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United Nations Industrial Development Organization

Interregional Petrochemical Symposium on the
Development of the Petrochemical Industries in
Developing Countries

Baku, USSR, 21 - 31 October 1969

IID

Distribution
LIMITED

ID/WG.34/8/Rev.1
13 February 1970

ORIGINAL: ENGLISH

PET.SYMP. A/6

DEVELOPMENT IN THE ORGANIC SECTOR OF THE
EUROPEAN CHEMICAL INDUSTRY 1/

Economic Commission for Europe
(ECE)

D00338

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1. INTRODUCTION

1.1. Aim of Study

The aim of this study is:

1. To trace the basic course of developments in the organic sector of the European Chemical Industry (excluding countries of Eastern Europe) over the 1964/1967 period.
2. To indicate possible developments as of 1970 and 1975.

The three fundamental guidelines around which the study was framed are as follows:

- a) Calculation of an overall index of production for the European organic chemicals industry and of the entire chemical industry with a view to highlighting and quantifying the main trends which characterized the organic sector.
- b) Estimation of the amount and types of raw materials used in the organic sector, particularly with regard to petroleum products, so as to measure the trends of the "petrochemical" share of European organic chemicals production.
- c) Examination of the market state and prospects for a number of main basic organic chemicals to ascertain the situation as regards production and that concerning the amount and breakdown of consumption.

For each of these groups of subjects, a survey has been made of information pertaining to the 1964/1967 period, and their possible evolution up to 1975 has been ascertained.

1.2. Sources of Information

In order to obtain reliable statistics on many of the products, it has often been necessary to have recourse to the services of experts and specialists specializing in such matters. In some cases, no information or if it were false, it would have been obtained otherwise. Estimates and calculations were made by experts and organizations closely in touch with the sector.

1.3. Limits of the study

As indicated in point 1.1., the study covers only the countries of Western Europe. This region has, in turn, been broken down into two homogeneous groups of countries, the EEC and EFTA, and a heterogeneous group embracing the other European countries which do not form part of these two economic units.

In view of the difficulties involved in obtaining the required information on the basic chemicals considered, the estimates as to the breakdown of consumption by sector of use and by group of countries should generally only be taken as indicative of the order of magnitude of the phenomena and not as an exact measurement thereof. This is also the case with the forecasts for 1970 and 1975, since in many instances there is considerable uncertainty as to the importance new processes or new sectors of use may assume.

2. GROWTH IN TOTAL AND ORGANIC CHEMICAL PRODUCTION

2.1. Trends in chemical production over the 1964/67 period

The trend of total chemical production in European countries over the 1964/67 period was calculated on the CIO 1958 indices, duly weighted by the value added of the chemical industry of the individual countries. The calculation was made both for the countries of Europe as a whole and for the homogeneous groupings concerned. These indices are set forth in Table 21.

Table 21
European Chemical Production Indices (1958 = 100)

Year	EEC	EFTA	Total for Europe
1964	197	156	187
1965	217	163	205
1966	242	174	225
1967	264	182	246

These indices for the two groupings were markedly different even in 1964, which indicates that the rate of growth in chemical output of the EFTA countries was well below that of the EEC during the 1958-1964

period. This trend was further consolidated over the 1964-1967 period when the growth rate for production in the EFTA countries was around 5% per year while that for the EEC was about 10% on average. Taking the countries of Europe as a whole, the growth rate for production was virtually that of the EEC grouping because the major proportion of production facilities (about 70% in 1967) are concentrated there.

2.2. Trends in organic chemical production over the 1964/67 period

The trend of European organic chemical production was based on the OECD indices for basic organic products.

No figures are available as to what proportion of the value added of the chemical industry in each individual country is attributable to the organic sector, thus it has not been possible to break down the overall index for Europe between the EEC and EFTA. Table 22 gives the indices for the organic sector as compared with those for the chemical industry as a whole.

Table 22

Indices for the output of the organic chemical industry and for the chemical industry as a whole in Europe (1958 = 100)

Year	<u>Organic Sector</u>	<u>Chem. Ind. as a whole</u>
1964	287	187
1965	326	205
1966	371	226
1967	424	246

The first obvious point which emerges from comparison of these indices is the exceptionally rapid rate of growth in the organic sector. Indeed, over the 1958-67 period, this sector averaged around 20% per year against 10% for the chemical industry as a whole. During the 1964-67 period, this trend continued, though it was not quite so marked (approximately 14% for the organic sector, while the industry as a whole remained almost unchanged at 9.7%). However, this slowdown was due to the slight recession which occurred during these years and to the temporary problems concerning reorganization of the European chemical industry. These

difficulties, together with other factors of a technical nature, led to a delay in bringing large, new olefine plants on-stream in a number of countries. This slowdown during the years 1964 to 1967 was followed in 1968 and 1969 by a big upswing in growth in the organic sector which, in some cases, resulted in shortages in the supply of some important products.

2.3. Expected development as of 1970 and 1975

On the basis of the expected growth in European consumption of basic chemical products in 1970 and 1975 (see point 4), the indices for the probable increase in the output of organic chemicals have been calculated. These indices, reported in Table 23, indicate the probable trends of the sector in the groups of countries examined.

Table 23

Orientive indices on probable growth in output of organic chemicals in Europe: 1970 and 1975 (1967 = 100)

Year	EEC	EFTA	Total for Europe
1967	100	100	100
1970	178	177	182
1975	322	343	333

These indices can only be taken as providing a rough guide, since they have only been calculated on the basis of a number of basic products and not on the whole group of products which govern growth in the organic sector. For example, acetylene and methanol are not included.

Despite these limitations, the table clearly shows that there should be a big upswing in European production over the 1967-1970 period (+22% per year on average) but that there should be another slowdown between 1970 and 1975 (with a rate of about 13-14% per annum).

While appreciating that the forecasts to 1975 are pitched on the conservative side, at the same time this slowdown may be attributed to the onset of a quieter period after a number of years of rapid expansion, and to a change in the structural conditions in which the European chemical industry - especially the organic sector - operates. Indeed in the years following 1970, it is expected that there will be a

slackening in the growth pace of net European exports (because of the increasing amount of industrialization in some groups of countries), while deceleration in the rate at which organic products are consumed internally may also be foreseen, in view of the quite high quantitative levels which will have been reached by then.

However, as will be seen in point 4, the growth rate for some products will move ahead more quickly after 1970 because of the particular situation which will appear in Europe (nitadi ne, for example).

1. RAW MATERIALS CONSUMPTION BY THE ORGANIC SECTOR

Foreword

The main sources of raw materials consumed by the organic sector are:

- Coal and coal derivatives
- Oil and fractions derived therefrom
- Natural gas
- Vegetable oils, molasses and other vegetable products
- Fats and other products of animal origin

Up to the end of the Second World War, the importance of petroleum and natural gas as feedstocks in Europe was practically nil. However, since 1950 there has been a virtual boom in the consumption of these two products, while the demand for other raw materials has remained stationary or has decreased. These years saw the birth of the petrochemical industry in Europe.

Consumption trends for raw materials over the 1966-67 period

It should be noted at the very outset that there are absolutely no statistical data available on raw materials consumption by the organic sector. However, the output of some main organic products, by raw material source, is given in table 30, so as to provide some idea of the relative importance of these sources.

Table 32

European production of basic organic products, by raw material source

	(Thousand tons)		
<u>Raw Material</u>	1965	1966	1967
Coal	2087	1790	1615
Oil and natural gas	6008	7720	9557
Others	1127	886	878
<u>Totals</u>	<u>9223</u>	<u>10396</u>	<u>12050</u>

Source: OECD; L'Industrie Chimique

Despite any reservations and uncertainties which might attach to the way these figures were derived (they are not perfectly comparable from one year to the next, and in certain cases some countries adopt different criteria for compilation), they clearly indicate the big increase in the output of organics from petroleum oil. Indeed, while production from other sources decreased, that from oil and natural gas rose from 65% of the total to 79% between 1965 and 1967.

To place these percentages in perspective, it should be recalled that around 10 million tons of basic organic products were derived from oil and/or natural gas in 1967. Though the actual input of these items was not known, it may be calculated that this figure was well above that for the quantity of basic organics produced, merely by considering the performance characteristics of the processing plants involved. The gross input of virgin naphtha used in Europe during 1967 merely for the production of olefins and aromatics has been calculated (taking due account of a certain recovery of benzene pyrolytic aromatics from steam cracking), so as to give some idea of the amount of oil feed stock consumed by the organic sector. This calculation indicates that over 25 million tons of virgin naphtha is used for this purpose. Naturally, the figure is for gross inputs, and, of course, a large part of the virgin naphtha used is returned to the oil cycle as byproducts of the chemical processes.

3.3. Expected consumption of oil products by the organic sector in 1975

Adopting the same criteria used for calculating the consumption of virgin naphtha in 1967, an assessment has been made of the quantity the European chemical industry will require to meet the demand for olefines and aromatics in 1975 (see point 4).

Even supposing that the average severity of cracking in Europe rises from 19% in 1967 to 25% in 1975 (measured in parts of ethylene per 100 of naphtha) and that all the aromatics in the pyrolytic benzene are extracted, it is estimated that the input of virgin naphtha in 1975 will be in excess of 60 million tons. This signifies that the gross consumption of virgin naphtha by the organic sector in Europe will rise to around 35% of that produced overall by the European refineries in 1975, making due allowance for the fact that some of Europe's acetylene and methanol will be derived from this source.

