, p. 189-190).

6.3 Utilization of Coal

The main activity in searching for alternative energy and feedstocks has been concentrated on the gasification of fossil solid fuels, mainly coal, to produce a synthesis gas mixture. The relevant processes have been well known since the 1930's and proven on an industrial scale. In the 1970's there was a great deal of emphasis in countries not members of OPEC and having substantial coal reserves, to develop technologies to convert coal-based synthesis gas to "petrochemicals" currently based on crude oil distillates or natural gas liquid. In some cases, this involved new approaches to older technology, such as carbonylation of formaldehyde to ethyleneglycol and in other cases, new process research to convert synthesis gas or methanol to such petrochemicals as ethylene, ethanol, styrene, paraxyclene, and vinylacetate. (Ref. 3/)

There is certainly more coal than there is oil or gas in the industrialized countries (including in this case, Australia, Canada, and South Africa) for principal reliance to be placed on it. Thus most of the technological effort has been to utilize coal. World coal reserve accounts for approximately 67.3 per cent of the proven fossil reserves with oil accounting for only 18.1 per cent and gas 14.6 per cent.

Table 6.2 World oil, gas and coal reserves (billion barrels oil equivalent) as of 1/1/1990

	Crude oil	Natural gas	Coal
North America (USA and Canada)	32	52	1,068
Latin America	125	51.8	72
Africa	58.8	53.3	316
Western Europe	18.8	38.4	431
Middle East	660.1	253.2	2
Asia-Pacific	22.6	49.5	324
CPES	84.1	312.6	1,504*
Total world:	1,001.3	810.9	3,717

* including China

Source: Several sources - for crude oil and gas mainly from gas and oil-journals, December 1989 issues, coal figure quoted from BP and AIEA).

Although there is a large number of processes for obtaining feedstocks for petrochemicals from coal, liquid and gas, the main obstacles of using coal or other alternative sources (tar sands, shale oil, and biomass) lie on the economic side. They are inherently more expensive, both in investment and operation. In the case of coal the main difficulties are connected with the following:

- the handling of big quantities which requires high investment;
- hydrocarbons from coal need hydrogen because of the low content or non-hydrogen in coal; and
- in general, efficiency with solids is lower in any chemical process than liquid.

As for the processes used to produce feedstocks for petrochemicals from coal, with the exception of the processes based on coal carbonization, which have been in use for a very long time to produce mainly aromatic hydrocarbons, all other existing processes produce ethylene precursors, such as: the Bergius process, the COED process (FMC Corporation), flash pyrolysis (Occidental Research Corporation), hydrogen donor solvent process (Exxon), H-coal process (Hydrocarbon Research Inc.), Fischer-Tropsch process, Mobil process, solvent extraction (National Coal Board).

6.4 "Tar sands" and "Oil-shale"

Other alternative hydrocarbons and energy sources could be obtained from the development of "tar sands" and "oil shale" deposits.

"Tar sands" or "oil sands" are sands containing very vicious hydrocarbons. The oil (tar) in the sands has to be extracted from the sand unlike the situation with petroleum which flows by its own pressure or by introducing pressure. There are some 3 trillion (3×10^{12}) barrels of oil in the world's tar sands, most of which are located in Venezuela, the USSR, Canada (Alberta), and the United States.

One of the major problems with tar sands is the high sulphur content of the recovered oil (3.5 - 5.0 per cent weight). The oil is highly aromatic and is consequently a good feedstock for gasoline. However, Canadian firms are using this oil for "petrochemical production".

"Oil shale" or oil in shale (rock) is a complex structure hydrocarbon, very much like asphalt. Its reserves are larger than tar sand according to Shell Oil investigations, and in its good deposits, the oil content would average 10 per cent. There are no technological impediments to using it as a commercial source of energy and/or feedstock. "Shale oil" extraction has been practiced for decades in Estonia. In Brazil and in China there are also small-sized recovery operations.

The naphtha from shale oil refining is highly paraffinic and thus leads to an excellent level of ethylene and propylene in conventional steam cracking.

6.5 Bio-origin products "Biomass"

Biomass (Bio-origin materials) as raw material for the petrochemical industry can be processed in several ways, namely fermentation, gasification, pyrolysis, hydroprocessing, and other chemical methods.

The only biomass derivatives for which the technology for conversion to usable chemical intermediates exists are ethanol via fermentation, synthesis gas via partial oxidation, and pyrolysis liquids via pyrolysis.

Fermentation is the oldest and best known route for both end products, alcohol and methane. Alcohol, a good starting material for petrochemicals, and once the main source for ethylene production, has been produced from sugar since the earliest days. Today this process is used on a large industrial scale to provide alcohol for motor fuel purposes, but research and development is underway to use cheaper raw materials such as starch and cellulose by biological means only.

Methane by fermentation of waste organic matter is also a well known process but it is suitable for fuel production on small scale and hardly serves as industrial feedstock.

From the economic point of view, the products of these processes which include synthesis gas, pyrolized liquids and ethanol are not in themselves generally considered commodity petrochemicals. Thus, further conversion to petrochemical products such as ethylene has to be examined in order to evaluate the economic competitiveness of biomass versus petroleum derived feedstock.

For example, ethyl alcohol could be obtained from fermentation of corn at a cost of 780 US dollars per ton (on the basis that corn be fed at US$ 230 per ton and corn straw for energy at US$ 35 per ton). To convert this to ethylene (1 ton ethylene requires 1.7 tons ethyl alcohol), the cost of ethylene would be around US$ 1,453 per ton.

In a country like Brazil using sugar cane in very large quantities, the position is much more promising where the cost of ethylene produced in this process was estimated at US$ 980 per ton at 1980 prices.

An interesting development in this field is the oxo-synthesis process used in the production of so-called oxo-alcohols for plasticiser production. Hydrolysis of wood or crop residues gives sugar, while the organic by-product is gasified to a CO-rich mixture. By a complex and interlinked series of reactions from the sugar and the CO-rich gas, vinylacetate or ethylacetate can be produced.

The major problems associated with utilization of biomass sources as energy and feedstocks for the chemical industry is the difficulty to collect the appropriate quantities (raw material), transport, and the logistic difficulties on the input side, together with low concentration of the products due to the biological processes which ultimately causes high cost.

Breakthroughs and surprises, and even revolutionary new results are expected from the biological routes, yet by their nature they would need a decade for commercialization and general acceptance.

6.6 Economic considerations

In conclusion, it could obviously be seen that alternative feedstocks for the petrochemical industry are available and the corresponding commercial processes exist to produce primary petrochemicals. Several industrial-scale plants are in operation around the world, research is going on, and new developments will certainly come out into view. But the actual utilization of any of these alternative feedstocks is critically related to the assessment that oil would become dearer and stay dearer than alternative resources and the production cost would be competitive. An estimate has been worked out to evaluate the economic view of these alternative petrochemical and energy sources, moreover, by treating all technologies in a unified manner, the following production cost for liquid fuels from coal, tar sand, and shale oil were estimated by Shell and updated by European Chemical News (1979).

Table 6.3 Production cost for liquid fuels from coal, tar sand, and shale oil

	Price per barrel of oil equivalent US$ (1979)
- liquid fuels from coal in the United States	US$ 30 - 37
- liquid fuels from imported coal in Europe	US$ 30 - 34
- liquid fuels from oil sands a/	US$ 15 - 25
- liquid fuels from shale oil	US$ 15 - 35

a/ already commercial in Canada

This data was based on the following coal prices:

	Price per barrel of oil equivalent US$ (1979)
- Indigenous coal in the United States	US$ 3 - 5
- Imported coal in NW Europe	US$ 8 - 14
- Indigenous coal in Europe	US$ 10 - 15
- (As reference, LNG imports into Europe)	(US$ 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.

Viability of these technologies is very much connected with the investment required. For "economic size" projects, the indicative data of Exxon and Flower show the following:

	Oil Shale	Tar Sands	Coal liquification
Plant size	50,000 bbl/day	150,000 bbl/day	58,000 bbl/day
Investment (billion US$)	2-3	3-4	4-5

Such investment levels could strain even the largest corporation (Ref. 2/, p. 196-198).

6.7 Role of specialties

The restructuring process which started actually in the mid 1970's and continued throughout the eighties has involved a series of measures to rectify the industry after the difficult period which it faced after 1973 to the early 1980's, one of which was the diversification in feedstocks, which was discussed above, and also the diversification in products, where producers in the developed countries felt that the market of most of the commodity petrochemicals became mature, the margin was narrow and the fields of new applications could hardly be expanded enough to encourage remaining happily with them. Thus, attention was forwarded towards specialties where the value added was higher and the area of applications was still not mature.

The standard plastics (PE, PP, PVC and PS) that account for 95 per cent of the total market and have a value of under US$ 2 per kilogram have reached market maturity, and only the higher-value engineering and high performance polymers are the products which are likely to experience above average growth because they are characterized by higher performance, high strength/stiffness, and heat resistance of prices of engineering plastics are considerably higher, ranging from US$ 2 to US$ 5 per kilogram. They comprise, for the sake of general classification, polyamide, polycarbonate, polyacetyl, polyphenylene oxide, polyester, and polycarbonate alloys, while so-called high-performance polymers comprise mainly polyarylate, polyether imide, liquid crystal polymers, polysulfone, polyethersulfone, polyphenylene sulfide, polyetherketone and polyacrylimide.

The development of engineering polymers is characterized by modification using filters and reinforcing materials and by alloying or blending polymers while high-performance polymers are characterized by the rotation of their mechanical and electrical properties, even at temperatures above 200°C, and their inherent flame resistance. The consumption of high-performance polymers is low compared with engineering polymers, but their prices are very high, at US$ 50 per kilogram or above.

In volume terms, high perfo.mance polymers account for less than 2.5 per cent of the total engineering polymers market and the largest single market is polyphenylene sulfide followed by polysolfone.

The major applications of engineering polymers, according to data available 1988, are listed in order of manner:

-	Transportation	27 per cent
-	Electrical and Electronics	22 per cent
-	Machinery and Industrial	11 per cent
-	Consumer and Recreation	11 per cent
-	Sheet and Film	10 per cent
-	Appliances and power toals	8 per cent
-	Monofilament	2 per cent
-	Other	9 per cent

World suppliers of Engineering polymers are still few and concentrated in America and Europe. General Electric stands as the biggest supplier, then Hoechst, Bayer, Dupont and BASF.18/

18/ Chemical Week, 1 November 1989

In Japan, during the period of 1978 and 1985, production of the five major engineering plastic resins (polyamide, polyester, polyacetal, polycarbonate, polyphenylene ether) registered an average growth rate of 14 per cent, compared with the 5.5 per cent of the five major commodity resins, LDPE, HDPE, PP, PVC, and PS. This trend encouraged the Japanese petrochemical manufacturers to push ahead with the development and commercialization of engineering plastics as specialty products of high added value.

