THE LOCATION OF THE PETROCHEMICAL INDUSTRY:
A COMPARATIVE STUDY OF THREE MAJOR WORLD REGIONS

by

JOHN RICHARD PEET
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Department of Geography

The University of British Columbia,
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Date October, 1963
The use of oil and natural gas for the production of chemicals is of recent origin, yet petrochemicals have already reached a position of major importance. Investment in the industry is growing at an extremely rapid rate, both in the developed and underdeveloped countries.

In this study the distribution of petrochemical production is examined in Western Europe, Japan and the United States. There are two main aims, to explain the distribution of the industry and to demonstrate the application of four methods of geographic analysis. Three of these methods, the examination of the historical development of activity, the analysis of the factors influencing the location of activity and the description of the major regions of activity, have been widely used in economic geography. The fourth, the comparison of the costs of production and transport involved in locating activities in various regions, has not been used, yet merits greater attention.

In Western Europe, a historical analysis of the petrochemical industry shows that the presence of an old established coal-chemicals industry has had a significant effect on subsequent developments. Three other factors, the influence of raw materials availability, the influence
of markets, and governmental action have also affected the location of petrochemical plants.

Japanese petrochemical plants are entirely located on the coasts, most of the raw materials for the industry being imported. The plants fall into a number of distinct groups, which are described regionally.

The United States also has several major regions of petrochemical production around coastal refining ports, at inland "gateway" points, in coal-chemicals centres, and on the Gulf Coast oil and gas fields. Economic factors which have led to the concentration of production in the Gulf Coast region are analysed according to the comparative cost method, which is found to be effective.

Comparative cost analysis provides a framework onto which empirical studies may be built. Thus it may be possible to construct a theory of location around this and similar methods.
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CHAPTER I

ECONOMIC GEOGRAPHY AND THE PETROCHEMICAL INDUSTRY

In the past thirty years a number of new synthetic industries making plastics, fibres, rubber and detergents have emerged and have made large demands on the chemical industry for raw materials. At the same time, in the energy market, oil and natural gas have gained in relative importance at the expense of coal, and the petroleum processing industries have yielded increasing amounts of by-products which can be converted into chemicals. The result of these two changes has been the petrochemical industry, the link between the manufacture of synthetics (which is the market for its products) and oil and gas processing (which supplies its raw materials).

As petrochemical production is the basis of a complex of related industries which are growing extremely rapidly, it would seem to be of some significance to the study of economic geography. Yet little reference has been made to this form of manufacturing in the geographical literature.

The petrochemical industry is, however, particularly suitable for geographic analysis. The recent origin of the industry obviates the necessity of delving deeply into the
past in order to explain present distributions. Also
capacity and production are growing at extremely rapid
rates and great changes are taking place in the location
of the industry. In 1940 an estimated $350,000,000 had
been invested in petrochemical plants and their equipment
in the United States, which then accounted for the whole
of world capacity.\(^1\) By 1950, $2,300,000,000 had been
invested, 87% in the United States and the remainder in
Western Europe and Canada. In 1960 the world total invest­
ment was about $10,700,000,000, 75% in the United States,
16% in Western Europe, 4% in Canada, 2.5% in Japan, and the
rest mainly in Latin America and Australia. This 1960
investment figure will almost have doubled by 1965, and an
explosion is taking place in the distribution of the indus­
try as new centres of production spring up in both developed
and underdeveloped areas.

Although statistical information on the petrochemical
industry is generally poor, a large amount of technical and
economic data on the raw materials and processes used,
(which is essential to the economic geographer) is available.
The main sources of this data are the chemical engineering
journals, such as Chemical Engineering Progress, Chemical

\(^1\)The U.S.S.R. and other communist countries are not
included in these figures, nor in this study. Information
on these countries is either not available or it is not
comparable with that on the rest of the world. All dollar
signs refer to U.S. currency.
Engineering, and Chemical Age, and the petroleum periodicals, such as Petroleum Refiner and The Oil and Gas Journal. The second major source of information is the work of Walter Isard and his associates and students in regional science. Isard has used the oil refining-petrochemical-synthetic fibre series of manufactures to demonstrate methods of location analysis and industrial complex analysis which he has developed.