4.1. Ethylene

Foreword

In order to make a thorough assessment of the present and future situation regarding ethylene and ethylene derivatives in the countries of Western Europe, it is necessary not only to examine the market for these products but also to take a look at the technical and economic trends during the years in question.

As already indicated in Point 3 on the subject of raw materials used in the chemical industry, ethylene production is increasingly coming to be based on the steam-cracking of petroleum fractions, and especially on virgin naphtha. By way of indication, it may be estimated that the proportion of ethylene produced in Western Europe starting from naphtha rose from around 84% in 1964 to 93% in 1967. However, mention must also be made of the plant planned for Spain (1) where the feedstock consists of gaseous fractions imported from Libya and of a number of other plants already in operation or on the drawing board which start from gasoil (e.g. Montecatini-Edison at Brindisi); these plants are of importance in that they provide examples of exceptions to the general trend. Nonetheless, it is not thought that in the future (at least up to 1975) gasoil or ethane (or other gaseous fractions) will increasingly be used to any extent, since it would appear that sufficient (1) It is uncertain whether this plant will actually be built.

cient naphtha will be available in Europe. Another very important factor which has accompanied the growth in European ethylene production over recent years has been the exceptional increase in the average size of new plants. Indeed, the view is now held that for an ethylene plant to be competitive internationally it cannot have a capacity of less than 200,000 tons per year, and plants capable of producing nearly half a million tons are already in operation. In general, apart from this increase in the unit capacity of the plants there is also a clearly marked trend towards more severe cracking. In point of fact, many plants now have crackers capable of producing more than 30 parts of ethylene for every 100 of naphtha feed, while around 1960 the average severity was only around 15-16%. Furthermore, in the plants where cracking is more severe, there is a very marked downswing in the percentage of products obtained along with the ethylene, namely of propylene and gasoline by pyrolysis. In the high-severity crackers, the quantity of propylene obtained is around 50% of the amount of ethylene produced, while in the low-severity units propylene production was something like 90% of the ethylene figure.

The increase in unit size of the ethylene plants has led to a big drop in the production costs of this product, because of the high factor of scale. As will be seen farther ahead, this has favoured the competitiveness of products derived from ethylene. This, in turn, has led to the rapid obsolescence of processes for obtaining certain derivatives from other basic raw materials (e.g. acetaldehyde by direct oxidation of ethylene instead of from acetylene).

A further point worthy of mention is the way certain processes, which permit the joint production of ethylene and acetylene, are gaining ground (e.g. Wulff type oxidant cracking). For certain products - monomeric vinyl chloride, for instance - these plants can, at times, be particularly advantageous.

4.1.2. Production trends over the 1964-1967 period

As can be seen from Table 412, the production of ethylene in Western Europe almost doubled over the four years in question; 1967 output being in excess of 3 million tons.

Table 412

Ethylene production in Western Europe (Thousand tons)

Grouping	1964	1965	1966	1967	Average growth rate 1964/67
EEC	1162	1369	1773	2322	26%
EEA	525	579	647	703	10%
Others	-	-	32	43	-
<u>Totals</u>	<u>1691</u>	<u>1948</u>	<u>2452</u>	<u>3068</u>	<u>22%</u>

It will be noted that the growth rate for European ethylene production maintained very high average values (over 20% per annum) despite the fact that output is running at a relatively high level. In general, high growth rates such as these are typical of the initial years after the introduction of new products, and they tend to fall off fairly rapidly when the quantity produced rises to any significant extent. The fact that this has not happened in the case of ethylene (except perhaps to a very limited extent) can be traced to two reasons. Firstly there is the very dynamic state of the market for products derived therefrom - as will be seen in Chapter 4.1.3. dealing with sectors of use - and secondly because the trend of ethylene production costs has made it profitable to adopt processes starting from ethylene rather than from other materials (e.g. PVC from ethylene rather than from acetylene).

The enhanced rate at which Europe's production of ethylene has grown derives particularly from the fact that the Common Market countries have increased output over the period in question at about 26% per annum, namely at virtually the same rate as in the preceding four-year period (1961-1964). In the EFTA countries, on the other hand, development has been relatively slow; this situation stems from economic factors concerned with the growth of sectors using ethylene and from the fact that there were delays in completing some plants planned for the U.K., which only came on stream during 1968. The output of the other Western European countries is still in the early stages, and only Spain is actively involved.

4.1.3. Consumption trends and user sectors

Since to date international trade in ethylene is relatively small, European consumption of this product to all intents and purposes is the same as production. Hence the remarks made in the previous point hold good.

The breakdown of ethylene consumption in the three European groupings considered, for the 1964-67 period, is shown in Table 413.

The most significant changes which occurred during the period may be summed up as follows:

- There was a big increase in the importance of polyethylene. Of the total amount of ethylene consumed polyethylene's share rose from 46 to 52% in the EEC and from 49 to 56% in EFTA. Polyethylene accounted for a very large proportion of ethylene consumption in the other countries, but this level cannot be considered significant since, in 1967, ethylene consumption in these countries had barely started and thus the use-breakdown by sector could not really be indicative.
- There has been a considerable increase in the consumption of ethylene for the production of vinyl chloride (both by cracking dichloroethane and by oxychlorination). The share attributable to this sector rose from 3.7 to 9% in the Common Market countries and from 4.4 to 7% in those belonging to EFTA. This upswing derives from the increasing economies possible by using ethylene as the starting point for the process rather than acetylene as was previously the case.
- There has also been an increase in the use of ethylene for some items grouped under the heading "Other products", especially for linear olefines and alcohols and for ethylene-propylene rubbers. Although from the quantity angle these products assume but modest proportions, their importance is destined to increase in the coming years. This point emerges more clearly from the forecasts made in 4.1.6., but the basic fact is that these products are still in the initial stages of development and the possibilities for their use are very promising.
- The proportion taken for the production of ethylene oxide has fallen. This is because there have been only slight increases in some important

Table 413

ETHYLENE CONSUMPTION BY DERIVATIVES IN WESTERN EUROPE COUNTRIES IN 1964 AND 1967

Derivatives	Years	EEC		EFTA		Others		Total	
		(1000t)	%	(1000t)	%	(1000t)	%	(1000t)	%
Styrene	1964	510	16.1	277	43.7	-	-	305	10.9
	1967	1,211	22.0	493	33.5	65	34.6	1,666	31.0
Ethylene oxide	1964	275	23.9	120	21.2	-	-	195	23.0
	1967	423	18.2	121	17.2	5	6.4	539	17.7
Methylbenzene	1964	105	9.1	40	7.1	-	-	145	9.5
	1967	201	9.6	56	8.0	-	-	257	9.3
Vinyl chloride	1964	65	5.7	25	4.4	-	-	90	5.3
	1967	206	8.4	48	6.8	-	-	254	8.9
Methanol	1964	35	4.8	25	15.0	-	-	120	8.2
	1967	67	2.9	60	6.5	-	-	127	4.1
Acetaldehyde	1964	100	8.7	-	-	-	-	100	3.8
	1967	143	6.1	-	-	7	9.0	150	4.8
Others (1)	1964	20	1.7	20	3.6	-	-	40	2.3
	1967	78	3.3	28	4.0	-	-	106	3.3
Total ethylene cons.	1964	1,150	100.0	565	100.0	-	-	1,715	100.0
	1967	2,328	100.0	703	100.0	78	100.0	3,109	100.0

(1) Linear alcohols and aldehydes, EP and EPT rubbers, ethyl chloride, etc.

uses of the ethylene glycol which is derived therefrom (especially for the preparation of antifreezes). Nevertheless, the consumption of ethylene for the production of this oxide is still second only to that for the production of polyethylene.

- The proportion destined for the production of acetaldehyde and ethanol has also decreased. In the case of the latter item, there has also been a downwarding in the absolute quantity of ethylene consumed on the European level. This particular situation is due mainly to the position in the U.K. where aldehydes, and hence acetic acid, were originally produced from ethylene, but with the construction of a new plant, acetic acid is now synthesized directly from petroleum fractions.
- The share of ethylbenzene has remained practically unaltered. It should, however, be noted that a growing percentage of this latter item is now being obtained by extraction from C₈ fractions in aromatic separation plants. Ethylbenzene from this source, which, of course does not involve ethylene, has, with the slow rate of growth in the consumption of products derived therefrom (mainly styrene, butadiene rubber and polyethylene) and with the slow rate of growth contributed to the growth rate for the consumption of ethylene for ethylbenzene at around the general average for ethylene.

4.1.4. Productive capacity

Ethylene production capacities for the countries of Western Europe are set forth in Table 414.

Table 414

Ethylene production capacities for Western Europe: 1967, 1970 and 1975

(Thousand tons)

Grouping	1967	1970	1975
EEC	1400	5500	7100
EFTA	1025	1900	2000
Others	140	300	300
Totals	4565	7700	9400

As always, when it is a question of comparing information on productive capacity, the further one delves into the future the less information there is available. In general, this results in there being a slowdown (largely fictitious) in the forecast growth rate in productive capacity. Indeed, while the growth rate for the 1967-70 period (for which complete data are available) is in excess of 20% per annum, the expansion plans announced for ethylene production over the 1970-75 period would indicate a figure of only a little over 4% per annum.

Since it is doubtful that there will be such a slowdown, it is to be expected that by 1975 Europe's ethylene production capacity will be well above the 4.6 million tons per year indicated in Table 414. This surplus is also partly born out by the forecast level of consumption at that date (see point 4.1.5.).