The world's strictest quality and cost requirements for engineering plastics as demanded by Japanese end-users such as automobile and electric appliance manufacturers, have facilitated the improvement in the quality of domestic products, which has resulted in a considerable quality advantage over foreign products. Consequently, in fields of application with strict quality requirements very few imported products are now used.

Japanese companies have developed a number of technologies aimed at product differentiation, such as those for polymer alloy and block copolymers.

6.8 Role of composites

Composite material is defined as a composition of two or more materials that provide an end product with advantageous properties not usually available from one of the constituents in isolation.

The most important class relevant to the petrochemical industry is the fiber-reinforced plastics which development has taken a special direction in the form of unidirectionally reinforced composites for components subjected to high mechanical and thermal stress. Many polymers could be used in composite production as well as different fibers are practiced.

Among the conventional composites, the glass-fiber reinforced polyester is the most widely used for buildings and pipes, the raw materials are unsaturated polyester resins and different classes of glass fibers. Glass fiber-reinforced plastic industry is already over 30 years old and has grown continuously to reach.

The major markets remain in the industrialized countries (80 per cent), while about only 20 per cent of the world glass fiber-reinforced plastics is used in Latin America (9.3 per cent), Africa, Western Asia and others. The major applications in the United States and Europe are in marine, construction, corrosion resistance applications (tanks, pipes, etc.), transportation, etc. In Japan, there are major use-pattern differences, with more usage in housing and marine applications and low usage in transportation and consumer goods.

Recently, there was a dramatic growth of usage in Western Asia mainly for water and sewage (i.e. corrosion resistance). The utilization in other developing countries has also demonstrated progressive growth and will be increased when the need for substitution for conventional materials arises.

The most striking feature of the fiber-reinforced plastics is the development of advanced composite materials, using different kinds of fibers mainly carbon and aramid fibers.

Advanced composite materials using one or hybrid fibers find very wide utilization in a variety of industries: military air craft, helicopters, roter blades, space shuttles, wind mills and flywheels, sport equipment (tennis rackets, fishing rods, skis, canoes, etc.), commercial and military boats, commercial aircraft (the Lear Fan will be all plastic including much carbon or carbon/aramid, which leads to 30 to 40 per cent weight saving over conventional construction: the Boeing 767 uses around 3 tons of composites which form 3 per cent of the total structural weight, automobile construction which saves in weight and ultimately in energy consumption, and in mechanical engineering fields advanced composites give high specific stiffness and strength especially with carbon-epoxy composites which are ideally suited for dynamic applications in textile machinery and printing presses to increase speed and reduce noise.[19/] (Ref. 18/)

6.9 More new materials

In fields as electronics, computers, space, etc., polymers are used with special functions such as electrical conductivity or optical properties which are just beginning market life. Liquid crystal polymers (LCP), created a new dimension in high-performance polymers. LCP's have properties of liquids

19/ E. Anderson and B. Lux, Potential applications of composite material and associated technology in developing countries, 1986 (viscosity) and crystals (anisotropy). Such a molecular structure makes LCP's capable of withstanding much larger forces than conventional partly crystalline polymers. Applications, especially in the fields of electronics, include connectors, coil formers and resisters.

Another new class of high-performance polymers comprises aromatic polyether ketones thermoplastics (PEK) with the highest heat resistance and long-term service temperature. These materials, because of their outstanding combination of properties have led to a whole new series of applications: functional parts in hot water meters, components in the motor vehicle field, in container construction and apparatus engineering for the chemical industry, parts for electric motors, relays, and wire and cable insulations.

These polymers are not actually used only because of their mechanical and thermal properties, but they offer certain functional properties such as optical behavior or electric conductivity. Transmission of information by optical means is achieved through optical waveguides such as fiber-optic cables. Compared with conventional long-fiber cables, these optical systems have the advantage of lower attention, a higher data transmission, lower weight, and less susceptibility to interference.

Development of this market has been dynamic, and more recent advances aim at the substitution, chiefly polymethyl methacrylate (PMMA) for the quarts glass used so far to make the optical fibers.

Many other examples could be cited for new material being developed and their new applications, such as the use of high-performance polymers as photoresists in the manufacture of integrated circuits, etc.

As these special performance polymers are newly introduced in the global market, research is still functioning, but it is quite premature to see what would be the future, quoting the phrase of Mr. Akira Yomiyana, Asahi Chemical Industry Company, Japan, "History proves that the unexpected is always to be expected", may explain what are the limits.

7. ENVIRONMENTAL IMPACT OF THE PETROCHEMICAL INDUSTRY

Petrochemical Industry involves today more than 500 different processing sequences, mostly of chemical nature coupled with a wide variety of petrochemical products which leads to the generation of different air and water pollutants along with solid wastes resulting during the production processes or from the disposal of the used end products. These wastes may produce a variety of adverse effects on public health and the environment. Different processes yield different types of pollutants which could not all be cited here, but examples of which are: tar, hydrochloric acid, ammonia, carbon dioxide and carbon monoxide, sulphur dioxide, nitrogen oxides, hydrogen sulfide, cyamides, mereaptans, sulphuric acid, acetone, benzene, aldehydes, different hydrocarbons, oil, nitric acid, methanol, formaldehyde, carbon black, phosphoric acid, dissolved solids, caustic soda, calcium chloride, etc. Most of these wastes cause serious harm to humans and the environment, some of which are highly toxic even in micro-weights.

Biodegradable organic matter discharged to receiving waters may produce anaerobic conditions in the receiving water. This condition may kill or drive off any aerobic organism including fish and other higher form animals. Anaerobic decomposition may also produce odor and color problems.

Thermal pollution will also affect receiving waters, including death and decreased productivity of many aquatic species.

7.1 Toxicity and safety

The petrochemical industry handles many toxic and poisonous materials, highly inflammable, often explosive, hazardous substances in huge quantities and under extreme conditions of pressures and temperatures, which imposes, by its nature, a maximum of possible safety measures. Thus, a high degree of instrumentation and automation was always one of the main characteristic feature of the petrochemical industry.

While in other industrial branches, a less sophisticated and a lower degree of mechanization may be adopted to suit the conditions in some developing countries, particularly in lower investment cost and lower operation problems, in the petrochemical industry the process conditions impose the maximum quality of automation in any region for safety reasons.

Nevertheless, and inspite of very few spectacular and widely published accidents, the record in the petrochemical sector still is considered good. All accident rates, related to the number of working hours accomplished or to the product value, place this branch among the safest, inspite of the above-mentioned real hazards involved. (Ref. 18, p. 60)

It is important to mention, however, that with the increasingly strict restrictions towards pollutant emissions, solid disposals, and other environmental and public health hazards attributed to petrochemicals, the industry has been burdened with a great deal of expenditure and worry which may lead to a significant reappraisal of their future plans for the development of new processes and products. This is certainly not a call for lessening the importance of environmental protection and public safety which, by all means should be the top concern. However, these rules and the time table for their implementation as well, should be considered and applied in a way that would not hamper the development of the industry. Further details of the impact of environmental control on the future of the petrochemical industry will be given.

Moreover, the petrochemical industry continues to stress on the protection of the environment, with efforts centering on the safe disposal of tar, sulfur, nitrogen oxides, and individual toxic substances that may be produced in chemical plants. These potentially hazardous materials must be controlled in the air, water, and solid emissions from each plant. There is a continuing need for the industry to work with government regulatory agencies throughout the world as they develop allowable exposure limits, specify control procedures, and schedule their implementation.

The most important development in this field as far as the chemical industry is concerned is the focus by recent legislation on the identification and control of individual toxic substances. In 1976, the United States passed two major laws that attempt to reduce dangers of exposure to these materials. The "Toxic Substances Control Act" is aimed at removing the most dangerous existing chemicals from the environment and preventing the most dangerous new chemicals from ever being marketed. The "Resource Conservation and Recovery Act" deals stringently with disposal of hazardous wastes.

In Europe, a list of toxic chemicals of prime concern in waste water were proposed for control by the Council of European Communities, and approved by the European Council of Ministers. In Japan, stringent regulations have been developed to cover toxic substances which might contaminate the soil or water. In Canada, effluent control regulations that apply to the petrochemical industry are under development. Environmental control has been estimated to account for 10 to 15 per cent of total investment by the chemical industry, both in Europe and the United States.

In conclusion, the need to protect the environment is a top priority goal of the petrochemical industry. A substantial portion of research and development and capital investment funds are being allocated for this important objective, and the industry is working closely with governments around the world to achieve this goal.20/

With this public consciousness and government concern, the problem of the environmental impact of the petrochemical industry is very well controlled, expenditures are practically absorbed, and new plants will be integrated with all required measures for safety and environmental control. Thus, newly industrialized and developing countries will certainly benefit from these achieved results by the fact that they could obtain plants with the essential safety and environmental control measures already incorporated in the design, also at higher cost.

7.2 Biodegradable plastics - would it solve the problem of solid wastes?

While recycling of some plastic materials, like HDPE, PET, PVC and PS, which is still in its infancy stage, is driven by economical motives, public relations stunts and environmental legislation, the issue of using degradable plastics whether photo or biodegradable is almost strictly governmental- and social consciousness-driven.

In spite of the progress made by the recycling processes of plastics, which became a major part of the chemical companies operations, these processes involve a great degree of uncertainty because of many obvious factors such as collection, generic separation, level of prices of recycled materials, etc. The process is still in its infancy stage and its future could very much be tied up with development of collection and generic separation techniques and the need for alternative feeds.

20/ Mr. James F. Mathis, Exxon Chemical Co., Intensified use of petroleum and natural gas for petrochemicals

What does seem certain is that the plastics industry will have to actively respond - through recycling and other means - to public concerns about the solid waste problem. But a meaningful economically-driven solution is still not available.

The other direction to the solution of the solid waste problem is the production of degradable plastics in forms of photodegradability, biodegradability or others by adding components which make plastic products susceptible to degradation (photo- and biodegradation). The common biodegradable products are starch-based, and their use is increasing in composting bags, diapers and trash bags.