The purpose of this study is twofold. It is designed to deal both with the economic geography of the industry per se, and the application of several different approaches to geographic study. First is a discussion of the approaches which can be used in the description and analysis of the geography of manufacturing.

1. Approaches to the Geography of Manufacturing

Economic geography seeks to describe accurately and explain rationally the distribution of economic activity. In particular economic geographers have concentrated on the use of the map as a method of describing distributions, to the extent that the adjective "accurate" is now deserved. The same cannot be said, however, for the geographer's

2"Petroleum" is used in this study to refer to both oil and natural gas.

explanations of economic distributions. While there are a number of distinct methods of approach to the study of these distributions, these have not led to the formulation either of generalisations which apply to more than one type of activity, nor to theories of location. Thus although there have been a few excellent descriptions of the factors influencing location decisions, no framework exists onto which individual studies can be built, and economic geography remains largely a collection of isolated and unrelated works. One of the reasons usually given for the slowness of geographers to put forward general statements on location, is the extreme complexity of the problem. It must be admitted that human activity is difficult to explain in any discipline, yet to claim that every situation is unique is much too easy a way out. It is giving up before the attempt is made.

The work of von Thunen, Weber, Hoover, Losch,

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5J. H. von Thunen, Der isolierte Staat in Beziehung auf Landwirtschaft und Nationalökonomie (Hamburg, 1826).


and Isard on theories of the location of economic activity is useful to the economic geographer, but is not easily adaptable to his needs in the examination of particular industries or types of agriculture (although Hoover and Isard provide examples of the application of their theories). What is needed in economic geography is a general framework built from trends discernable, from actual observation, in the location of economic activities. This collection of generalisations should be adaptable for the accurate analysis of any one type of activity.

In this thesis, a concept of location is put forward, and a method of analysis in accordance with this point of view is developed. This concept and analytical method is compared with others in common use in economic geography.

Four methods of approach to the geography of manufacturing can be recognized, (1) Historical, (2) Regional, (3) Factor and (4) Comparative Cost.

The Historical Methods

Historical methods either involve the study of past distributions of activities for their own sake, or explain

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10An example of both types of historical study is P. G. Hall, The Industries of London since 1861 (London: Hutchinson and Company, 1952).
present patterns of production through an examination of historical development. Only the second of these will be discussed here.

Distributional shifts in industry are due principally to two types of change. Firstly the processes used by industry change and secondly the distributions of raw materials, markets and other influencing factors change. As an example of the first, in the iron and steel industry the amount of coal needed to produce a ton of pig iron has decreased, gradually freeing the industry from the necessity of a coal field location, and of the second, old coal and iron ore fields have been exhausted and new ones opened up. Thus different patterns of production rise and fall, each system leaving remnants which continue to exist as anomalies, and each system influencing the growth of the next. Present patterns can therefore be seen as stages in the development of industries.

Examples of this type of study are the books and articles of N. J. G. Pounds and F. Lukermann. This type of work is particularly useful in accounting for those parts of a distribution that are legacies of previously existing location factors, although inadequate attention is

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usually given to the conditions which have allowed the anachronisms to continue to exist.

The Regional Method

There are at least two types of regional methods used in economic geography. One is the description of regions and the industries in them; the other is the description of an industry regionally. E. Willard Miller\textsuperscript{13} devotes the first half of his book to a world survey of all industries, region by region, and the second half to a number of case studies such as iron and steel, aluminium, machine tools and motor vehicles, each of which are discussed by country and region. Explanation of location in this type of work usually takes the form of an analysis of the relationships between an industry in a region and other phenomena such as, in the case of textiles, water power, soft water availability, damp climates, and coal fields. Most articles on industry in the geographical literature describe one industry in one region or country, and usually also discuss the relationships between the industry and other phenomena in the same area. For example, how much has the location of one industry in an area influenced the development of a second industry?