Taking a look at the 1967 figures, it would appear from a comparison of the capacity data given in Table 414 and the production data in Table 412 that the plant utilization factor is between 60% and 65%. However, this conclusion is only partially correct, since a further understanding of the figures must be remembered that many of the plants were in stream starting 1967 and that these would have had several months to work up to full production.

Except in particular cases, it is not thought that the size of the obsolete plants which should therefore gradually be shut down, would substantially modify the order of magnitude of the total capacity figures indicated above.

4.1.5. Expected growth in consumption: 1970 and 1975

It is particularly difficult to try to forecast trends in the consumption of ethylene since basically this entails indirectly forecasting the development of a large section of the European organic chemical industry. Indeed, ethylene is the starting point for some of the most important synthetic resins (polyethylene, PVC and polystyrene), synthetic rubbers (SBR) and synthetic fibres (polyesters).

The forecasts have been made by starting from the main primary derivatives (e.g. ethylene oxide) and by examining the expected trends

on the internal market and possible exports for the end products obtained from each of these. Of course, the expected productive capacity trends for the intermediate and end products have also been considered in this examination, the results of which are summarized in Table 415.

From a first overall examination, it would appear that up to 1970 the growth rate in European consumption of ethylene should remain practically the same as that over recent years, namely, a little over 20% per annum. Then, in the years up to 1975, the growth rate should slow down slightly and has been considered to be around 17% per annum.

The foregoing remarks which apply to the countries of Western Europe as a whole basically hold good for each of the three geographic areas considered. For EFTA countries and "Other countries", however, it is thought that the expected slowdown after 1970 will not be so marked as in the EEC group. This is because in some of these countries consumption will still be in the initial stages of the growth (the fastest stage) or, in other cases, because plant capacity will have to be increased considerably to ensure costs remain internationally competitive.

On the subject of growth in main derivative products, it must be stated first and foremost that the synthetic resins (polyethylene and PVC) will yet again account for an even larger share of total ethylene consumption, moving up from 64 to 67%. This derives essentially from the fact that consumption for PVC will continue to move ahead at a rate above the average for ethylene consumption as a whole, since some of the PVC presently made starting from acetylene will be synthesized from ethylene instead.

Polyethylene deserves to be dealt with separately, in view of the fact that it occupies the number one position in the ethylene-use table (over 50% of all ethylene produced is used to make polyethylene). Despite the fact that production of this resin has already reached elevated levels (1.6 million tons in 1967), the demand on the internal European and export markets is likely to remain so great that it is expected to double, approximately by 1970 (over 3 million tons) and to double again by 1975. Apart from the two types of polyethylene presently on the market (high and low density), the production of ethylene copolymers with small percentages of propylene and butylene will assume increasing and ever-more marked importance, since by

Table 415

FORECAST ETHYLENE CONSUMPTION IN WEST EUROPEAN COUNTRIES TO 1970 and 1975
('000 t of ethylene)

Derivatives	Year	ETC	NETA	Others	Tot. Western Europe '000 t	%
Polyethylene	1967	1.210	390	66	1.666	53.0
	1970	2.390	650	135	3.175	52.0
	1975	5.000	1.300	200	6.500	54.0
Ethylene oxide	1967	423	121	5	549	17.7
	1970	650	300	25	975	16.0
	1975	1.200	550	40	1.790	14.5
Ethylbenzene	1967	201	56	-	257	8.3
	1970	380	90	37	507	8.3
	1975	680	150	70	900	7.5
Vinyl chloride	1967	200	43	-	254	8.2
	1970	620	115	-	735	12.0
	1975	1.190	290	90	1.570	13.0
Swit. ethanol	1967	67	60	-	127	4.1
	1970	175	75	-	250	4.0
	1975	250	100	-	350	2.9
Acetaldehyde	1967	143	-	7	150	4.3
	1970	245	-	18	263	4.3
	1975	430	-	20	450	3.7
Others (1)	1967	78	28	-	106	3.3
	1970	160	50	-	210	3.4
	1975	300	100	30	430	3.5
Total	1967	2.328	703	78	3.109	100.0
	1970	4.620	1.250	215	6.115	100.0
	1975	9.100	2.600	450	12.000	100.0

(1) Linear alcohols and olefins, EP and EPT rubber, ethyl chloride etc.

this method it is possible to vary the characteristics of the resulting resin over a very wide range. Naturally, this will mean that the resins will find a place in new applications and be such as to meet the increasingly severe requirements of the processors.

Polystyrene is another very important resin derived from ethylene (this is the most important sector in which ethyl benzene is used). Consumption growth possibilities for this resin are good (especially in the case of expanded polystyrene) but slightly less so than for polyethylene. Of the other ethylbenzene derivatives with good growth prospects must also be numbered the ABS (acrylonitrile - butadiene - styrene) copolymer the production of which should top the 150,000 ton mark in 1975. Synthetic rubbers of the SBR type (styrene - butadiene) will, on the other hand, tend to brake the growth rate in the demand for ethyl benzene inasmuch as production of these rubbers in Europe over the coming years will only advance at about 5-6% per annum. Indeed, this is the commonest type of rubber among those which have been on the market for any length of time and hence the most liable to suffer from competition exerted by newer synthetic rubbers in the various sectors of application.

Apart from synthetic resins, ethylene glycol (derived from ethylene oxide) will assume considerable importance for the production of polyester fibres. By way of indication, it may be estimated that by 1975 some 20% of the oxide produced will be used for making synthetic fibres, as against 10% in 1967. The call for the oxide (as glycol for polyester) is without doubt the most dynamic sector of consumption for this product. Nonetheless, the overall growth in oxide will be considerably less rapid than that for polyester film because other important oxide-consuming sectors, especially antifreeze for vehicles (antifreeze consists essentially of glycols), will continue to advance at only a relatively moderate rate.

It is expected that over the 1967-75 period there will be a considerable growth in the consumption of ethanol and acetaldehyde from ethylene, especially because of the demand for these products for polyvinyl acetate and solvents of the acetic series. In the case of aldehyde in particular, the upswing in output will be fairly high both because of market

factors and because plants starting from acetylene will not be so competitive. However, the already modest role played by these two products as regards total consumption of ethylene is destined to decrease even further in the future.

The term "other products" covers ethylene-propylene rubbers (copolymers and terpolymers), ethylene-vinyl acetate copolymers, ethyl chloride, dibromoethane, straight-chain alcohols and olefines obtained by polymerisation of ethylene, etc. Some of these very numerous products have been on the market for a long time (e.g. dibromoethane and ethyl chloride) though others have only been recently introduced on an industrial scale (ET rubbers, higher straight-chain alcohols, etc.). The growth prospects for certain of this latter group appear quite promising, though in some cases there are still difficulties to be overcome from the technical and applications aspects (e.g. difficulties encountered with the ET rubbers in tyre production): so far, these have slowed down the development potential.

4.2. Propylene

4.2.1. Foreword

Though propylene can be produced on an industrial scale by a variety of processes (extraction from refinery gas, dehydrogenation of propane, cracking of C_3-C_4 gaseous fractions) the bulk of Europe's output comes from the steam-cracking of virgin naphtha, when it is obtained along with ethylene. Indeed, as mentioned in the previous chapter, for each 100 parts of ethylene produced by cracking naphtha, between 50 and 90 parts of propylene are also obtained, depending on the severity of the cracking process. Since most of the cracking plants are built to satisfy the strongly increasing demand for ethylene, this has resulted in most European countries having an excess of propylene. In point of fact, until quite recently there was no possibility of using all this propylene for chemical purposes at many of the installations, and so it was utilized as a heat source. Naturally, this led to the production costs of the main product - ethylene - being higher.

Work has followed two major lines to overcome this difficulty:

1. the severity of the cracking has been increased, thus reducing the quantity of propylene produced per unit of ethylene
2. research on the chemistry of propylene has been intensified with a view to boosting the demand for chemical purposes (thus ensuring a greater economic return).

As a result of these efforts, processes have been worked out for the synthesis of acrylonitrile (from propylene and ammonia), for stereospecific polypropylene and for the oxidation of cumene industrially for the production of phenol, etc.

4.2.2. Production trends over the 1964-67 period

Before commenting on European production of propylene, it should be made clear that this refers solely to separated propylene (generally highly concentrated), and not to the total amount of propylene obtained from the steam-cracking plants, and - to a lesser extent - from some refineries too. In actual fact, it often occurs that the propylene produced is not separated but is used, along with other gases, as fuel. Consequently, the stated propylene production as shown in table 422 constitutes but a part of the propylene theoretically available. In 1964, for example, only 35% of the propylene theoretically produced was separated and then used as such. It should, however, be added that as a result of the combined effect of the two lines of action indicated in point 4.2.1., the proportion of totally available propylene separated over the 1964-67 period has risen sharply. Indeed, the 1967 declared production of propylene (1.9×10^6 tons) was equal to around 40% of the total propylene obtained from the steam-crackers.

European propylene production trends over the four-year period in question are shown in table 422.

Table 422

EUROPEAN PROPYLENE PRODUCTION - 1964-67

(Thousand tons)

Grouping	1964	1965	1966	1967	Average annual growth rate
EEC	707	859	1140	1483	28.0
EFTA	243	275	336	408	18.9
Other countries	-	-	8	40	-
Totals	950	1134	1484	1931	27.0

The average annual growth rate for propylene production over the 1964-67 period (about 27%) is higher than that for ethylene over the same period. This is due to the fact that the first large plants using the newly perfected processes (especially for acrylonitrile, polypropylene and oxo-alcohols) came on stream.