In the United States, about 289 million pounds of degradable plastics were produced in 1988. It is also projected that by 1993 it will reach a little less than 2 billion pounds, but in the year 2003 the United States' production of degradable plastics may exceed 8 billion pounds (plastics in litter and landfill).

Advocates of degradable plastics maintain that the technologies have, in fact, a variety of growing long-term applications. Photodegradable products, which are supposed to be exposed to sunlight, clearly do not solve the landfill problem, but they do help solve the litter problems. Polysar's environmental plastic group in Masachussetts, USA, markets a vinyl ketone copolymer that makes polyethylene and polystyrene degradable in sunlight.

Some environmental observers, however, raise questions about the performance of specific degradable plastics which are not delivered as promised. The matter is not to make a degradable additive, but to incorporate it in products that break down rapidly.

Finally, in view of the many questions raised, criticisms and uncertainties of the viability of recycling economy and the long-term effectiveness and impact and types of the biodegradable polymers, it is quite premature to draw any definite conclusions concerning the prospects of these issues before allowing some more time.

8. WHAT HOLDS THE FUTURE? 1990's

In order to speculate about the future, the past and present status of the petrochemical industry has to be examined. Accordingly, the evolution of the industry, from its early development, has been reviewed in some detail in the above sections up to the time of the mid-eighties where it began to show signs of relative stability and a brighter future.

With margins becoming above levels at which reinvestment is attractive, all producers simultaneously realized this fact, and consequently, petrochemical industry worldwide is currently on the threshold of a major investment boom. About 29 ethylene plants were awarded between 1986 and 1989, and almost as many are revamped or debottlenecked. A similar situation may be applied for almost every major derivative.21/

Reduced demand growth and low profits which dominated the industry in the late 1970's and early eighties have dampened the manufacturers' enthusiasm for new product technology. Many routes for the production of key petrochemicals are close to their limits in catalyst efficiency and reactor design, and long-term decline in innovation has been occurring in petrochemical-polymers as well as -monomers, which suggests that limits of technology are being approached and further research and development spending may yield meager results. These phenomena are consistent with the fact that many of the major petrochemical product lines are a number of decades old. Although there have been major changes in processes (for example, the change from solution-based polymer processes to gas-phase processes and the use of

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21/ Philip Leighton, Petrochemical Investment - Are we headed towards overcapacity?, London, Trichem Consultants Ltd, 4 July 1989

Figure 8.1 <u>Index of real domestic demand 1970 - 1988</u>

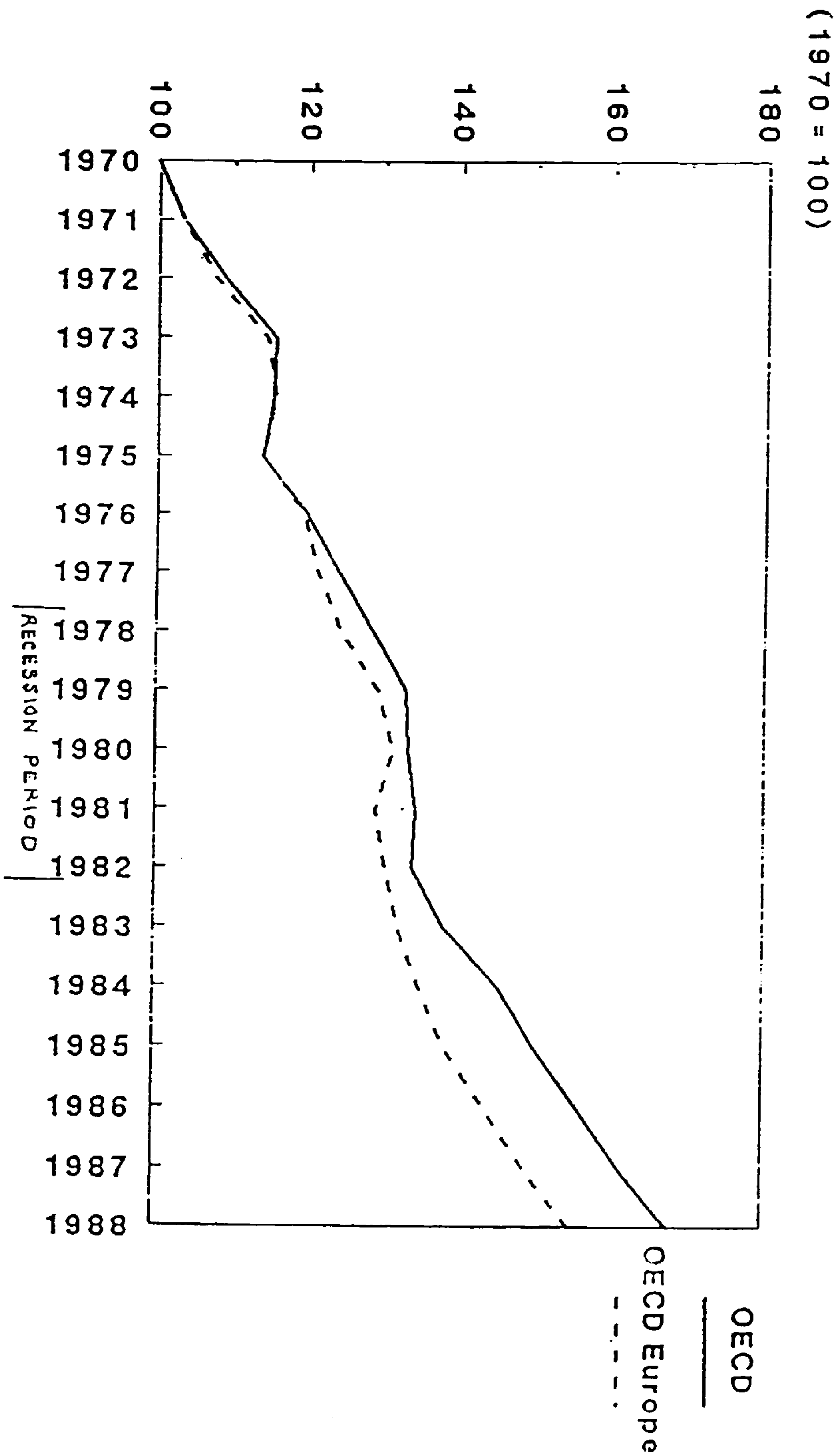
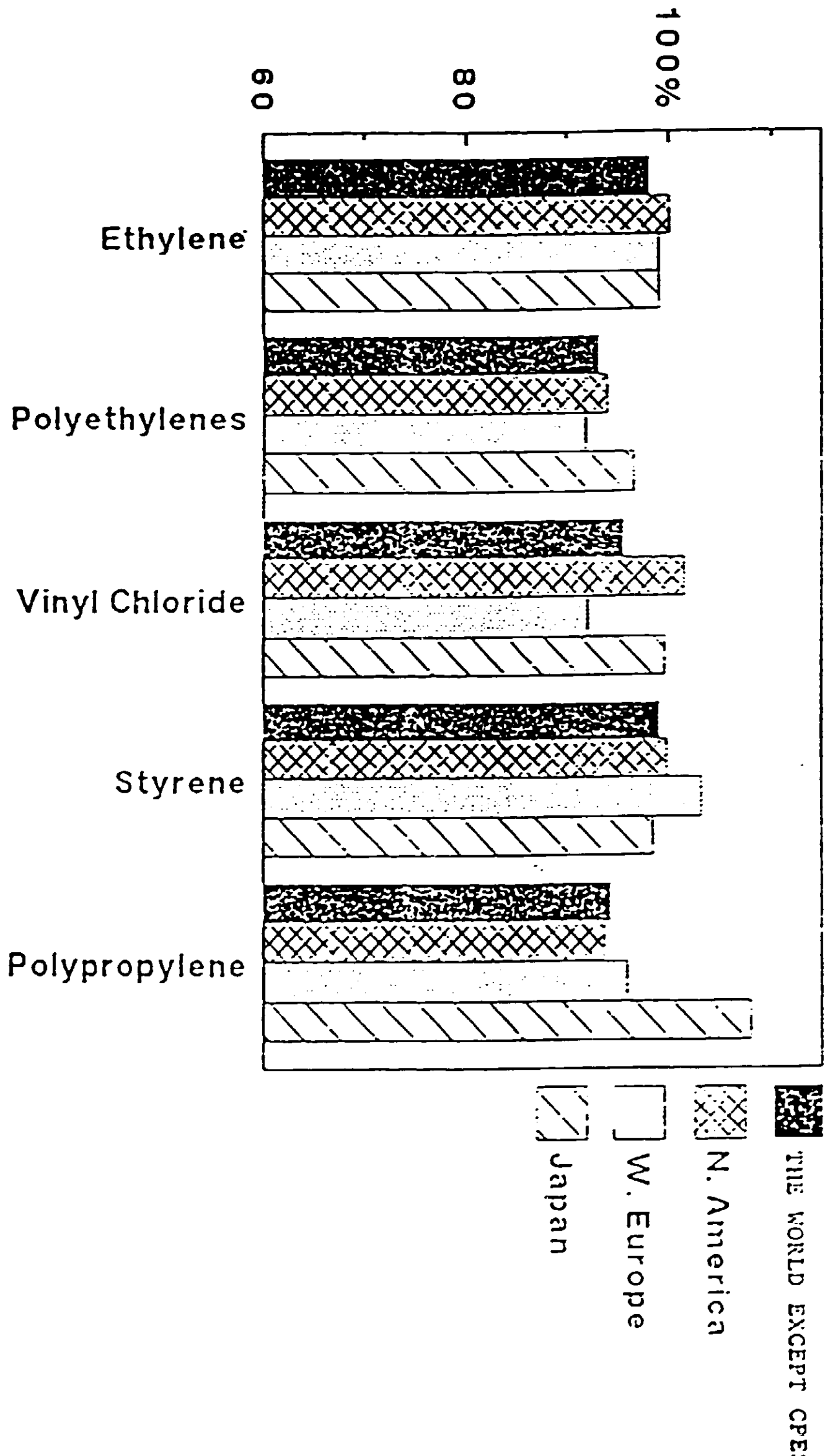


Figure 8.2 <u>**Operating rates for steam crackers and main derivative units 1988**</u>



low-pressure instead of high-pressure polyethylene processes). These changes have not been sufficient to overcome the dwindling opportunities for new innovations. The relatively few process innovations that will occur are likely to be minor, and consequently, few new petrochemical products will be commercialized. Therefore, new strategy of the petrochemical producers, in order to increase their earnings, is to concentrate on plant productivity improvement and to continue to differentiated products by developing new grades of existing plastics, fibers and elastomers, and to provide technical support and application development. That means, they must look for innovation opportunities elsewhere. That is, of course, in the so-called specialty chemicals, especially the categories that are expected to expand at three or more times the rate of the GNP, such as the chemicals used to make microchips, diagnostic reagents, synthetic lubricants, and advanced new materials including high-performance polymers, composites, and ceramics (Ref. 11/).