One of the drawbacks to treating industries

regionally is that when several regions are studied the same location factors occur time after time, so that accounts become repetative lists. Because the same factors re-occur, they are frequently treated according to a stereotyped system and not according to their significance to the industry. If an industry is examined in only one region, difficulties of comparison are created, for no industry is isolated from external influences and connections, and at least a partial survey of several regions is necessary.

The Factor Method

In the factor method, locational influences are treated in turn. Each factor is described, the influence of each is discussed, and examples of plants located in response to each are given. In an analysis of the iron and steel industry of the United Kingdom, the influence of governmental activity might be discussed, and the iron and steel plant at Ebbw Vale in Wales would possibly be given as an example of the effect of this factor on the location of a plant. In Estall and Buchanon\textsuperscript{14} there are two chapters which illustrate the use of the factor method. This method provides a much more satisfactory explanation of the forces affecting the location of industry than the methods discussed so far, as each influencing factor is usually dealt with in detail as a subject in itself. However the main detraction of the method is the impossibility of deciding, on a rational basis, which factors have the

\textsuperscript{14}\textsuperscript{14}Estall and Buchanon, \textit{op. cit.}, pp. 171 and 194.
greatest effect on location. The number of plants located primarily in response to each factor is one, rather crude, way of obtaining a measure of significance, yet for accurate results questionnaires must be sent to large numbers of companies in the industry under consideration. Two studies in which this has been done are those of McLaughlin and Robock,15 and Greenhut and Colberg.16 Apart from the more obvious practical difficulties involved, questionnaires are only useful as general guides, for companies are unwilling to give detailed information. Thus location factors must be described in such terms as "access to markets" which has a different meaning for each company. It should also be mentioned that the original reason for location may not now be important, for the subsequent growth of a plant may be for a number of completely different reasons.

The Comparative Cost Method

In a number of practical studies, W. Isard17 and


associates\textsuperscript{18} have used, among other methods, what is called here the comparative cost approach to location analysis. In this method a region's attractiveness to an industry is measured by the costs in that region of the various requirements, (raw materials, power, labour, etc.) of the industry, and comparisons are made between production and transport costs in alternative regions.

Most of the work done in this field has been directed towards the examination of present costs in several regions. Using this as a basis, predictions are then made on the possible future location of industry.

This type of study has the advantage over the factor method of being concerned with general economic tendencies rather than the vast variety of directly causing and indirectly contributing factors which have influenced location. It is also free from the bias of the investigator's individual experiences and opinions.

2. Development of a Comparative Cost Method

Industrial plants vary in density and size. Two methods of location analysis are necessary to deal with these two elements.

It could be said that an industry is concentrated in a region either because most of the plants which comprise that industry are in the region, or because the plants in it are larger in size than those elsewhere. Similarly, there are two aspects to the explanation of an industrial distribution, the original reasons for the location of plants at certain places, and the general factors which have influenced their rates of development since. The terms particular and general location factors will be used to represent these two influences.

For any particular industry, some regions are more economically attractive than others for the location of plants. The comparative cost method is a means of measuring the attractiveness of a region. In this method, no attempt to assess the particular factors involved in the location of plants is made although if a company knows that it will have generally lower costs in one region than in another it is quite likely to locate there. The main aim of the method is to accurately describe and compare the general economic forces which cause variations in the rates of growth of industrial plants located in a number of regions.

The effect of general location factors may be seen from the following hypothetical example. Suppose a company has several plants of roughly equal size in different regions and finds that it can operate one of them at a lower
cost than the others. Suppose, also, that demand for the company's product is increasing. Then, providing that transport charges from the lowest cost region to the growing markets do not exceed the low cost region's advantage over other "nearer to the markets" regions, the company will expand its operations in the lowest cost region.