Turning to the breakdown of production by geographic area, it will be seen, on comparing table 422 with the ethylene production table, that the EEC accounts for a larger percentage of Europe's propylene production than for its ethylene output. This is because of the greater development of the production of phenol via cumene and of detergent bases derived from propylene in the Common Market countries over the period under review.

4.2.3. Consumption trends over the 1964-67 period

The consumption breakdown given in table 423 refers solely to propylene for chemical use. Comparing these figures with those for production in table 422 (there is little international trade in this item) it will be seen that only some 10% of the propylene produced in Europe (as effectively separated propylene) goes for uses other than chemical. In fact, these are generally "energy" uses (GPI mixes or refinery use in alkylation or polymerization plants for gasoline)

Table 423

CONSUMPTION OF PROPYLENE FOR CHEMICAL USES - 1964-67
(Thousand tons)

Grouping	1964	1965	1966	1967	Average annual growth rate
EEC	630	790	1030	1280	17.0
EFTA	250	250	300	380	15.0
Other countries	-	-	-	10	-
Totals	880	1040	1330	1670	24.0

It should, perhaps, be mentioned that in some instances the reported difference between production and consumption for chemical use may be due to difficulty in obtaining exact and exhaustive statistics both on the production and uses of propylene. Hence, the figures in the preceding tables must be viewed only as a reliable indication of the order of magnitude of the factors under examination, and not a precise measurement of them.

4.2.4. Assessment of the chemical uses of propylene

Up to around 1964, the chemical uses of propylene in Europe mainly concerned the production of intermediates for synthetic detergents (propylene tetramer and - for some special types of surfactants - trimer), iso-propyl alcohol (most of which are used for making acetone) and of propylene oxide (almost entirely converted to glycols and polyethers). The production of glycerine from propylene has never been of any great importance in Europe.

As will be apparent from table 424, the trend of these uses was fairly reasonable over the 1964-67 period, but the growth rates (apart from that for the oxide) were not high. As a consequence, these products accounted for but 43% of the total European consumption of propylene in 1967. One of the main reasons for this slowdown is the almost complete disappearance of tetramer production in Germany as a result of legislation which demands the use of bio-degradable products for synthetic detergents.

Neither polypropylene nor the oxo-alcohols have been included among the above-mentioned products for which the use of propylene had reached significant levels in 1964. This is because production on a large scale had barely got under way in 1964. Hence, they are to be considered among the "new" products in the range of chemical uses of propylene. As such, there has been a rapid growth rate (especially in the case of oxo-alcohols) during the review period. Indeed, by 1967 they accounted for 30% of the total consumption of propylene, against some 20% in 1964. Between 1964 and 1967 the production of acrylonitrile from propylene and ammonia also got under way on a wide scale. As mentioned earlier, before these new plants were constructed, the whole of Europe's acrylonitrile output came from processes using acetylene and hydrocyanic acid.

The breakdown of propylene consumption among the three groups of countries shows some typical features. Leaving aside the "other countries" where the chemical utilization of propylene had hardly started in 1967, the main differences between the EEC and EFTA may be summed up as follows:

1. Cumene production was more important in the EEC countries while the opposite was the case with isopropyl alcohol. The main reason for this is that phenol production is not so important in the EFTA group (especially in the UK) since hardly any nylon 6 (and hence caprolactam) is made; hence, in these countries acetone must be synthesized almost exclusively from isopropyl alcohol. In the Common Market countries, on the other hand, the sustained demand for caprolactam for nylon 6 strongly stimulated the demand for phenol (then largely made from cumene) which led to a big output of acetone as a co-product.
2. The production of detergent bases from propylene is of greater importance in the EEC than in the EFTA. This is because the EFTA countries have used other bases for detergents for a considerable time and because part of the tetramer was imported.

4.2.5. Growth in productive capacity

Before examining the figures in table 425, it should be made clear that the declared propylene capacities are, in some cases, open to discussion. This is because it is not always apparent whether the indicated

Table 424

PROPYLENE CONSUMPTION BY MAIN CHEMICAL DERIVATIVES IN EUROPEAN COUNTRIES
IN 1964 AND 1967
('000t of propylene)

Derivatives	Years	EEC	EFTA	Others	Total Europe	% of Total
Acrylonitrile	1964	-	-	-	-	-
	1967	140	40	-	180	10.8
Polypropylene	1964	45	19	-	64	7.3
	1967	110	50	...	160	9.6
Cumene	1964	127	23	-	150	17.0
	1967	210	40	-	250	15.0
Propylene Oxide	1964	55	25	-	80	9.1
	1967	120	40	-	160	9.6
Oxo Alcohols	1964	55	50	-	105	12.0
	1967	270	85	-	355	21.3
Isopropyl Alcohol	1964	143	102	-	245	27.9
	1967	230	95	10	335	19.5
Others (1)	1964	205	31	-	236	26.7
	1967	200	30	-	230	14.2
Total propylene consumption	1964	630	250	-	880	100.0
	1967	1.280	380	10	1.670	100.0

(1) Mainly tetramer, trimer and synthetic glycerine

capacity is the theoretical capacity (for potentially available propylene) or the actual capacity (i.e. the capacity of the separation plant). However, taking the most probable assumption that in the future the separation capacity will tend to approach the potential capacity, examination of the declared capacity will thus provide a useful guideline.

The situation as of 1967 and the forecast for 1970 and 1975 (on the basis of known projects) is shown in table 425.

Table 425

PRODUCTIVE CAPACITY FOR PROPYLENE IN EUROPE (1967) AND FORECASTS FOR 1970 AND 1975
(Thousand tons)

Grouping	1967	1970	1975	Average annual growth rate	
				67 - 70	70 - 75
EEC	2210	3030	3350	11.1	2.0
EFTA	740	1250	1420	19.0	2.6
Other countries	50	150	300	33.0	15.0
<u>Totals</u>	<u>3010</u>	<u>4430</u>	<u>5070</u>	<u>13.7</u>	<u>2.7</u>

Comparing these figures with those for ethylene, it will be seen that the expected increase in propylene capacity over the coming years is lower. As mentioned, this is due to the increased severity in cracking. Taking a European average, cracking severity should pass from 66 parts of propylene per 100 parts of ethylene in 1967 (average-severity cracking) to 53 parts in 1975 (high-severity cracking).

Again, in the case of propylene, the 1970 and 1975 projections have been made starting from the expected developments in the internal European markets and from the possibilities of exporting products derived from propylene (taking due account also of the expected production capacity for these), and working back to the demand for propylene generated by these items.

The results are summarized in table 426.

Table 426

FORECAST PROPYLENE CONSUMPTION IN WEST EUROPEAN COUNTRIES TO 1970 AND 1975
(1000 t of propylene)

Derivatives	Years	EEC	EFTA	Others	Total Europe	% of total
Acrylonitrile	1967	140	40	-	180	10.8
	1970	500	250	-	750	23.5
	1975	1,020	650	...	1,730	30.0
Polypropylene	1967	110	50	...	160	9.6
	1970	210	120	20	350	10.9
	1975	580	310	50	970	16.4
Cumene	1967	210	40	-	250	15.0
	1970	300	60	-	360	11.2
	1975	400	100	...	500	9.3
Propylene Oxide	1967	120	40	-	160	9.6
	1970	190	60	20	270	8.2
	1975	280	100	35	415	7.2
Oxo Alcohols	1967	270	35	-	355	21.3
	1970	450	120	20	650	20.5
	1975	800	220	35	1,115	19.4
Isopropyl Alcohol	1967	230	95	10	335	19.5
	1970	300	140	25	465	14.0
	1975	350	210	30	590	10.2
Others	1967	200	30	-	230	14.2
	1970	300	65	-	365	11.0
	1975	350	70	...	420	7.4
Total Propylene consumption	1967	1,230	380	10	1,670	100.0
	1970	2,250	900	35	3,235	100.0
	1975	3,850	1,750	150	5,750	100.0

The main points which emerge from an analytical examination of the figures in this table are as follows:

- a) There will be a very big growth in the demand for the "new" products - especially vinyl acetate copolymerization - which, by 1975, will take some 45% of the propylene oxide in Europe by the chemical sector.
- b) Oxidation and propylene oxide will develop apace.
- c) Cumene and isopropyl alcohol will grow very slowly in comparison with the rates for other propylene derivatives.
- d) Among the former products there are some which it is presumed will diminish considerably in demand (e.g. propylene for repair), while others should experience developments. Of this latter group, there are the ethylene-vinyl copolymer (especially the copolymer), the use of propylene as a copolymer with styrene for making certain types of polymers, etc.

The reasons why it is expected that the production of acrylonitrile from propylene will develop so rapidly is to be found:

- 1) in the favourable prospects of the markets for products which use acrylonitrile (especially in the fibres, output of which should grow at 20% per annum up to 1975)
- 2) in the substitution of a acrylonitrile-from-acetylene processes (these plants will be phased out) by acrylonitrile-from-propylene processes
- 3) in the favourable possibilities of exporting acrylonitrile outside Europe

There will be a big increase in consumption of polypropylene in the coming years. Demand will be stimulated by the fact that larger plants, improved technology and the lifting of present restrictions in many countries will lead to a reduction in price which will enable the product to be placed in a number of new uses. It is also expected that stereoblock copolymerized polypropylene (polyallomers) will find widespread application, thus considerably increasing the utility of the product in question.