On the other hand, the level of process technology which is now increasing again, is directed towards identified objectives such as the use of ethane and propane as feedstocks for certain olefin derivatives (vinylchloride), acrylonitrile and aromatics. Research and development efforts are, as well, redirected from immediate to longer-range problems. Increasing competition from energy-rich newcomers in base and commodity materials has spurred a shift of research and development efforts towards downstream activities. In regions where feedstocks are scarce, like Japan, research and development is focusing for the longer term on the search for alternative feedstocks such as synthesis of petrochemicals using methanol and synthesis gas as feedstock (C, chemistry), conversion of barrel bottoms and vacuum residues to feedstock for olefin plants, and the diversification into high-technology fields such as electronics and biochemistry.

There is another important factor governing the development of new innovations, that is the environmental and workers health regulations, particularly in the industrialized countries.

A more rational policy would be to encourage petrochemical companies to move resources into the higher value-added activities in which the industrialized countries have a comparative advantage, and that is the innovation of new chemical products.

8.1 Trends in feedstocks

In the petrochemical industry, the feedstocks availability and prices have been and will continue to be an important factor in shaping the future of this industry. Historically, coal was for more than a century the main raw material, not only for organic chemistry including petrochemicals, but also for many other chemical industries.

Today, petrochemical industry, in practice, is totally dependent on oil- and natural gas-based raw materials: naphtha, gas oil, LPG, and natural gas, whose primary utilization is energy generation. Therefore, petrochemical feedstock availability and price will be very much determined by the general energy situation. World energy balance suggests that for the next decades there will be no need to force the world petrochemical industry to a drastic change in raw materials from the present hydrocarbon basis.

Naphtha which was the dominant feedstock for petrochemicals, especially in West Europe and Japan, is globally continuing to be the main feedstock both for olefins and aromatic production and will not lose its leading role, but its share is constantly decreasing in Europe in favor of other hydrocarbons, both heavier and lighter than naphtha, while it is increasing in the United States, with lesser change in Japan.

In 1988, naphtha constituted about 54 per cent of the global ethylene feedstock and is expected to be around this level in 1995 (Table 8.1).22/

Table 8.1 Global Ethylene Feedstocks (per cent)

	1988	1995
Naphtha	54	56
Ethane	26	24
LPG	12	14
Gas oil	6	5
Refinery gas	2	1
	100%	100%

Ethane is an obvious choice for ethylene production wherever it is available, and its role is predominant in the oil and gas rich developing

22/ Arthur D. Little, International Business Planning, July 1989 countries (Middle East, North Africa, etc.) expanding in Europe and declining in the United States.

LPG is a very favorable alternative, but its utilization depends on its prices because many other users will compete for it. Fuel oil and other heavy fractions are more expensive to process, as far as both investment and operation are concerned. Thus, the cost relationship will decide the share they can acquire.

From the above situation portrayed and with new reserves of oil and gas being discovered, oil and natural gas-based hydrocarbon resources will continue to dominate the petrochemical industry's feedstock picture during the whole of the 1990's and probably into the early 21st century, particularly if the soft petroleum market will be maintained and the prices of gas and refinery products are consequently stabilized at relatively reasonable levels.

However, a shift among these different oil and gas-based hydrocarbons will prevail in favor of each other depending on regional availability, prices, and types of yield policies aimed at ethylene crackers, as it will be seen when the trend in feedstocks is analyzed in the main petrochemical producing regions. However, the picture of the world feedstock use for olefins as it stands in 1986 may be illustrated by Table 8.2.

Table 8.2 World Feedstock use for olefins 1986 a/

	Naphtha Gas oil	Propane Butane	Ethane/ Refinery gas	Other	Total
Western Europe	86	9	5	0	100
United States	23	22	55	0	100
Latin America/Canada	38	2	57	2	100
Middle East/Africa	11	0	72	-	-
Asia/Pacific	86	14	0	0	100
Japan	93	7	0	0	100
Total	55	13	31	1	100

a/ OPEC Bulletin, November 1987, p. 15

8.2 Feedstock trends in Western Europe

In West Europe, Naphtha is by far the most common feedstock for petrochemicals. The major constituent of naphtha cracking is the olefins - ethylene, propylene, butadiene and butenes. Aromatics extraction uses two principal feedstocks: pyrolysis gasoline from olefin plants and reformation from refinery operations. Although, the major purpose of the reformers in the oil refineries is to make an aromatics-rich stream for gasoline blending, about a seventh of this amount is used for aromatics extraction for the petrochemical industry.

The trend towards the use of lighter feedstocks in Western Europe has begun in the recent past (1978-1979) when naphtha's price was over US$ 300 per ton, 1.3 - 1.4 times the price of the basic crude, and when LPG became available from the North Sea fields, Middle East and North Africa. Increasing competition for naphtha in the gasoline pool has also enhanced the gradual shift from naphtha in favor of lighter hydrocarbons.

In the mid 1960's, ethylene crackers were operated at almost 100 per cent on naphtha feed, in 1978 naphtha feed accounted for about 90 per cent, gas oil 7 per cent, LPG 2 per cent and ethane 2 per cent, and in 1985 the shift from naphtha was more pronounced where naphtha share as feedstock in ethylene plants dropped to 70 per cent, gas oil rose to 10 per cent, LPG increased to 12 per cent and ethane occupied 7 per cent. This trend is forecasted to continue in the future (1990's) but at a much slower rate than that of the recent past. 23/

Table 8.3 Ethylene feedstock slate in West Europe (per cent) a/

	Naphtha/ Gas oil	Propane/ Butane	Ethane/ Refinery gas
mid 1960's	99 (98+1) b/	less than 1%	less than 1%
1973	98 (94+4)	1	1
1978	97 (90+7)	2	1
1982	90 (84+6)	8	2
1985	81 (70+11)	12	7
1986	82.8	9.9	7.3
1990	80.3	11	8.7
1995	79.7	11.3	9

a/ compiled from several sources
b/ the high figure in brackets represents naphtha and the small figure for gas oil

23/ A profile of the West European Petrochemicals Industry, Association of petrochemicals producers in Europe (APPE), 1986

The use of ethane in Europe is not easily justified on economic ground compared to naphtha, since it is not in surplus and should be valued as a fuel equivalent, nevertheless, it is forecasted to be increased as the new units (Moss Morran in the United Kingdom) increase capacity and operating rates.

The increasing worldwide surplus of LPG should, however, justify further investment in LPG cracking facilities (mainly for propane) in Europe as a flexible alternative to naphtha, particularly in the Mediterranean area. As for the use of LPG, it will depend on satisfactory economics, with the delivered price of propane (or butane) required to be lower than the break-even value for the feedstock relative to naphtha. In the case of propane this value is typically less than 0.9 times naphtha price, whereas for butane the value is closer to naphtha price.24/

8.3 Trends in the United States

In the United States, light feedstocks have always been the major source of ethylene. Until 1970, light feedstocks (ethane and refinery gas, propane and ethane) constituted about 85 per cent of the ethylene crackers feed while naphtha and middle distillates remained at 13 to 17 per cent. Trends in recent years have been towards increasing the use of naphtha and middle distillates, marking a significant shift not only in the feedstocks pattern used but also on the petrochemical spectrum in general.

This shift will lead to the increase of propylene and butadiene production from the naphtha based crackers and ultimately the dehydrogenation facilities of butadiene will be closed, since butadiene from heavier feedstocks will cover the US total demand. Moreover, the supply of benzene from olefin plants will increase to more than double.

The use of ethane in the United States will decline significantly as the price of ethane rises to fuel equivalent value and with availability being limited. Table 8.4 illustrates the feedstocks shift for ethylene production in the United States since 1970 and the forecast until 1995.

24/ Middle East energy and chemicals, Bahrain Seminar, 12 April 1988

Table 8.4 Evolution and future forecast of feedstocks for ethylene production in the United States, 1960's to 1990's (per cent)

	1970	1976	1982	1986	1990	1995
Naphtha and gas oil	13	21.8	30	30.9	29.8	33
Ethane and refinery gas	52	53.9	45.7	48.6	41.8	36.6
Propane	33)	19.1		)	)	)
	)35.0		)24.3	)20.5	)28.4	)30.4
Butane	2)	5.2	)	)	)	)
Total	100	100	100	100	100	100

Naphtha and gas oil appear to increase their share in the United States feedstocks until well past the end of the century, resembling a considerable shift to heavy liquid cracking for plants built or planned for the future, which in turn, may be due to a poor outlook for increasing the supply of NGLs. The decrease of natural gas and the high cost of extracting NGLs in new gas plant facilities will also limit the availability of ethane for steam cracking.

Other alternative feedstocks, such as the heavy petroleum residue, still no economically attractive technology has yet been commercialized that could be cited normally as an essential source of petrochemical feedstocks.

Nevertheless, there are indications that the products' yield of vacuum gas oil is quite comparable to that of naphtha.

8.4 Feedstocks trends in Japan and the rest of the world

With only a minimal domestic supply of fossil fuels, Japanese industry, and particularly the petrochemical industry, is almost entirely dependent on overseas sources. Naphtha is the predominant feedstock (93 per cent) in Japan, almost similar to the case in Western Europe, but with no access to lighter feedstocks which Western Europe has enjoyed from the North Sea Oil fields and North Africa.

Naphtha and other petroleum derivative feedstocks are imported by a special association of importers known as PFIC (Petrochemical Feedstock Importing Company). The alternatives in the feedstock situation in Japan is quite limited. Following the second oil crisis, during which Japan was most affected because of their energy structure (imports of oil and naphtha), and there was a large price difference per energy conversion unit between oil and coal. This price difference in using oil or coal as an energy source led to a major move-away from oil to more economical coal in such industries as electric power generation, steel and cement. As a result, heavy fuel oil consumption dropped sharply, and a large number of refineries actively expanded FCC (Fluid catalytic cracking) capacity. The petrochemical industry was thus able to easily accommodate the propylene and butylene recovered from FCC off-gas as new feedstock.