Alternatively, if there is a decrease in demand, the lowest cost plant will be the last to close down and may even be increased in size if the other plants are completely closed. The larger the lowest cost plant is compared with the other plants, the greater its advantage becomes through economies of scale, which occur in most industries. When several companies are affected in the same manner, the growth of large plants in the one region leads to external economies which further increase the region's attractiveness to the industry. In this way an evenly distributed industry can become highly concentrated.

To determine the extent of a region's cost advantage, a comparison must be made of several regions. This comparison should take into account variations in the cost of manufacturing a product, (caused, for example, by variations in the prices of factors of production -- raw materials, labour, etc.) and also variations in the cost of shipping products from each region to the markets.¹⁹ In

¹⁹This is the cost division used in this thesis because of complicating factors. However, it is suggested that a better division is (1) those costs corresponding
the comparison of production costs two types of information are required, firstly, the amounts of each input used in the production of a certain amount of end product, and secondly, the price of each input in each region under consideration. In the comparison of input prices a discussion of each ensues which is similar to the factor method mentioned earlier, except that more accurate comparisons are possible. However it can easily be seen that these price comparisons are not enough, alone, for a comparison of the attractiveness of regions, for inputs vary not only in price, but also in significance. For example, one unit of factor A (an input such as labor) may be used in the production of one unit of output, and the price of A may vary by 100% between two regions; factor B (e.g., steel) may vary in price by only 5% between two regions, yet if 100 units are used, factor B has a greater effect on variations in production costs than factor A. By considering factor or input price alone the vital influence of factor significance would have been lost. Production costs take both factor cost and factor significance into consideration.

The other main cost variation to be considered in a comparison is caused by differences in the distances between the regions under consideration, and the large markets for

with the value added to raw materials at any plant, and (2) those costs resulting from the transport of raw materials to the plant, and products from it.
the product being analysed. Transport costs are also influenced by the media available. For example, the presence of large waterways decreases the costs of shipping bulk commodities to market. The comparative cost method thus comprises two types of comparison, production costs and transport charges.

3. Arrangement of the Study

This study examines the petrochemical industry through four different approaches used in economic geography. First, however, it is necessary to discuss the technology and characteristics of the petrochemical industry. Then Chapters III, IV and V deal with the petrochemical industries of Western Europe, Japan and the United States. Chapter III shows the use of the factor and historical methods, and Chapters IV and V demonstrate the regional method. Finally, Chapter VI is an explanation of the development of petrochemical production on the Gulf Coast of the United States and exhibits the comparative cost method.
CHAPTER II

THE PETROCHEMICAL INDUSTRY

In the chemical industry a small number of simple raw materials are used to manufacture a great variety of complex, valuable products. The processes used to accomplish these conversions are technically complicated and plants are expensive. Petrochemicals, which in the past twenty-five years have been the most rapidly growing segment of the chemical industry, involve particularly complicated and expensive equipment for their manufacture. This chapter will describe some of the economic and technical characteristics of this new industry.

1. Definition and Economic Characteristics

The term "petrochemical" was first used in the nineteen forties to describe an offshoot of the oil and chemical industries, which was emerging as a separate entity, at that time in the United States. "Petrochemical" has gradually been accepted throughout the world, although in Europe "petroleum chemical" is also used to refer to the industry. However, the number of interpretations of the two terms in the preparation of statistics are as numerous as the agencies collecting and publishing information on
the industry.