The future growth of propylene oxide will depend on trends in the two main sectors where it is used, namely flexible expanded polyurethane resin (which should move ahead strongly) and unsaturated polyester resins. With regard to the latter, if, as seems likely, it is possible to work up large-scale processes for automating the pressing system to a large extent, there could be a marked increase in demand for resin and thus for propylene oxide.

It should be noted, moreover, that the development of new processes for the direct oxidation of propylene (and hence the foreseeable reductions in production costs) could contribute to a greater or lesser extent to more widespread oxide consumption. As a result the envisaged growth rates for consumption up to 1975 could be somewhat higher.

Cumene and isopropyl alcohol will be discussed together since both are used for the production of acetone. However, while until recently it was supposed that the isopropyl alcohol method did not offer any interesting prospects since an increasing quantity of acetone was being obtained as a by-product of the oxidation of cumene, it is now thought that there will still be room for isopropyl alcohol in the future. This is because cyclohexane is being increasingly used instead of phenol for producing cyclohexanone. As a result, there has been a decrease in the growth rate of phenol consumption to a level below that expected for acetone.

4.3. Butadiene

4.3.1. Foreword

Butadiene was first produced on an industrial scale between the two wars, as a starting material for the synthesis of Buna-type synthetic rubber. Indeed, from the chemical aspect, butadiene is the product whose structure most closely resembles isoprene (methylenbutadiene), which is the basic monomer of natural rubber. Since rubber was difficult to synthesize in those days at a reasonable cost, industry turned to butadiene.

Many processes were developed for the industrial production of butadiene, the main ones being:

- .From acetylene and acetaldehyde followed by aldolization
- .From ethanol and acetaldehyde (derived from the former),

- .By dehydrogenation of n-butane or n-butylene
- .By separation from other C₄ fractions obtained during steam-cracking.

To all intents and purposes, the first two processes were the only ones used during and immediately after the Second World War.

In the post-war period when the production of synthetic rubber was freed from defence restrictions, industry turned to dehydrogenation processes, since not only were these cheaper, they also started from raw materials which were more widely available.

When the production of synthetic rubber got under way in Europe in 1958 (particularly the synthesis of the SBR type) butadiene was generally obtained by dehydrogenation of C₄ fractions. Italy was the sole exception. For a number of years this country made butadiene from acetylene but later went over to the n-butane dehydrogenation process.

Nowadays, most of the butadiene produced in Western Europe is obtained by separation from other C₄ fractions which result from steam-cracking processes for ethylene production. In these steam-crackers, between 15 and 30 parts of butadiene are produced for every 100 parts of ethylene (depending on the severity of cracking). The cost of butadiene made in this manner is low, since all that has to be done is to separate it from the other C₄ hydrocarbons with which it is mixed.

This latest advance in the technology of butadiene production is particularly important, for the following reasons:

- 1) It ties availability of butadiene to the production of ethylene, the demand for which is growing much faster than the demand for butadiene.
- 2) It will create an availability of butadiene in Europe at costs well below those in the States where the proportion of ethylene produced by naphtha cracking is still relatively low, though on the increase.

These two reasons may provide the premises for important changes in the future prognosis of production in certain sectors of the European and American organic chemicals industry. Some facets of this are discussed in Point 4.3.6.

4.3.2. Production trends over the 1964-67 period

As can be seen from table 432, European production of butadiene over the period under consideration grew at a fairly moderate rate (about 15.2% per year) to reach 520,000 tons in 1967.

Table 432

Butadiene Production in Western Europe

(Thousand tons)

Grouping	1964	1965	1966	1967	Average annual growth rate
EEC	240	300	336	402	13.7
Efta	100	110	115	113	4.2
Other countries	-	-	4	5	-
Totals	340	410	455	520	15.2

Some 40% of Europe's butadiene output in 1964 was produced by dehydrogenation, but this figure had dropped to around 20% by 1967.

Since the amount of butadiene which can be obtained from the C₄ fraction of steam-cracking will, in the near future, largely exceed the European demand for this product, it is to be expected that the dehydrogenation plants (with their more costly product) will be gradually phased out. As a result, for a time, the excess of production over expected European demand should be reduced.

4.3.3. Consumption trends over the 1964-67 period

The consumption of butadiene in Europe, over the period in question, increased more slowly than output. Hence, what was once a shortfall gradually came to be a surplus. Indeed, until 1966 European countries were net importers of butadiene to the tune of 20,000-30,000 tpy. In 1967, on the contrary, the situation changed completely and European production was in excess of consumption.

This trend should become even more accentuated in the coming years, and according to some sources, Europe will be producing some 150,000 tons in excess of requirements by 1970, and 250,000 tons by 1975.

4.3.4. Sectors of use

Virtually all the butadiene consumed goes for chemical uses, direct use being limited to some minor quantities utilized as a propellant.

Almost all the butadiene destined for chemical uses went for the production of synthetic rubbers (around 91% in 1967). Most of the remainder went for the production of ABS resins (acrylonitrile-butadiene-styrene). One other chemical use worthy of note is the production of butadiene trimer (used as a basic material for making Nylon 12).

Regarding synthetic rubbers, up to 1962 butadiene was only used for the production of the SBR type (styrene-butadiene rubber). This is one of the most important rubbers in general use, and finds particular application in the construction of light tyres (for cars) and for technical purposes. A small percentage was also used for the production of nitrile rubbers (butadiene-acrylonitrile) which find technical application where good resistance to oil and solvents is required. The production of 1,4-cis polybutadiene (a rubber with a regular stereo-structure) started in Europe in 1962. As can be seen from table 434, output of this type of rubber increased rapidly and by 1967 it accounted for 11-12% of all synthetic rubbers made in Europe. However, the importance of polybutadiene as a sector using butadiene is much more marked (it accounted for 21 of all butadiene consumed in 1967) because the specific consumption of butadiene for this type of rubber is 1.15, as against 0.65 (average for all types) in the case of SBR rubbers.

Polybutadiene is used exclusively in mixes with other rubbers because of the difficulties involved in processing this rubber. Since polybutadiene is very abrasion resistant it is not surprising that its major use (80-90%) is for tyre treads, mixed with SBR. The remainder is used by the shoe industry and for the production of shockabsorbing polystyrene.

The production of butadiene trimer (cycloolefentriene), used for synthesizing Nylon 12, has developed on an industrial scale during the

Table 434

BUTADIENE CONSUMPTION BY MAIN CHEMICAL DERIVATIVES IN EUROPEAN COUNTRIES
IN 1964 AND 1967
('000t of butadiene)

Derivatives	Years	FRG	FRYA	Others	Total Europe	% of total
SB rubber	1964	190	71	-	261	71.9
	1967	242	82	6	330	61.0
Polybutadiene	1964	61	6	-	67	18.0
	1967	70	23	2	95	18.0
Nitrile rubber	1964	11	3	-	14	3.9
	1967	19	5	-	24	4.9
ABS resins	1964	6	2	-	8	2.2
	1967	12	5	-	17	3.1
Others (1)	1964	3	2	-	5	1.4
	1967	15	3	-	18	3.7
Total butadiene consumption	1964	271	85	-	357	100.0
	1967	366	118	8	492	100.0

(1) Mainly butadiene trimer and tetrahydrophthalic anhydride.

last few years, especially in Western Germany. Up to now, Nylon 12 has only found limited application for the forming of mechanical parts which call for great precision and corrosion resistance.

The use of butadiene for the production of tetrahydrophthalic anhydride (for special polyester resins) and tetrahydrophthalimide (used in some pest control products) should also be noted.

4.3.5. Production capacity

As indicated in table 435, the productive capacity for butadiene should reach 1.7 million tons per year by 1975.

Table 435

PRODUCTIVE CAPACITY FOR BUTADIENE IN WESTERN EUROPE (Thousands tons)

Grouping	1967	1970	1975
EEC	470	940	1150
EFTA	150	300	510
Other countries	10	10	50
Totals	630	1250	1710

These figures also include butadiene made in dehydrogenation plants which account for 200,000 tons approx. and which, it is expected, will gradually be phased out. Making allowance for this factor, the available capacity would then be around 1.1 million tons in 1970 and 1.5 million in 1975.

Comparing the productive capacity for butadiene from steam cracking in 1967 with that for ethylene, it is seen that the butadiene capacity merely accounted for a little over 10% of that for the reference product.

The theoretical availability of butadiene from medium severity steam cracking (as prevailed in 1967) was approximately 20% of that for ethylene. Thus, it can be seen that many small ethylene plants did not find it

worthwhile splitting out the C₄ fractions which carry the butadiene. However, by 1975 the expected butadiene capacity is estimated to be around 16% of the ethylene capacity; this corresponds almost exactly to the theoretical availability with high-severity cracking.

This result will be made possible by the big upswing in the average dimensions of the cracking plants which, in almost all instances, makes the extraction of butadiene a worthwhile proposition.