Owing to these business environments, Japanese medium and long-term strategies were directed towards feedstocks savings by improvement in catalyst (e.g. improved catalysts resulted in a reduction of approximately 13.5 per cent in propylene consumption per ton in the production of acrylonitrile between 1974 and 1985), diversification of feedstocks (such as the production of methyl methacrylate MMA from isobutene, which is extracted from bottom of barrel fractions of naphtha cracking, instead of the acetone cyanohydrin route), shift from commodity to specialty products of high value added, concentrating on high growth products such as nylon 66 which has enjoyed a 12 per cent growth rate per year, synthesis of petrochemicals by using methanol and synthesis gas as feedstock (C chemistry), increasing use of refinery by-products, and diversification into high-technology fields such as electronics and biochemistry.[25/] (Ref. 13/)

As for the rest of the world, trends vary. In the Far East (Korea, China, etc.) the emphasis is on naphtha, in regions such as Middle East, North Africa, and Alberta, Canada, the use of ethane has been favored but the use of heavier feedstocks is increasing.

In Latin America, low cost natural gas is available in Venezuela, Chile, and Argentina. Brazil has improved its gas situation and it is a naphtha surplus country. Thus, the region has less of a feedstock problem in general and the installed capacity for aromatics far exceeds the regional demand.

Methanol capacity is also in excess of demand, and with the entry of the

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25/ Hydrocarbon processing, May 1987 and Reference 13/, p. 36

new plant in Chile, regional capacity will be far in excess or requirements.

In conclusion, the global feedstock slate for ethylene is projected to move away from ethane towards LPG, with the use of naphtha virtually constant. There will be a reduction in the use of gas oil. The proportion of propylene obtained as a co-product of ethylene will rise, particularly in the United States, while in Europe, the increased need for propylene would have to be obtained from refinery sources.

There is an increasing quantity of mixed C_4 stream both in the United States and Europe which will have to be co-cracked (or fuelled) as demand for butadiene rises more slowly than supply from steam crackers, and prices fall to the equivalent of naphtha value for the mixed C_4 stream. As a result, there will be an increasing surplus of butadiene worldwide, dehydrogenation production processes will cease in the United States, and the limited amount produced in Eastern Europe and in Latin America will also diminish.

8.5 Trends to use alternative feedstocks

The situation of utilizing other alternative routes for petrochemical feedstocks, mainly coal and biomass, is connected more with the economics of these processes. Even with the possible new processes entering in the next decade, differences in the production costs will probably remain in favor of the hydrocarbons.

Moreover, in any case, whether coal or biomass, and whichever process route will be chosen, the main problem to be solved will be fuel production, while petrochemical feedstock will play only a secondary role. Brazil demonstrates this clearly, ethanol from biomass (sugar cane) became of concern for solving the motor fuel problem, but the petrochemical industry still relies mainly on the hydrocarbons coming from the processing of local or imported hydrocarbons.

Thus, by examining the global feedstock matrix, the feedstock situation is more favorable for the developing countries having hydrocarbon resources for the development of their domestic petrochemical industry.

8.6 Trends in petrochemical products (Basic petrochemicals)

World ethylene demand is predicted to grow at a rate of 3.2 to 3.4 per cent per annum to the year 1995 where the world total demand is estimated to reach 64 million tons in 1995 versus about 75 million tons nameplate capacity (Table 8.5). Developing countries' name plate ethylene capacity in 1995 is forecast to reach 15.9 million tons up from 9 million tons in 1985. Thus, their share in world ethylene capacity will rise from 17.6 per cent in 1985 to 21.3 per cent in 1995 (Table 8.6)

Table 8.5 World Supply/Demand analysis for ethylene 1988-1995 in million tons ethylene a/

	1988		1995	
	Name plate capacity	Demand	Name plate capacity	Demand
Region:				
North America	19.0	19.0	25.7	22.0
Western Europe	14.6	14.7	18.9	17.5
Asia and Oceania	7.7	7.8	12.4	11.0
Latin America	3.0	2.7	4.2	3.4
Middle East and North Africa	2.9	2.2	4.6	3.9
Eastern Europe	7.4	4.8	9.2	6.1
Total	54.6	51.2	75	63.9

a/ with a little more optimistic estimate for the growth rate in Eastern Europe from 1990-1995 (however, data for Eastern Europe is an estimate based on available data in 1985 and 1987)

Table 8.6 World Ethylene Capacity 1985 - 1995 in million metric tons

Regions	1985 a/	1988	1990	1992	1995
North America	17.4	19.0	20.6	24.3	25.7
Western Europe	14.0	14.7	15.2	16.6	18.9
Eastern Europe	6.5	7.19 b/	7.55	7.93	8.75
Japan	4.3	4.295	4.295	4.795	5.3
Total developed countries	**42.2**	**45.185**	**47.65**	**52.5**	**58.65**
Asia	3.42	3.645	4.9	5.6	7.1
Middle East of Africa	2.67	2.9	3.0	3.2	4.6
Latin America	2.91	3.0	3.7	4.2	4.2
Total developing countries	**9.00**	**9.545**	**11.6**	**13.0**	**15.9**
World Total	51.2	54.73	59.25	65.5	74.55
Share of developing countries in per cent	17.6	17.44	19.6	19.9	21.3

a/ UNIDO Data Base 1985

b/ Data for 1987 have been taken for 1988, and future forecast was based on 2.5 per cent growth rate per annum; other information is compiled from several resources

Demand growth is forecast to be stronger in the Far East, particularly in the newly industrialized countries (NICs), Asia, Middle East, Africa and Latin America, with overall demand outside the United States and West Europe averaging about 5 per cent per year. Growth in West Europe will be affected by the continuing loss of derivative exports, holding back ethylene demand growth to less than 2 per cent. The United States will also exhibit a weak growth rates (1.8 - 2 per cent). However, in Western Europe the balance will remain tight in the ethylene supply/demand picture until 1991/1992 when significant new capacity will come onstream.

The other aspect of trends in the ethylene industry is the different feedstocks used which was discussed in detail in the relevant section dealing with feedstock and feedstock alternatives, which could be summed up by the continuation of the use of lighter feedstock in Europe but at much slower rates than in the recent past. In the United States, the use of ethane should decline, and increased naphtha use will be more in trend. For the rest of the world the situation depends on the regions while the global balance will demonstrate a move away from ethane to LPG feedstocks, with naphtha being almost constant (54 - 56 per cent).

From the technological point of view, there is, in fact, little to say about process design and operation technique. The single major process of the production of olefinic base materials (Ethylene, propylene and butadiene) remains steam cracking. The cracking operation itself has reached a very high degree of development. In practice, the original ethylene manufacturing process has not changed fundamentally over the last 35 years or so, yet a great deal of technological improvement has been introduced coupled with more than a tenfolds increase in single plant capacity which brought a considerable decrease in total resources requirements to produce a unit amount of ethylene (less steel and other construction material, less feedstock and energy consumption, less operating manpower and lately more flexibility in using a wider range of feedstocks). Many modern ethylene plants have introduced process computers with tasks ranging from single data logging and alarm to full supervisory control for optimum performance of the entire plant.

Accomplishment of significant growth in the size of ethylene plants illustrates the economic advantages afforded by scale which results primarily from the reduction in capital-related cost per unit of ethylene produced. In a few instances single-train ethylene plants (no duplication of compressors or other equipment, except for the pyrolysis heater) have now reached a capacity of up to 700,000 t/year. However, the economy of scale diminishes when going to very high plant capacities. More costly field fabrication of some large equipment items becomes necessary, and the operation involves increased economic risks from exposure to possible start-up delays, unforeseen operating interruption and changing market conditions.

8.7 Trends in other olefins (propylene and butadiene)

In the case of propyelene, the situation of its production is rather difficult to be precisely assessed. Propylene supply is largely dependent on the output from ethylene crackers (as by-product) and from refinery operations. In most regions, the main source of propylene is the olefin plant with the exception of the United States where about 47 per cent comes from refinery operations (Table 8.7)

Table 8.7 Propylene Production Split (Per cent)

	Ethylene Co-Product	Refinery	Dehydrogenation
Western Europe			
1986	85.3	14.7	
1990	82.5	17.5	
1995	80.2	19.8	
United States			
1986	73.7	46.3	
1990	57.6	42.4	
1995	61.0	39.0	
Global			
1986	74.7	25.3	
1990	75.8	24.2	
1995	76.1	23.9	0.7

In continuation of the analysis of trends, as the new crackers will use lighter feedstocks (such as ethane and natural gas liquids) following the general trends in world feedstocks for ethylene crackers, less propylene and butadiene would be expected. However, the pattern of utilization, especially for propylene, is going in the opposite direction. Propylene derivatives, especially polypropylene are growing much faster than those of ethylene.

In Europe, demand for propylene is stronger than for ethylene, hence, it will require reduction in cracking severity and increasing supplies from refineries and perhaps from imports. Moreover, propylene is used in refineries for motor fuel purposes to increase the octane number according to regulations restricting the lead content in gasoline. In the United States, the reverse is true, with the propylene from refineries (46.3 per cent versus Western Europe 14.7 per cent in 1986) likely to drop as a proportion of the total production to reach about 39 per cent in 1995 (Table 8.7 above).

However, the United States remains a prime source for any global shortage of propylene (the proportion of propylene obtained as a co-product of ethylene will rise). Worldwide, propylene/ethylene demand ratio will be almost 50/50 by 1995, higher in Western Europe (0.627), just a little higher than the world ratio in the United States (0.518) and lower than in the rest of the world (0.445). Table 8.8 illustrates the propylene consumption, the rate of growth and the forecast for 1995 demand.

For butadiene, there will be no supply problem, as there will be an increasing surplus of butadiene worldwide, particularly in Western Europe. Increasing quantities of mixed C_4 will have to be co-cracked or fuelled as demand for butadiene will rise more slowly than supply from steam crackers, as it was mentioned in the paragraph dealing with the feedstock trends above.