Definition and Measurement

"Petrochemical" is used in this thesis to refer to "a chemical compound or element recovered directly or derived indirectly from oil or natural gas hydrocarbons and intended for chemical markets."20

Each part of this definition is included for a particular purpose. "A chemical compound" implies that such oil products as gasoline are not petrochemicals because these products are not chemical compounds but are, rather, mixtures of hydrocarbons. "Or element" permits the inclusion of carbon black which is composed of carbon only. It should be noted that no reference is made to the inorganic or organic nature of petrochemicals for both types are in fact included. However, not all definitions include both. The Organisation for Economic Co-operation and Development (O.E.C.D.), and its predecessor, The Organisation for European Economic Co-operation (O.E.E.C.), have used the term "petroleum chemical" to refer only to organic chemicals.21 As the North American usage of the term "petrochemical" definitely includes inorganics, difficulties of


21 The definition used by the O.E.E.C.-O.E.C.D. is, "an organic substance the raw materials of which come from oil, or refinery gas, or natural gas."
comparison are created.

"Recovered directly or derived indirectly" is intended to include both chemicals produced directly from oil and gas, and also chemicals produced from these basic petrochemicals. "From oil or natural gas hydrocarbons" implies that only the hydrogen and carbon content of raw materials is used, and none of the impurities like sulphur. For the purpose of this study the extraction of sulphur from sour oils and gases will not be considered a part of the petrochemical industry. "Intended for chemical markets" excludes such finished products as plastics and synthetic fibres which are sold outside the chemical and related processing industries.

There are many border line cases in which industrial plants are difficult to classify. For example, in which industry should a plant producing both petrochemicals and plastics be included? Or if a plant uses both oil and coal as raw materials, is the output petrochemical or coal-based? Problems of this type have been solved by determining whether the major part of the raw material inputs or product outputs are derived from oil and gas. A further difficulty is double counting. In the same plant a chemical X may be produced from oil or natural gas. X may be used for the manufacture of a chemical Y, and Y could be further processed into Z. At each stage a part of the output of X, Y and Z may be sold to other plants. The problem is, should
the capacity or production of the plant be measured in terms of X, or X plus Y plus Z, or Z plus the proportions of X and Y sold to other companies, or some other combination? This is further complicated by a lack of capacity and production data so that the measurement of all these combinations is not possible. The method used in this thesis is simply the addition of X, Y and Z in the preparation of capacity data, regardless of the double counting of Y and the triple counting of Z.

The measurement units used are pounds (lbs.) or tons of chemicals. Amongst the drawbacks to this measurement is the fact that a pound of one chemical may be worth many times as much as a pound of another. The O.E.E.C. measures petrochemical production in terms of the weight of the carbon content of products, which while it reduces all chemicals to a common denominator, also compounds the problem of the comparability of statistics.

**Economic Characteristics**

There are several economic characteristics which should be mentioned as distinguishing the petrochemical industry from other forms of manufacturing.

The petrochemical industry is capital intensive to a degree reached by few other industries. Plants are expensive, highly automated, and complicated. Consequently direct labor requirements are small, although the total
labour bill of the firm may be quite high when maintenance crews, and those employed in research and marketing are included. Research is extremely important and new discoveries are quickly developed commercially, giving monopoly profits for short periods of time (until competitors catch up). The industry is flexible in its use of raw materials as feedstocks for the same product can be drawn from a number of different sources. Finally, the industry is, as its name suggests, a combination of two others, petroleum and chemical. The effect of this combination is twofold. On the one hand petrochemical production uses processes and materials derived from both industries. On the other hand, investment capital and ownership also comes from both industries.

Petrochemical producers gain considerable economies from large scale operations. Economies are also gained by the agglomeration of several plants at one place. Processes are continuous and products interchangeable so that each plant is highly dependent on the other. Similar services and utilities are required by each plant and the collective provision of these also gives economies. Thus the optimum situation in the petrochemical industry is a large complex interconnected by chemical pipelines and using a small number of raw materials, principally petroleum, salt and water, to produce a great variety of valuable chemicals.
2. The Technology of the Petrochemical Industry

This section is intended as an introduction to the technology and terminology of the petrochemical industry. No prior knowledge of petrochemistry is needed to understand this thesis. A glossary is provided so that many of the terms used need not be intentionally remembered at the outset.