4.4.6. Consumption forecasts for 1970 and 1975

It was particularly difficult to frame European butadiene consumption figures for 1970 and 1975 (table 436), since there will be substantial changes in the structure of butadiene production in Europe over this period, and hence in production costs too. Indeed, an overall shortage of butadiene (necessitating the use of dehydrogenation plants) will become transformed into a considerable excess vis-à-vis forecast requirements. As stated, this will result in the dehydrogenation plants being shut down, since their costs are higher than those extracted butadiene from steam-cracked C₄ fractions. The expected excess of butadiene in Europe could be dealt with by recourse to one or more of the following alternatives:

- 1) Development of new applications: The expected excess will possibly lead to substantial reductions in the price of butadiene because of competition. Thus, a fillip will be given to development of processes using butadiene as the starting point, rather than other materials presently utilized. By way of example, mention may be made of processes for the production of chloroprene (monomer used for making synthetic neoprene-type rubbers) based on butadiene rather than other processes using acetylene. Then there are those for the production of nitrile (from which is derived hexamethylene diamine and then Nylon 6/6) as well as the ones for production of the trimer (from which Nylon 12 is derived), etc. Some of these processes, or others not mentioned, could have huge possibilities for growth, since they cut production costs of the derivatives. Hence, these could be utilized in sectors which were previously closed to them. For instance, at the moment, it is considered that Nylon 12 and neoprene can only be utilized for special applications, owing to

Table 436

FORECAST BUTADIENE CONSUMPTION IN WEST EUROPEAN COUNTRIES TO 1970 AND 1975
('000t of butadiene)

Derivatives	Years	TRC	BTVA	Others	Total Europe	% of total
SB Rubber (1)	1967	242	82	6	330	67.0
	1970	260	110	30	400	55.5
	1975	430	170	50	650	56.0
Polybutadiene	1967	78	23	2	103	21.0
	1970	155	40	15	210	28.2
	1975	205	90	25	320	27.7
Nitrile rubber	1967	19	5	-	24	4.9
	1970	24	14	-	38	5.1
	1975	40	20	...	60	3.2
AKG resins	1967	12	5	-	17	3.4
	1970	22	10	-	32	4.3
	1975	50	20	...	70	6.0
Others (2)	1967	15	3	-	18	3.7
	1970	40	5	-	45	5.9
	1975	50	10	-	60	5.1
Total butadiene consumption	1967	366	118	8	492	100.0
	1970	521	179	45	745	100.0
	1975	775	310	75	1,160	100.0

- (1) Conventional SBR and emulsion type (Solprene)
(2) Chloroprene, adiponitrile, trimar, etc.

their high cost. Should their price drop markedly, their market would expand greatly.

- 2) Export of Butadiene: In view of the different structure of the American petrochemicals industry, most of the butadiene produced in the USA in the coming years will still be derived by dehydrogenation. Thus it could well be that the Americans will consider it worthwhile importing large quantities from Europe rather than keeping their old dehydrogenation units on stream and/or building new ones though naturally the country will certainly retain sufficient domestic capacity to meet strategic demands.
- 3) Export of derived products: The favourable position which will prevail in Europe regarding supplies of butadiene will make the export of butadiene derivative products particularly competitive on the international markets. Thus, taking things to an extreme, it might be worthwhile promoting new initiatives in traditional sectors which utilize butadiene, since the resultant products could be profitably placed on world markets.

In view of what has been stated, it will be appreciated just how difficult it is to forecast European consumption of butadiene in 1975, because at the present time it is still impossible to evaluate what weight each of the foregoing alternatives may have.

Naturally, the figures in table 436 take account of these factors while at the same time they are based mainly on information presently available as to new plants which it is thought will be built before 1975. In the case of SBR rubbers, for example, it has been assumed that the growth rate will be greater than that over recent years where production is concerned, since new types (such as adiprene) have good development possibilities; moreover, imports from the USA should decrease.

Assessment of growth in consumption of "other products" has been governed by knowledge of projects which are known and which, in all probability, will be implemented. Similar difficulties and solutions are encountered in the case of butadiene consumption in "other countries". Here, consumption is still at an early stage and little is known of the size of the industries involved or the direction in which these are heading.

Since it is precisely in the "other products" sector (which includes new products and new processes) and in the "other countries" that growth in consumption could be particularly rapid, the forecasts for 1975 in table 436 may well be on the conservative side.

4.4. Benzene

4.4.1. Foreword

Benzene was the first important hydrocarbon used on an industrial scale as the raw material for synthesizing other organic compounds. Indeed, up to the First World War, the organic chemicals industry was essentially based on the production of synthetic dyes and pharmaceuticals (apart from explosives); the starting point for the synthesis of these was often an aromatic hydrocarbon, especially benzene.

In those days, benzene was produced in coke ovens in which coal was destructively distilled to make metallurgical coke or town gas; then, benzene production largely exceeded demand.

Even as late as 1950, sufficient benzene was produced in coke ovens to cover market requirements for chemical uses and for direct uses by the solvent industry and by the oil industry for blending into high-grade gasoline, for instance.

After that time, particularly in the USA, growth in the chemical uses of benzene (especially those concerned with the production of synthetic resins, fibres and rubbers) developed so rapidly that output from coke ovens could not be increased fast enough to keep pace, production from this source essentially being linked to the growth rate of the steel industry (which was relatively much lower). Consequently, to meet the booming demand, benzene and its homologues started to be made from suitably treated petroleum fractions. This is generally done by catalytic reforming of a suitable cut from virgin naphtha (this greatly enriches the aromatic content of the cut). The aromatics and other hydrocarbons produced are then selectively extracted by solvents, after which the aromatic mixture is selectively distilled to yield benzene, toluene and xylene in the state of purity required by the consumer.

However, this process yields about three times as much toluene as it does benzene, while the chemical industry's demand is almost precisely the reverse of this proportion. Thus, it pays the benzene producer to dealkylate toluene rather than refine the excess. This course of action has rapidly increased benzene availability and ensured that the demand is satisfied.

In nearly all countries, the production of benzene from coal is dropping, both because of better steel-making techniques (with a considerable reduction in the amount of coke needed per ton of steel) and because of the greater natural purity of benzene from petroleum.

Because of the great volume of petroleum products obtained together with the aromatics which must go back into the oil-products processing cycle and also to facilitate transport of the benzene and its homologues, during the last few years the production of aromatics has come to be concentrated in the hands of the major oil companies. (This is in not contrast with the position as regards olefines where, especially in Europe, the major part is produced by chemical firms alone or in partnership with an oil company. In the latter instance, the oil company merely supplies the virgin naphtha, in many cases, while the chemical firm runs the plant and markets the products.)

The production of pyrolytic benzene aromatics as by-products in the steam-cracking of olefins is assuming growing importance, particularly in Europe.

Indeed, from the technical aspect, great interest is being shown in the production of benzene by disproportionating toluene. In this type of process, two molecules of toluene yield one molecule of benzene and one of xylene. Compared with dealkylation, these processes offer the advantage of the methyl group not being converted to methane (and thus used as a fuel) but of being exploited for alkylation to xylenes.

4.4.2. Production trends 1964-1967

European benzene production for the 1964-67 period is shown in table 422. It will be seen that over the four years considered, production has increased at an annual average rate of 13% or so. However, the starting

point for this output (coal or oil) has changed very considerably during this time. Indeed, the quantity obtained from coal has fallen slightly while that derived from oil has tripled from around 200,000 tons in 1964 (about 23% of the total) to approximately 700,000 tons in 1967 (a little over 50% of the total).

Table 442

EUROPEAN BENZENE PRODUCTION (1)
(Thousand tons)

Grouping	1964	1965	1966	1967
EEC	678	841	915	996
EFTA	204	180	215	345
Other countries	9	11	11	16
Totals	891	1032	1139	1357

(1) pure benzene only

It should be added that there is often confusion in interpreting the production statistics for benzene since some refer just to pure benzene while others cover commercial grades and benzene for fuel in I engines. The foregoing figures are for pure benzene only. However, in the case of some countries, figures for commercial benzene are also included since it proved impossible to isolate the use from the other.

As will become apparent in paragraph 4.4.1., the importance of commercial benzene is not great and has, in fact, waned considerably in recent years.

4.4.1. Consumption trends 1964-1967

Despite the big increase in European production of benzene from oil, during the period under consideration demand was still running a good way ahead of supply. Indeed, it will be seen from table 443 that the net deficit of benzene in Europe increased from 220,000 tons in 1964

to 400,000 tons in 1967.

Table 443

BENZENE: AVAILABILITY, DEMAND AND NET DEFICIT IN EUROPE OVER THE
1964 - 1967 PERIOD
(Thousand tons)

	1964	1967
Production	890	1360
Consumption	1110	1795
Net deficit	220	435

The bulk of Europe's benzene imports comes from the USA and Eastern Europe. It is likely that in the coming years this situation will be reversed and that Europe will become a net exporter of benzene (as benzene proper and in derivative form). This will occur because of the healthy growth in European production capacity (partly deriving from the major oil companies' global strategic policies) and because of the possible drop in potential availability of aromatics from oil in the USA.

4.4.4. Sectors of use

As mentioned earlier, benzene is used:

- as it is, mainly as a solvent (in the paint and adhesive industries, etc.) and as a fuel in some high octane gasoline formulations, especially in Germany; in these cases a high degree of purity is not required;
- as raw product for organic syntheses, in which case very pure benzene is often required.

Direct use increased in importance up to the start of the 60s, after which the international shortages of benzene and the high growth rate of some chemical products progressively led to a reduction in the use of benzene as a fuel. Solvent use also dropped sharply as a result of certain

legislation prohibiting its application in many cases because of its toxicity.

At the present time it is thought that not even 5% of all benzene consumed goes on non-chemical uses, in Europe.

By way of indication, table 444 shows the breakdown of benzene consumption for chemical purposes in 1964 and 1967. From this it can be seen that about 80% of all benzene used goes for the production of cumene, ethylbenzene and cyclohexane.