Table 8.8 Propylene Consumption Projections (million metric tons)

				Average Annual Growth (per cent)	
	1986	1990	1995	1986-90	1990-95
Western Europe	7.5	8.3	8.9	2.6	1.5
United States	7.6	8.8	10.1	3.6	2.9
Rest of World	8.4	10.3	12.9	5.3	4.5
Total	**23.5**	**27.4**	**31.9**	**3.9**	**3.1**

One of the most outstanding technological developments in the propylene industry is the dehydrogenation of propane to propylene. The first commercial plant employing this technology is nearly due to start-up in Thailand based on UOP Process.

In this process, propylene could be produced independently from ethylene or refinery operations. The economy of this process is linked to the prices of propane and it is most suitable for regions rich in gas resources.

8.8 Aromatics

Basic aromatics, which comprise benzene, toluene, and xylenes (BTX), are used to produce a very large variety of compounds, most of which have many outlets and applications. World trends in aromatics are certainly driven by their major derivatives: polystyrene, nylon 66 and 6, rubbers, detergents (LAB), cumene and phenol, maleic anhydride, polyurethane, alkyd resins, plasticizers, and the especially important products, TPA and DMT for the manufacture of polyester fibers.

The trends in aromatics will be represented in this study mainly by benzene which presents, in principle, the same forecasting problems as propylene, sourcing in both oil refineries and petrochemical operations, and demand for both petrochemical and many other uses.

Both petrochemical producers and oil refiners reform naphtha in BTX units, which in most industrialized countries account for over half of the aromatics capacity. In addition, oil refineries produce aromatics as by-products of petrocoke and pyrolysis gasoline operations.

In Europe, about fifty percent of all benzene is produced by extraction from pyrolysis gasoline, an ethylene co-product. The balance comes from reforming and hydrodealkylation.

The demand for benzene has been growing very slowly in industrialized countries where many outlets for benzene and its derivatives are in mature industries, such as housing, textile and other industries having well developed infrastructure. However, only in areas such as engineering thermoplastics there may be rapid growth. The major derivative of benzene is ethylbenzene, a raw material for polystyrene, a product with a large market in the plastics and rubber industry. From para-xylene, TPA and DMT intermediates are made, forming the raw materials for polyester fibers. In developing regions, especially the new industrialized countries, benzene has a great potential. In fact, growth rates in Latin America and Asia have been high. Demand for xylene (especially P-xylene) is tied up mostly to the demand for synthetic fibers. Among the specialized chemical companies, AMOCO has significantly increased its involvement in the Asian area. The China American Petrochemical Co. Ltd., a joint venture, will expand the production of purified terephthalic acid (PTA) to one million metric tons per year by early 1990. Another joint-venture for the production of PTA is located in South Korea.

In conclusion, benzene supply will not suffer shortage and perhaps, there will be no need for expansion of production capacity until the second half of 1990. World demand in 1990 for benzene is estimated at 18.1 million tons and for 1995 at about 22.6 million tons. However, should the clean air law be passed in the United States, benzene will be more in excess.

The aromatics business has lately seen some sharp price increases and tight supply, particularly benzene, toluene, and para-xylene in the United States and Western Europe after a few years of low demand growth and low production rates. Moreover, a combination of factors appear to be involved in this change. A take-off in US demand for premium unleaded gasoline has boosted refiners' captive needs for aromatic streams as octane enhances. Demand for the key benzene derivatives, styrene and cumene/phenol, has been sustained, and a series of plant outages has served to keep the pressure up. The incident at Deutsche Shell's major aromatics plant in Godrof, West Germany in November 1988 and later other subsequent incidents in the US - a reformer fire at AMOCO's Texas city plant, and incidents at Phillips' Sweeny, TX plant, and Tenneco's Chalmette, LA refinery, as well as problems at plants run by Lyondell, Amerada Hess, Sun Canada, Cain, Koch, Dow, Shell and Exxon - and production problems at a number of Asian plants in Japan, India and others have helped to compound the problem.26/

Benzene prices have continued to be higher after a long period of stagnation and production outages. Although, there is virtually no new capacity due on stream, operating rates are due to follow the industry's trend and rise from a current 78 per cent rate to 85 per cent by 1992. With demand for benzene increasing as styrene plants start-up, there will be some considerable tightening of benzene supply. The price differential between benzene and toluene is wide enough to justify start-up of idle toluene hydrodealkylation units which should bring some incremental benzene supplies to meet chemical industry demand.

Among several basic petrochemicals which have lately experienced good growth, with some being expected to grow at double the sectors average, is para-xylene. This is mainly related to its use as raw material for polyester fibers, resins, and films. Worldwide, production capacity was increased for

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26/ Chemical Week, 28 March 1990

para-xylene derivatives with demand particularly strong for polyester. US producers have taken advantage of the strong export demand, in particular for para-xylene derivatives, to satisfy demand for the surging local market for polyester. Major expansions have been announced to obtain increased supplies, mainly for export to those consuming regions.27/

8.9 Trends in plastics

The plastics industry is the largest and most important sector within the petrochemical industry all over the world, having such wide-spread applications, so many product varieties and well established technologies in most of its areas. Demand for plastics is strong, and there is no sign of any reversal in this trend despite environmental pressures against plastics use.

The world total consumption of thermoplastics in 1988 was estimated at 70 million metric tons. For engineering plastics, the figure is, of course, much smaller: 2 million tons or about 3 per cent of all thermoplastics. (Ref. 18/)

The major five thermoplastic polymers, or so-called commodity polymers, commodity plastics, or standard plastics are HDPE, LDPEs, PP, PVC and PS. The world total consumption of these five polymers amounted to approximately 62.6 million tons in 1989 (Table 7.9). Demand is growing throughout the world for these commodity polymers, although the trend varies for each product and region. The total world consumption is forecast at a little over 81 million tons for 1995 (PVC 20 million tons, HDPE 13.92, LDPE 13.57, LLDPE 8.14, PP 13.57 and PS 12.14 million tons).

Taking into consideration the global trends for the individual commodity polymers, low density polyethylene (LDPE) is expected to exhibit the lowest growth rate per annum - 1 per cent - through to 1995, followed by polystyrene (PS) and polyvinylchloride (PVC) each at growth rates of 3 per cent a year. High-density polyethylene (HDPE) and polypropylene are forecast to grow at 5 per cent, and linear low-density polyethylene (LLDPE) will exhibit the higher growth rate, 11 per cent.

27/ Chemical Week, 28 March 1990

In consideration to the relative importance of the major markets (regions) for bulk thermoplastics, it could be recognized that LLDPE has quickly made significant progress in the USA. This situation arises from a number of reasons including the price at which the polymer was sold. Because it has a broad spectrum of applications, HDPE is an important product globally. For PP and PS, the industrialized regions account for about two-thirds of the global consumption, and one third is consumed by the rest of the world, mainly because about 50 per cent of the PP consumption is in the injection molding of items used in industrial applications such as the automotive industry and domestic appliances which are concentrated in the developed regions. This is similar to the situation of polystyrene (PS) which is employed mainly for the packaging and production of consumer goods, the requirements for which are beginning to develop in newly industrialized countries. PVC is one of the earliest polymers, it is widely used in pipes and flexible sheet products. Regions outside the USA, Western Europe and Japan account for about half of the global consumption of PVC.

Because of the relative low profitability of commodity polymers, it is expected that plastic producers will be prompted to seek more technological improvement and to increase research and development. Innovations in process technology to ensure the lowest possible production costs will be sought, as well as the development of special grade resins of those polymers aimed at higher value. In fact, many of the special grades of commodity thermoplastics can replace engineering polymers, particularly where applications are overspecified. For example, new ultra-high impact polystyrene grades are replacing ABS and polycarbonate in appliance and automotive applications.

Meanwhile, the commodity polymers also continue to be substituted for each other, mainly on price grounds. High-density polyethylene and injection-grade polypropylene tend to replace each other in many basic consumer goods applications depending on which is cheaper, while there is increasing substitution by either product for costlier PS in the packaging area.28/

Trends in the engineering plastics and high-performance polymers are obvious: the standard plastics have reached market maturity, and the products

28/ Chemical Week, 20/27 Dec. 1989, p.19

of higher-value added and which are likely to experience above average growth rates in the future are the specialty polymers.

Many producers in the developed countries have turned to engineering polymers which are distinguished from standard grades by their higher performance - in terms of high strength/stiffness and heat resistance. The average prices of engineering polymers are considerably high, ranging from US$ 2 - US$ 5 per kilogram. Among these engineering polymers are: polyamide (nylon), polyacetal, polycarbonate, polyphenylene oxide and polyester. Other performers in the business also include some specialty grades of standard polymers such as polyethylene, PVC and reinforced PP.

Development within the engineering polymer group is characterized by modification using fillers and reinforcing materials and by alloying or blending polymers.

High-performance polymers are characterized by the retention of their mechanical and electrical properties, even at temperatures above 200°C, and their inherent flame resistance. The volume sold is small, but prices are very high (about US$ 50/kilogram). Those materials include polyarylate (PAR), polysulfone (PSU), polyetherketone (PEK), etc., which were discussed before in more detail. The development of fiber-reinforced plastics has taken the special form of unidirectionally reinforced composites for components subjected to high degrees of mechanical and thermal stress.

In spite of high prices and high value-added of these groups of engineering and high-performance polymers, their production and consumption are almost solely in the developed regions with consumption quantities being very low compared to those of the standard polymers. (Of the total world thermoplastics, the consumption of engineering plastics is only 3 per cent as was mentioned before.) Thus the market of engineering and high-performance polymers suggests some worries resulting from possibility of over-capacity in some specific product areas, as this sector became overcrowded with suppliers. (Ref. 18/)

With the wide spread of applications covered by the petrochemical industry, especially the bulk thermoplastics, and with the industry having become truly global, the major influence on the demand is the overall level of economic activity.

Table 8.9 World consumption of commodity polymers (main 5 thermoplastics) in million metric tons a/

	West Europe	North America	Japan	East Europe	Latin America	Middle East + Africa	Asia	WORLD TOTAL	
	1989	1989	1989	1989	1989	1989	1989	1988	1989
HDPE	2,649	3,619	881	1,033	641	374	1,302	10,219	10,499
LDPE + LLDPE	5,074	4,896	1,294	1,989	1,546	773	1,962	17,244	17,534
PP	3,257	2,824	1,681	607	435	353	1,687	10,154	10,844
PVC	5,068	3,810	1,847	1,002	934	932	2,745	15,980	16,338
PS	1,669	2,458	995	757	382	208	893	6,458	7,362
	17,717	17,607	6,698	5,388	3,938	2,640	8,589	60,055	62,577

a/ Modern plastics international, January 1990, page 31-46
Eastern Europe, Asia, Latin America, Middle East and Africa, according to available information in years 1985/1986/1987 with 3-7 per cent rate of growth added per year according to the type of polymers and region

In the United States, for example, slow housing starts in 1990 will affect demand for construction materials such as PVC, and sluggish auto sales will obviously affect key automotive materials like acrylonitrile butadiene stryrene (ABS) resins and synthetic rubber.