Chemistry and the chemical industry may be divided into two parts, inorganic and organic. Organic chemicals usually contain carbon, while inorganics do not, although this division is complicated by the fact that carbon black (i.e., carbon) is considered to be an inorganic chemical. Organic petrochemicals are mainly used by industry, especially the new synthetic types of manufacturing while inorganic petrochemicals, such as ammonia, ammonium nitrate and urea, are largely fertilizers to be used in agriculture. In this study, organic petrochemicals are discussed in more detail than inorganics, partly because organics are produced in greater quantities from oil and natural gas, and partly because organics are much more valuable. For example, in the United States the average value of inorganic petrochemicals is 2.5¢ a pound, while organics are worth an average of 16¢ a pound.22

A general knowledge of the technology of any industry is essential before that industry can be accurately distinguished from other types of manufacturing. In the case of the petrochemical industry this knowledge is particularly important for the following reasons. Little has been written on the industry in the geographical literature and there is, therefore, a heavy reliance on the petroleum and chemical journals which deal almost exclusively with technology. A technical knowledge is also required before the factors of production of the industry can be put into some order of significance; it is obviously necessary in a location study to know how much raw material is necessary to produce a given amount of finished product. Such factor requirements vary greatly both between industries and within any one industry. Changes in the processes used often have great effects on the distribution of plants in the industry because factor of production requirements change. Finally a knowledge of technology is needed before the terminology of the industry can be understood and used.

The petrochemical industry has a number of recognizable stages of production. Raw materials for the industry are derived from oil and natural gas; these materials are separated and changed to form a small number of hydrocarbon feedstocks (see Table 1) which are further converted into basic chemicals. The basics are then subjected to a wide variety of different processes to yield a large
<table>
<thead>
<tr>
<th>Hydrocarbon Feedstocks</th>
<th>Basic Chemicals</th>
<th>Intermediates</th>
<th>Finished Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td>Hydrogen</td>
<td>Ammonia</td>
<td>Carbon Black</td>
</tr>
<tr>
<td></td>
<td>Methane</td>
<td>Hydrogen Cyanide</td>
<td>Nitric Acid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acetylene</td>
<td>Urea</td>
</tr>
<tr>
<td></td>
<td>Ethane</td>
<td>Ethanolamines</td>
<td>Acetic Acid</td>
</tr>
<tr>
<td></td>
<td>Ethane</td>
<td>Ethylene</td>
<td>Acetaldehyde</td>
</tr>
<tr>
<td></td>
<td>L.P.G.</td>
<td>Ethylene Oxide</td>
<td>Polymers</td>
</tr>
<tr>
<td></td>
<td>Propane</td>
<td>Propylene Oxide</td>
<td>Polymers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Glycol</td>
<td>Polymers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tetramer</td>
<td>Polymers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Allyl Chloride</td>
<td>Polymers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Polypolypropene</td>
<td>Polymers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Butadiene</td>
<td>Polymers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Butyl Alcohol</td>
<td>Polymers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Isobutylene</td>
<td>Polymers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cyclohexane</td>
<td>Adipic Acid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Styrene</td>
<td>Synthetic Rubber</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phenol</td>
<td>Polystyrene</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Toluene</td>
<td>Resins, Bonding Agents</td>
</tr>
<tr>
<td></td>
<td></td>
<td>xylenes</td>
<td>Synthetic Detergents</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pthalic Anhydride</td>
<td>Polystyrene</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Terephthalic Acid</td>
<td>Explosives</td>
</tr>
</tbody>
</table>

number of intermediate chemicals. Finally, these intermediates are, to some extent, recombined to give a smaller number of non-petrochemical finished products (see the far right hand column of Table 1). Each of these stages will be dealt with in turn.