Of all the chemical derivatives of benzene, only consumption for cyclohexane and ethylbenzene has increased at a growth rate above the average for all benzene consumptions, which was about 13% in the 1964-67 period. For cyclohexane in particular, the average annual growth rate over this period was in excess of 40%. This big upswing derives from the fact that cyclohexane is replacing phenol in many processes (adopted in almost all the new plants) for the production of caprolactam (for Nylon 6) and adipic acid (for dyes and plasticizers), being more convenient. As a result, there has been a slowdown in the growth in phenol demand (and thus for cumene derived therefrom) which has come to be increasingly tied up with the development mainly of phenolic resins. Indeed, so far, phenol consumption for new products such as the polycondensates and epoxy resins has still not attained equal importance. Benzene consumption for chlorobenzenes is also largely bound up with phenol production. However, since the production of phenol via chlorobenzenes is not presently competitive with that involving the oxidation of cumene, the amount of chlorobenzenes used for this purpose has gradually diminished in recent years. In practice, this decrease has been counterbalanced by the development of other chlorobenzene derivatives (mainly DDT and other insecticide bases); however, the growth in the consumption of these has been particularly slow.

It will be recalled that the demand for benzene for alkylation to ethylbenzene (most of which is hydrogenated to styrene) has risen at an above-average rate for benzene uses as a whole. This is due mainly to the great boost provided by the demand for polystyrene - especially the expanded variety - and for ATF (acrylonitrile-butadiene-styrene) and SAN (styrene-acrylonitrile) resins. Growth in the use of styrene for the production

Table 444

BENZENE CONSUMPTION BY DERIVATIVES IN EUROPEAN COUNTRIES IN 1964 AND 1967
('000t of benzene)

Derivative	Years	SEC	MFDA	Others	Total Europe	% of the total
Cumene	1964	280	55	-	335	30.2
	1967	405	75	-	480	26.6
Ethylbenzene (1)	1964	260	100	-	360	32.4
	1967	490	135	-	625	35.0
Cyclohexane	1964	55	45	-	100	9.0
	1967	180	100	-	280	15.5
Dodecylbenzene (2)	1964	70	15	...	85	7.8
	1967	100	20	...	120	6.7
Chlorobenzene	1964	80	20	...	100	9.0
	1967	90	25	...	115	6.4
Maleic anhydride	1964	40	8	-	48	4.3
	1967	65	15	-	80	4.5
Others	1964	50	22	10 (3)	82	7.3
	1967	60	25	10 (3)	95	5.2
Total benzene consumption	1964	835	265	10	1.110	100.0
	1967	1.390	395	10	1.795	100.0

- (1) Excluded that obtained from xylene isomers separation.
- (2) Linear dodecylbenzene included.
- (3) Merely indicative.

of SBR (styrene-butadiene) rubbers has however proceeded at a slower pace.

Other products obtained by alkylation of benzene are intermediates for detergents (dodecylbenzene, branched and straight chain). Over the period in question, there has been a gradual swing from a situation where only branched detergent intermediate alkylates were produced, to one where straight-chain alkylates are taking on growing importance. This is mainly because of the Federal German Government's decision to ensure that only the highest grade anionic detergents shall be used, and these, in point of fact, are synthesized from straight-chain alkyl benzenes. This trend is now being followed by other countries who wish to reduce water pollution. The desire to reach the highest degree of detergent breakdown has also spurred other producers to choose straight-chain type surfactants (which form the active bases in detergent formulations) but these are not benzene alkylates.

The consumption of benzene for maleic anhydride (used especially in the production of unsaturated polyester resins) has grown at a sustained rate.

Items listed under the heading "other products" starting from benzene are not of great importance if taken individually; of these, reference may be made to the nitrobenzenes (for the production of aniline), diphenyl, etc.

4.4.5. Expected growth in capacity as of 1970 and 1975

Table 445 has been drawn up on the basis of known increases in productive capacity for benzene up to 1975.

Table 445

Grouping	1967		1970		1975		Average annual growth rate 67/75
	total	from coal	total	from coal	total	from coal	
EEC	1135	505	2185	500	3480	480	14.8
WTA	370	165	900	160	1150	150	15.2
Other ctrs.	20	20	100	20	300	20	10.3
Totals	1545	690	3185	680	4930	650	15.6

(1) Almost exclusively pure benzene

The main considerations which may be put forward on examination of this table are as follows:

- Even in this case, the lack of information on projects to expand capacity beyond 1970 means that the growth rate decreases (at least apparently) from around 27% per year during the 1967-70 period to a little more than 7% per year between 1970 and 1975.
- In the next few years, the increase in capacity will derive exclusively from oil sources and the amount coming from coal (about which there are also many doubts as to the real capacity) will tend to decrease. The growth rate in capacity from oil between 1967 and 1970 (27%) is still lower than the actual rate of increase recorded annually in the production of benzene from this source in Europe over the 1954-67 period (35%).
- It is apparent that such a high growth rate in production from oil which is considerably higher than the average overall growth in benzene consumption during the same period (35% in the case of production from oil, against around 18% for consumption) - derives from the need to move out of the net deficit position which has prevailed in Western Europe for so long.
- In a strategic world panorama, Europe will have an oil market position during the next few years (and even after 1970) which will permit the production of benzene at very advantageous prices, thus it is probable that supply will exceed internal demand. Hence, as already indicated in 443, Europe could become a net exporter of benzene (as such and in the form of certain primary derivatives).

4.4.6. Expected development in consumption as of 1970 and 1975

The points made below relate exclusively to chemical uses of benzene, since there are no reasons to expect that there will be any increase in the present very modest quantities of benzene used as such.

Purely as a guide, the forecast consumption of pure benzene for chemical uses in 1970 and 1975 is set forth in table 446. This table also confirms that the trend towards a marked increase in the importance of

ethylbenzene and cyclohexane at the expense of all other products which already started to become apparent in the 1964-67 period, continues up to 1975.

For ethylbenzene particularly, expected growth in European output will be high (around 18% per annum in the 1967/75 period) with the result that instead of accounting for 35% of total benzene consumption, it will account for 41% by 1975. Though the growth of styrene derivatives should occur at a high rate, especially in the case of certain types of resin, such as expanded polystyrene and ABS, it hardly seems likely that the whole of Europe's ethylbenzene output in 1975 will be consumed by the producer countries themselves. Because of the global strategic policies adopted by the majors, it is possible that part of the ethylbenzene (or styrene) output will be exported to the USA.

Furthermore, in view of what was stated in 4.3.6. regarding the possibility of increased European exports of butadiene derivatives, part of the styrene could be exported in the form of rubber or synthetic resins.

In the case of cyclohexane too, the growth in European production up to 1975 will also occur at a sustained rate (about 20% per annum). There are three main reasons for this: a) certain European countries will increase internal production so as to reduce imports; b) cyclohexane will replace phenol in many processes and so consumption of the former will expand at a faster rate than that of the sectors consuming-derivative products; c) the constant and sustained growth in European production of polyamide fibres (both 6/6 and 6) which accounts for most of the cyclohexane consumed.

These reasons together will result in the amount of benzene consumed for cyclohexane moving upwards from 15.6% of the total in 1967 to a little below 23% in 1975.

Apart from the products indicated, the remainder of the main benzene derivatives will develop at a below-average rate. In the case of cumene (see 4.26) the slowdown will be particularly marked because even taking due account of the expected possibility of exports to the USA, the

Table 446

FORECAST BENZENE CONSUMPTION IN WEST EUROPEAN COUNTRIES TO 1970 AND 1975
('000t of benzene)

Derivatives	Year	ECU	OEFTA	Others	Total Europe	
					'000t	%
Cumene	1967	405	75	-	480	26.6
	1970	600	120	-	720	24.2
	1975	800	200	...	1,000	21.0
Ethylbenzene (1)	1967	490	135	-	625	35.0
	1970	920	210	80	1,210	40.7
	1975	1,600	350	170	2,120	44.2
Cyclohexane	1967	120	100	-	280	15.6
	1970	350	200	...	550	18.5
	1975	650	400	40	1,090	22.8
Dodecylbenzene(2)	1967	100	20	...	120	6.7
	1970	120	25	10	155	5.6
	1975	160	40	20	220	4.6
Chlorobenzene	1967	90	25	...	115	6.4
	1970	80	25	...	105	3.5
	1975	100	30	...	130	2.7
Maleic anhydride	1967	65	15	-	80	4.5
	1970	80	20	...	100	3.4
	1975	105	25	...	130	2.7
Others	1967	60	25	10	95	5.2
	1970	70	30	15	115	4.1
	1975	85	35	20	135	2.0
Total	1967	1,390	395	10	1,795	100.0
	1970	2,230	630	105	2,965	100.0
	1975	3,500	1,030	250	4,780	100.0

(1) Excluding that obtained from xylene isomers separation.

(2) Linear and branched dodecylbenzene.

proportion of benzene consumed for this item will probably drop from 26.6% of the total in 1967 to 21% in 1975. However, around 1975 the importance of cumene production could increase because certain new processes use phenol for making caprolactam, and these seem to be more advantageous not only vis-à-vis the older established processes but also with regard to those starting from cyclohexane.

In the case of alkylbenzenes for detergents, apart from what has been said regarding propylene consumption for these products, it may be added that at least up to 1975 it is difficult to imagine that these might be replaced to any great extent by non-alkylated products (e.g. higher straight-chain alcohols) to such an extent that benzene consumption for this sector might freeze or even decrease.

Growth of the other primary derivatives of benzene up to 1975 will more or less remain in line with what occurred during the 1964-67 period; this is dealt with in paragraph 4.4.4.