On the other hand, several products show very good growth rates, such as PP in particular and methanol which is expected to perform strongly as a result of soaring demand for the octane booster methyl tert-butyl ether (MTBE). In conclusion, the petrochemical industry in North America is in quite a good shape entering the 1990's.

As for Japan, Japanese companies appear to have a strong leaning towards the idea of making investments, being particularly encouraged by some demand forecast statistics which suggest such investments.

In Western Europe, demand growth for petrochemicals is likely to be steady for the next three years at 2.5 per cent - 3 per cent.

The significant trend in the world petrochemical industry today is the new boom of investment in the Middle East. Saudi Arabia has embarked on another round of major investment, and other complexes are planned in a number of countries: Kuwait, Qatar, Iraq, and Abu-Dhabi. An 80,000 tons/year PP plant is already under construction in Kuwait, and other basic and thermoplastic polymer units have started construction, while others are at different implementation stages. Such plans will certainly leave their mark on the general trends in the region (Ref. 29/).

The question which remains without a clear answer now is the impact of the recent changes in Eastern Europe, and in particular the "unification of Germany", on trends in the petrochemical industry in general and on the commodity thermoplastics in particular because of their direct and immediate importance in building the various sectors of the economy.

8.10 Methanol gaining new prospects

Largely as a sequence of the 1970's oil crisis which changed the international energy price structure, methanol has begun to show promise of becoming a rival and a substitute for naphtha in practically all applications of the latter: as a transport fuel (gasoline), a satisfactory fuel and a petrochemical feedstock.

While methanol is used in the manufacture and processing of a large number of chemicals, its major application until very recently has been as a raw material for the manufacture of formaldehyde, for which, in turn the largest use is for plywood adhesives (urea and phenol-formaldehyde resins) and as a solvent.

New uses for methanol have developed in the course of time, such as in methyl methacrylate, DMT, single cell protein (SCP) and acetic acid manufacture as well as its today's energy related applications which have emerged as fuel and indirectly through the use of MTBE (Methyl tertiary butyl ether), which is an octane inhancer more environmentally acceptable than the conventional octane improving additive tetraethyl lead (TEL). MTBE is made by reacting methanol and isobutylene, and its market is considered as very bright. Moreover, methanol is also used in gasoline blending.

There have been many development efforts and research and development activities devoted to other uses of methanol in areas which were once promising for becoming large consumers of methanol, such as single-cell protein. However, it seems that more time is needed for such uses to prove their viability in larger commercial application.

Apart from its energy related applications, a new application for methanol has been as a raw material for acetic acid. Monsanto's revolutionary technology for acetic acid production replaces conventional hydrocarbons such as naphtha, butane, LPG, ethanol and, most important, ethylene as a raw material base. The new technology of Monsanto, which is a precursor of the C_1 technology, has the potential of replacing all other routes to acetic acid except in low capacity operation. It was estimated that at the early 1980's about 40 per cent of the world capacity of acetic acid in the developed countries had been, or was, in the process of being replaced by the new route. Methanol consumption for acetic acid in Western Europe was forecast to grow by 1990, 22 fold over the 1979 level. Methanol world capacity, consumption and future demand are summarized in Table 7.10.

Table 8.10 Methanol world capacity, consumption and future demand (million tons)

Year	1980	1987	1990	1995 a/ b/
Capacity		20.4	21.2	21.2
Total demand	12	16.4	18.6	20.8

a/ Hydrocarbon processing, Sept. 1986, p. 19
b/ No speculation is included for additional new plants or shutdowns

89 per cent of the methanol production is currently used to produce different chemicals: formaldehyde (for adhesives, plastics, etc.), acetic acid (for paints and adhesives, etc.), methyl methacrylate (for transparent plastics, etc.), while 5 per cent goes into MTBE manufacturing and 6 per cent into gasoline blending.

8.11 New applications of methanol

Should new technologies recently developed be successful, methanol will take over the role that naphtha has played in the energy and chemical industries. Among the new prospects for methanol are:

8.11.1 Methanol as transportation fuel

Two technological alternatives have emerged in this connection: the direct use of methanol as a gasoline blender or as a 100 per cent substitute for gasoline, and indirect methods. Of the indirect methods, the most important development is that of Mobil's MTG (methanol to 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.

8.11.2 Methanol as chemical feedstocks

The development of C_1 chemistry, Monsanto's acetic acid process and Tennessee Eastman's acetic anhydride process, followed by the Chevron and Halcon process to make ethylene glycol and vinyl acetate from methanol, are obvious indications for new methanol-oriented technologies of high commercial value. And finally, Mobil's process, methanol to olefins, for the production of ethylene from methanol, will open a wide door to petrochemical feedstocks.

9. IMPACT OF INCREASING ENVIRONMENTAL CONCERN ON THE FUTURE OF THE PETROCHEMICAL INDUSTRY

Increased and continuing environmental pressure in the industrialized countries has become one of the major problems affecting the industry's future. In spite of the effective measures, intensive research and development activities, and strenuous efforts taken by petrochemical producers for securing more safety and less pollutant emission and disposal, new regulations and acts are continuously being issued for still more severe restrictions.

As a great number of petrochemical producers have already adjusted their processes and plant operations to cope up with the environmental requirements, more intensive pressure is being imposed, with an increase in investment of 10-15 per cent. Besides some hesitation occurs in developing new products for which the impact and relevant environmental restrictions are uncertain.

In particular, the plastics industry, the wider sector of the petrochemical area, is facing serious environmental problems where regulations restrict disposal of so many types of polymers. Instances of restriction placed on the use and disposal of plastics are many. For example, environmental pressure on polystyrene, a product widely used in the packaging industry, has dictated a switch-back to paper or cardboard in some consumer packaging applications. More intense environmental pressure is now placed on PVC in line with the chlorine issue. Environmentalists have called for a ban on PVC production because of the potential release of Hcl during incineration, although the industry is claiming that this matter can be effectively dealt with by suitable scrubbing systems. Moreover, demands are being made for a complete ban on certain plastics and for the use of recycling in some applications, particularly consumer packaging. Observers in Japan and Western Europe see that if such restrictions are placed on certain packaging materials, there could soon be overcapacity in some products that are tight today. Accordingly, this issue has to be taken very seriously and could place a new frontier in the management of the industry.

As for new material in the area of low molecular weight, specialties are more difficult to apply commercially than in the area of polymers due to regulations requiring rigid toxicity and other types of testing. And last but not least, the newly proposed clean air act in the USA may initiate new attitudes towards the future prospects of the industry.

In conclusion, as much as public awareness and governmental concern about the impact of the industry on public health and environmental protection is important, it is also essential that these regulations be fairly and realistically analyzed so as to be designed in a way that would not unreasonably limit the development of the petrochemical industry either technically or economically.

10. CONCLUSIONS

From the review of the world trends in technological development in the petrochemical industry and the related issues of this industry, the following conclusions are made:

- The decade of continuous restructuring processes, aided by favorable changes in the global economic environment and the lately-occurring drop in oil prices has successfully brought the petrochemical industry to a relative state of stability characterized by high operating rates, high margins and good prospects. Overcapacity was absorbed, tightness of the major petrochemical markets has been witnessed and a boom of new investments has been launched.

However, the lessons of the past are still looming in the background and as the old Japanese saying goes: "once it is past the throat, the hotness is forgotten" should always be remembered for any future plans. Mistakes were of little account in the rapid growth era, but this is no longer the case. Therefore, with caution no earth-shaking events or real recession will be expected in the petrochemical industry in the near future.

- The level of investments which has recently been undertaken as a result of cyclical peaks of profitability is generally considered to be greater than the market's short term needs. Thus, an overcapacity in some petrochemical products will be expected in the early 1990's, but it will soon be reduced by 1995. This is also applied to the profits which may suffer when most of these plants are due for production. But recovery is also likely in the mid 1990's. Polypropylene, for instance, is undeniably being overbuilt. However, as polypropylene is a relatively rapidly growing commodity material and with the possible closure of old plants, recovery will most likely occur well before mid 1995.

- In spite of the important concomitant technological development, the shape of the petrochemical industry in the 1990's will be determined by commercial and business strategies more than by technology.

- The Petrochemical industry has become truly global in every respect, and it is expected to become increasingly so in the 1990's. Supply/demand imbalance in any region is reflected on other regions, cross-border investment and joint ventures are seen every other day, sell-out, acquisition and merging are widely in trend and the growing awareness throughout the world of the environmental responsibilities became universal. The incidents of globalization which were searched for after the oil crises and during the restructuring processes have become now a matter of fact, and integral part of the petrochemical industry. Examples are numerous and the process is ongoing.

Therefore, any future planning will have to take the global picture into greater consideration than in past years. Today, an incident happening in one part of the world within the petrochemical industry will affect a nation's supply/demand balance such as the incident which occurred at Deutsche Shell's aromatics plant in West Germany in November 1988 transforming Europe from a net exporter of aromatics to the USA to a net importer. Along same line, export demand for styrene in the USA had cooled down in mid 1988 when Chinese buying of polystyrene became slower.

However, the most outstanding feature of globalization is the Western world's policy in avoiding to a certain degree, competition with the Middle East in the production of traditional commodity polymers and consequently switching to specialties.

- Another general aspect concerning world petrochemical future trends are the recent events in Eastern Europe, particularly the unification of the two Germanies, which will undoubtedly provide strong encouragement for investment there. Moreover, Western firms are already looking for joint-venture opportunities.[29/]

- An overall review of the world feedstock situation indicates that there is no, and will not be, a fear of shortage in feedstock availability, but there may exist some economic considerations for favoring one feedstock over another. There are certainly enough coal reserves in the world, and the use of oil and gas in chemical production is more noble than their uses in energy generation.