4.5. Para-xylene

4.5.1. Foreword

Para-xylene is one of three xylene isomers, the other two being ortho-xylene and meta-xylene.

To all intents and purposes it was not produced on an industrial scale until after 1945 when output of polyester fibres got under way. Para-xylene is one of the basic components of these fibres since it is the raw material for making terephthalic acid which, through esterification with ethylene glycol and polymerization, is turned into the polyester from which the fibre itself is spun.

At the present time, para-xylene is usually separated from the meta isomer by selective crystallization, the ortho isomer first having been separated, in general, by distillation.

Since there are no major uses for the meta isomer in the chemical industry at the moment, and as it occurs in a proportion of almost twice that of the para, many producers have installed isomerization units which enable meta-xylene to be transformed into the para variety. In this way, it is possible to keep the supply of para-xylene in line with the sustained

demand, without excessively increasing the quantity of associated low-value products (which have to be returned to the refining cycle).

4.5.5. Production trends 1964-67

As shown by table 452, European production of para-xylene more than doubled during the 1964-67 period and stood at 177,000 tons in the final year.

Table 452

EUROPEAN PARA-XYLENE PRODUCTION: 1964-1967 PERIOD (Thousand tons)

Grouping	1964	1965	1966	1967	Average annual growth rate %
EEC	45	72	84	102	31
EFTA	41	57	70	75	22
Other countries	-	-	-	-	-
Totals	86	129	154	177	27

During the period in question, European production of para-xylene was concentrated in just four countries: France, Germany, Italy and the United Kingdom. The EFTA group, or more precisely the U.K., was responsible for a very large proportion of total output (about 48% in 1964 and 42% in 1967), far more, in fact, than in the case of other basic products of the organic chemicals industry (around 20-25% in 1967). There are historical reasons for this, since the U.K. was the country where polyester fibres were discovered and where growth was particularly rapid. Consequently, growth in the output of the raw materials for these fibres has always been ahead in the U.K., and even today that country exports large quantities of para-xylene as such and in the form of the dimethyl ester of terephthalic acid.

4.5.3. Consumption trends 1964-67

Total European consumption of para-xylene over the 1964-67 period increased a little less rapidly than did production. The result was that the slight deficit recorded in 1964 had become an almost perfect balance by 1967.

However, as regards the individual groupings, there was a net deficit of para-xylene in the EEC countries, while EFTA had a surplus. Trade between the two groups was thus maintained at a high level. The situation is summed up in table 453.

Table 453

EUROPEAN PRODUCTION AND CONSUMPTION OF PARA-XYLENE IN 1964 AND 1967
(Thousand tons)

Grouping	1964		1967	
	Production	Consumption	Production	Consumption
EEC	85	71	102	126
EFTA	41	26	75	50
Other ctrs.	-	-	-	-
Totals	86	97	177	176

There is no consumption of para-xylene in the "other countries" because, although some of these countries produce polyester fibres, these are made from imported dimethylterephthalate.

4.5.4. Sectors of use

From what has been stated above, it is clear that practically the only industrial use of para-xylene at the present time is for oxidation to terephthalic acid and subsequent processing to polyester fibre. The consumption figures given above refer exclusively to quantities used for the production of terephthalic acid. It has not been possible to assess the other possible uses for the production of para-xylene sulphonic acid, but in any case the quantities involved are not great.

4.5.5. Expected growth in capacity as of 1970 and 1975

Table 455 has been compiled on information presently available.

Table 455

EUROPEAN PARA-XYLENE PRODUCTION CAPACITY AS OF 1967, 1970 AND 1975
(Thousand tons)

Grouping	1967	1970	1975
EEC	120	250	510
EFTA	80	250	320
Other countries	-	-	-
Totals	200	500	830

Here again, known projects for new plants (or plant extensions) for para-xylene production in Europe after 1970 are certainly only a part of those which will effectively be implemented by 1975. This explains the big drop in the para-xylene capacity growth rate from 35% per year in the 1967-70 period to 10% in the 1970-75 period. Such a drop finds a support in a slowdown in demand since, as will be seen below, the growth prospects for polyester fibre production will remain sound.

4.5.6. Expected development in consumption as of 1970 and 1975

As the growth in the consumption of para-xylene is almost exclusively linked to growth in European output of polyester fibres, the forecasts of the level of European demand for para-xylene have been based on the expected trend in the production of these fibres. To complete the picture, account has also been taken of possible European exports of terephthalic acid (or of the dimethyl ester).

European production of polyester fibres is presently booming (between 1967 and 1968 output increased 44% bringing it to 308,000 tons) and there are good reasons to feel that in the future, too, the increase will continue

to run a fairly high level. Para-xylene consumption will also keep pace or even run at a higher level because of possible exports of terephthalic acid. Table 456 sets forth a broad outline of the possible levels of European consumption of para-xylene as of 1970 and 1975.

Table 456

EXPECTED EUROPEAN CONSUMPTION OF PARA-XYLENE IN 1970 AND 1975

(Thousands tons)

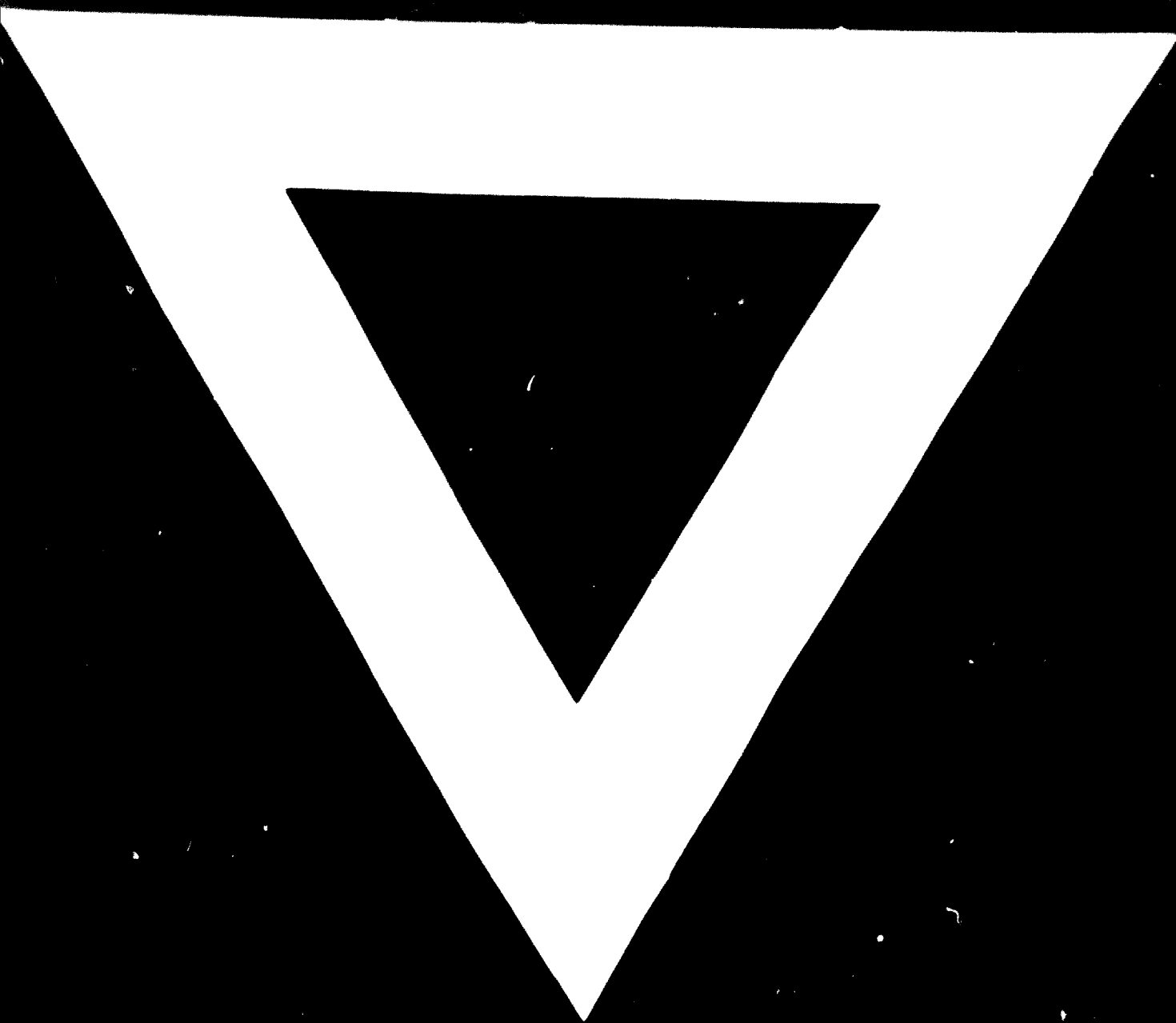
Year	EEC	OEFTA	Other countries	Total for Europe
1967	126	50	-	176
1970	250	80	-	330
1975	550	220	..	750

Thus for the countries of Europe as a whole, the average annual rate of growth of consumption would be about 23% for the 1967-70 period and 18% for the 1970-75 period.

By 1975, consumption could even exceed the 750,000 tons indicated in table 456, because growth in European polyester fibre production could exceed the forecast 18% and because it is not known precisely whether certain terephthalic acid plants will be built in some of the "other countries", and if so, what their capacity will be.

Comparing the consumption levels for para-xylene set forth in table 456 with the forecast production capacities, it ensues that as from 1970 Europe could have excess capacity and therefore could be in a position to export considerable quantities of this product.





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