With the new reserves of oil and gas being discovered and the stabilized prices of gas and refinery products being at relatively low levels due to the soft oil market, oil and natural gas-based raw materials will continue to dominate the petrochemical industry's feedstock situation into the 1990's and most probably into the 21st century, particularly in the Middle East which will have sufficient oil and gas reserves to assure them a significant market share in the next century. However, among these oil and gas-based feedstocks, there may be a shift in favor of each other pending regional availability, prices, and products sought from ethylene crackers.

- The global feedstock slate for ethylene is projected to move away from ethane towards LPG, with the use of naphtha virtually constant (54-56 per cent), while there will be a reduction in the use of gas oil. Associated gases and other new gasfields yield natural gases relatively rich in methane; and LPG is growing in quantities.

In Europe, the move is from naphtha towards lighter feedstocks: ethane and LPG. This trend will continue, but at a slower rate than in the recent past. However, ethane use may not be economically justified in Europe.

In the United States, the use of ethane will decline, and the use of LPG will increase, with the ethylene crackers remaining flexible to the choice of feedstocks.

In the Far East, the emphasis will be on naphtha, and in regions such as the Middle East, the use of ethane continues to be favored, but increasing use of heavier feedstocks will be considered.

29/ Chemical week, 28 March 1990, p. 24

The proportion of propylene obtained as co-product of ethylene will rise, particularly in the United States, while it will decrease in Europe where increased needs for propylene will have to be obtained from refineries.

- From the review of the world feedstock situation in the present study, it could be concluded that alternative feedstocks for the petrochemical industry are available, particularly from coal and biomass sources, and corresponding commercial processes exist to produce primary petrochemicals from these materials. Several industrial-scale plants are in operation around the world, and research is going on for new developments which will certainly surface. In the industrialized countries, also, there is a growing tendency to "stretch" petroleum by making "light-end" products from heavy ends "bottom of the barrel". However, the main obstacle to a worldwide competition from these alternatives lies in economics rather than technology or availability, as they are, in general, inherently more expensive in both investment and operation.

- Although there is a strong trend towards the production of higher-value engineering and high-performance polymers, especially in the developed regions, commodity polymers (HDPE, LDPEs, PP, PVC and PS) are continuously gaining more importance and good growth rates and are progressively expanding all over the world, including industrialized countries where these products have reached market maturity. These polymers constitute the greatest segment of the petrochemical industry accounting for over 63 million tons in 1989, about 75 per cent of which are consumed in the developed regions. World consumption of these polymers is expected to reach over 81 million tons in 1995. For the near future, LLDPE will globally exhibit the highest growth rate among other commodity thermoplastics (10-11 per cent/year), followed by HDPE and PP (5 per cent a year), and PVC and PS (about 3 per cent), and the lowest rate of growth is expected to be demonstrated by LDPE at about one per cent. Thus, commodity polymers will still hold the lead for the petrochemical industry in the future, especially in the developing countries where they will have a brighter future.

- As for the regional relative importance of the commodity polymers (bulk thermoplastics), two main factors are to be considered, the pattern of end uses reflected by the products (polymers) and the stage of market development. However, in general, HDPE is globally important because of its broad spectrum of applications. PP and PS applications are mostly concentrated in the developed regions in automobile, domestic appliances, and in packaging applications. PVC consumption is shared equally between the industrialized regions and the rest of the world. LDPE maintained its importance in Western Europe and the rest of the world, while LLDPE has quickly made significant progress in the United States.

- In the developing countries including the Middle East in particular, commodity thermoplastics will continue to represent suitable investment opportunities. For PP, the Middle East is likely to achieve a competitive position in the regional market in the short term and will gradually increase its global competitiveness in the future. PS and PVC market will exhibit increased growth in the Middle East region and will offer opportunities for petrochemical producers in the region.

- On a global basis, it seems that the prospects will continue to be LLDPE and HDPE, probably in combined swing plants.

- Although engineering and high-performance polymers have experienced high growth rates, possess higher value added and have attracted producers, they are exclusively produced, and almost exclusively consumed in the industrialized countries, as the areas for their application are not yet developed in the developing countries and not even near development in some of these regions. Moreover, the specialty product market is more customer service intensive which requires the identification of the consumers' demands and problems so that the manufacturer could tailor-make the products to suit these specific demands.

With these factors in mind and the possibility of early maturity of specialty polymers in the industrialized regions, worries have been expressed that an over-capacity could be expected. Some specific product areas are already, or will likely become, overcrowded with suppliers and therefore may face some shake-ups in the future.

- Many of the current routes for the production of most of the key petrochemicals are close to their limits in reactor design and catalyst efficiency. The processes are well established, technologies are quite proven, and per unit production capacities have reached the critical economic size in many of these products. Nevertheless, there have been continuous efforts to improve operation efficiency (optimization) through the development of higher catalysts' activities and longer life, saving energy through better heat recovery and other measures, lowering the level of wasted utilities, utilization of different feedstocks, and avoiding the use of hazardous reactants.

Thus, apart from several identified technological development targets such as the use of ethane and propane as feedstocks for the production of certain olefin derivatives (vinylchloride, acrylonitrile) and aromatics which are still not commercialized, and the production of propylene from the dehydrogentation of propane, a prospect which is still awaiting the results of the first commercial UOP unit in Thailand which is due for start-up, there is generally, no major process technology development or breakthroughs to be expected in the near future. Event of great significance, such as the production of linear low-density polyethylene (LLDPE) in the mid 1970's may occur. History proved that what could not happen, always happens.

- As a trend, research and development activities have been greatly dampened after the oil crisis and the world economic recession in the early 1980's because of the low demand, poor profits, and the relative maturity of most of the process technologies. Latley, the level of research and development has increased again for medium- and long-term strategies concentrating mainly on the fields of alternative feedstocks, such as the utilization of methanol and syngas as feedstock (C_1 chemistry), conversion of barrel bottoms to feedstock for olefin plants, innovation in conventional processes in terms of energy saving, production efficiency and cost reduction, better quality of conventional products (standard plastics), the development of new product applications, and development in high-technology fields such as electronics and biochemistry.

Research and development in process technology seems to have received less attention within the near-future strategies and is forming a minor part of research and development budgets.

However, in spite of the relatively limited defined objectives of the future research and development activities, positive accomplishments may lead to considerable development in the petrochemical industry, especially in the area of C_1 Chemistry which is considered the most interesting and promising field involving the technology of molecular rearrangements in order to create different compounds containing several carbon atoms from a simple one of only one carbon atom, methane, carbon monoxide, and methanol.

- Environmental protection, and high standards of public health and safety requirements are of top concern to the petrochemical industry. Numerous measures and great expenditure have lately been dedicated for the assurance of safe operating conditions, worker protection and adequate control of dangerous pollutants, in the form of process adjustments, and the recovery of undesired disposed materials including the proper disposal of petrochemical products, mainly plastics. Producers in developed countries have been diligently working in line with government regulations and sticking closely to the adopted standards.

However, there seem to be continuous environmental pressures, stringer acts and rules, and stricter regulations being imposed on the level of pollutant emissions and very much more on plastics disposals, including the recyclable group. This trend has been affecting producers' enthusiasm for future development of new products whose prospects regarding environmental issues can not be assessed. Examples are more restrictions on the use of polystyrene for some consumer goods, the banning of PVC production because of hydrochloric acid release during incineration, a complete ban on certain plastics such as recyclable materials in consumer packaging, etc.

11. RECOMMENDATIONS

In considering the analysis of the world petrochemical industry and its different aspects, the following recommendations may be suggested:

- Commodity plastics have a bright future, and the rate of growth of all of the five major polymers (HDPE, LDPEs, PP, PVC and PS) are steadily increasing in the developing regions, while the per capita consumption is still very low. In addition. although these commodity polymers have reached maturity, there is still room for further developments in the future, especially in producing improved grades, increased output, improved performance and processability. However, particulars concerning choice of polymers, production capacities, and others will be determined according to the detailed feasibility study for the concerned country. The production of these polymers is most promising in developing countries with high availability of energy and feedstock resources at relatively low prices.

- Research and development in the developing countries is to be directed towards downstream industry activity and marketing rather than on up-stream processes and technology.

- Support should be given to the healthy trend that developed regions are continuing to exhibit signs of avoidance of competition with the new entrees, mainly in the production of commodity polymers, and concentrate on the technology-intensive products, high-value engineering polymers and high-performance polymers, with continuing improvements in the development of the commodity polymers, for which these materials still have ample room. The globalization of the industry has consolidated the trend of new division of labor in this sector along the product lines and activities.

- Serious and close co-operation between the industrialized regions and developing countries newly entering the petrochemical industry to co-ordinate future production plans, especially for basic petrochemicals, should be encouraged, having in mind that by 1995 most of the European ethylene crackers will reach quite an advanced age: about 5.5 million tons ethylene capacity will be 20-25 years old, about 3.5 million 15-20 years old, 2.6 million 10-15 years old and 2.2 million 25-30 years old. New capacities should be deployed to areas having competitive edge in production.

- In order to avoid, as much as possible, the mistakes of overcapacity greater market transparency is needed. Thus a close network of production and marketing data is required based on interregional co-operation. This requirement is particularly important for developing countries which generally lack experience in this field.

- It is premature for the majority of the developing countries to start thinking of producing specialty petrochemicals. A gradual building-up of capabilities and marketing demand should be exercised.

- Considering the difficulties of obtaining know-how for the production of synthetic fibers' raw materials such as polyester and acrylic in the developing countries it is advised that such industries be established on the basis of joint-ventures in order to cater for the huge needs of local markets for synthetic fibers.

- Besides ethane, other alternative feedstocks for ethylene production should be considered by oil and gas rich countries to ensure the production of required by-products, propylene and butadiene, and, as much as possible, to obtain aromatics. Therefore, ethylene crackers should be built with the maximum economic flexibility which could offer the possible choice of raw materials within the technological limitations and in accordance with the availability of feedstock and the products sought from the cracking.

- It was very essential for the developing countries with petrochemical industry and for those planning to have one, to establish or further develop their research and development capabilities in petrochemicals to both serve their immediate needs and long term strategy. Such capabilities take into consideration the development of indigenous resources, adoption of new technologies to local conditions, development of new processes and technologies, improvement of products and grades of polymers and their applications and search for new products. Adequate consideration should be given to solve problems of environmental protection, public health and safety.

To establish and support R & D centers in the petrochemical producing developing countries with the required infrastructure (human and physical), as well as to promote the highest level of national, regional and international forms of co-operation, co-ordination and integration among these centers in order to save expenditure and time and to develop national and regional capabilities.