**Raw Materials**

A hydrocarbon molecule contains certain numbers of hydrogen and carbon atoms; for example, methane (CH\(_4\)) contains one carbon atom and four hydrogen atoms, ethane (C\(_2\)H\(_6\)) two carbon and six hydrogen atoms. The other hydrocarbons in this series, known as "paraffins" are propane (C\(_3\)H\(_8\)), butane (C\(_4\)H\(_{10}\)) and "pentanes plus" (C\(_5\)H\(_{12}\) to C\(_8\)H\(_{18}\)).

**Natural Gas**

Natural gas is a mixture of paraffins, although it may also contain impurities. If methane predominates it is "dry," and if propane, butanes and pentanes make up a large proportion of the gas, it is "wet." Natural gas which is wet causes blockages in pipelines due to liquefaction, therefore the heavy fractions, propane, butane, pentanes and to some extent ethane are extracted before the gas leaves the field. The natural gas processing industry yields liquified petroleum gases (L.P.G.s), which are composed of propane, butane and ethane, and natural gasoline, which is made up of pentanes.\(^{23}\) L.P.G.s are of major

\(^{23}\)For a more detailed account of the gas processing
importance as organic petrochemical raw materials although for reasons which will be discussed, natural gas itself is mainly used for inorganic petrochemicals.

Oil Products

Crude oil also contains paraffins. In addition aromatics (e.g., benzene, toluene and xylenes) and naphthenes are present. However, only occasionally is crude oil itself used in the petrochemical industry, for most feedstocks are derived from oil refinery by-products. In oil refining, crude oil is separated or distilled into the products shown in Table 2. This is carried out by heating the crude oil in a furnace and leading the resultant gases into a fractionating column. Vapour comes from the top of the column and liquids from the bottom. This process is then repeated several times with a separation of light (i.e., with low boiling temperatures) and heavy products taking place in each column.

When large gasoline yields are required, the gas oil products of distillation are cracked, either thermally or with the aid of a catalyst (catalytic cracking), to give gasoline. Catalytic cracking has now largely taken the place of thermal cracking because it provides a more valuable range of products, particularly a higher quality gasoline.

It also yields considerable quantities of gases which are extremely useful as petrochemical raw materials. Catalytic reforming is a process applied to heavy gasoline. During reforming a gas which has a high hydrogen content is produced and this also is a valuable chemical raw material.

In addition to these gases, the petrochemical industry utilizes some of the liquids which are joint refinery products of gasoline and fuel oil. Gas oils or naphthas, (naphthas are similar to gasoline and are either heavy or light) can be cracked thermally to yield a range of
products similar to those of a refinery, except that gas yields are maximized. Also the L.P.G.s produced during the distillation of crude oil can be used as petrochemical raw materials.

The main raw materials of the petrochemical industry are, therefore, liquid refinery products such as naphtha, L.P.G.s from natural gas or oil, and natural and refinery gases.

Hydrocarbon Feedstocks and Basic Chemicals

The paraffins are the main feedstocks in the petrochemical industry although recently aromatics have been increasing in importance. As they occur naturally in oil and gas, paraffins are unreactive. However, if the paraffins are cracked (i.e., lose some hydrogen atoms) they become very reactive and move easily convertible into basic chemicals. When paraffins are cracked, "olefins" are formed. Ethane (C₂H₆) forms ethylene (C₂H₄), propane (C₃H₈) is cracked to propylene (C₃H₆) and butane (C₄H₁₀) forms butylenes (C₄H₈). Methane (CH₄) does not have an olefin, which detracts from its usefulness as a raw material for organic chemicals. However, both methane and the other paraffins may be cracked to form acetylene (C₂H₂). A great number of other rearrangements of the carbon and hydrogen atoms are possible, but apart from the cracking of propane to yield ethylene, these processes are not used
commercially. The paraffins and their olefins can be summarized as follows:

<table>
<thead>
<tr>
<th>Paraffin</th>
<th>Olefin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>Acetylene</td>
</tr>
<tr>
<td>Ethane</td>
<td>Ethylene</td>
</tr>
<tr>
<td>Propane</td>
<td>Propylene</td>
</tr>
<tr>
<td>Butane</td>
<td>Butylene</td>
</tr>
</tbody>
</table>

Acetylene is usually made from methane (natural gas) by cracking at temperatures in the 1500°C - 1600°C range. Methane may also be used to produce hydrogen, which in combination with nitrogen from the air, forms ammonia. When ammonia is made from refinery gases, it is usually the hydrogen rich gases of catalytic reforming units that are utilized.

Aromatics are recovered from concentrates, yielded during such operations as catalytic reforming, by a number of separation techniques, chiefly distillation, extraction and absorption. The olefins, acetylene, ammonia and the aromatics will be referred to as basic chemicals. These basics are shown in column C of Table 1.

**Intermediates**

The production of intermediates from basics involves a large number of diverse processes such as reacting with chlorine, water and other compounds, adding or subtracting hydrogen atoms, and oxidation. Ethylene is
made into ethylene oxide either by a reaction with chlorine and water (chlorohydrin process) or by oxidation with air or oxygen. Ethylene glycol is made from ethylene oxide by hydration (i.e., a reaction with water). Polyethylene is made from purified ethylene by mixing with oxygen, compressing to form a liquid, chilling solid and then chopping into flakes. These are similar processes for deriving intermediates from propylene, butylene, acetylene and the aromatics. Although these processes have been simplified, it can readily be seen that in practice they are more complicated than those of most other industries.24

Nearly all intermediates are sold to non-petrochemical consumers for further conversion into such products as synthetic rubber, synthetic fibres and plastics or for a wide variety of uses in all types of industry. Some of these consumers, especially synthetic rubber and parts of the plastics industry, (e.g., polyethylene) are integrated with petrochemical production. However, most consuming industries are completely separate and are located in the major industrial regions and near large centres of population.

The petrochemical industry thus uses the by-products of oil and gas processing to manufacture chemicals which in turn form the raw materials of the synthetic industries. Gases and liquids from oil refineries, natural gas processing plants and pipelines are first converted into a small number of basic chemicals. Then a wide variety of processes are used to produce a large number of intermediates. The intermediates are sold to non-petrochemical consumers.

Other technical characteristics of the industry will be introduced where necessary in the following regional chapters, but as far as possible these will relate to the material presented in this chapter.
CHAPTER III
WESTERN EUROPE

In Western Europe, although the production of chemicals from petroleum has been carried out on a large scale only since the early nineteen fifties, the coal-chemicals industry has long been established. Therefore, a discussion of the considerable influence which this previously existing industry has had on the modern development of petrochemical manufacturing becomes an integral part of the discourse on Western Europe. The transition (or, more accurately, revolution) of the chemical industry from coal to petroleum raw materials demonstrates the historical method of geographic research.

Four major factors have affected the distribution of the petrochemical industry: (1) the effects of raw material supply, (2) market orientation, (3) the influence of a pre-existing chemical industry, and (4) the influence of political decisions. These factors are dealt with in turn as examples of the application of the factor method.

1. The Growth of the Petrochemical Industry

Chemicals have been produced in large quantities in Western Europe since the beginning of the century, and the
industry employs between 6% and 8% of the labour force in all of the five major European Common Market Countries and the United Kingdom. The chemical industry now employs 1,700,000 persons in the countries of the Organisation for European Economic Co-operation (O.E.E.C.) and has a value added of $9.5 billion, compared with an employment of 840,000 in the United States and a value added of $14.4 billion.

Evolution of the Industry

Oil and natural gas only came into prominence as chemical raw materials in the early nineteen fifties, although the first petrochemical plants were built during the Second World War. Petrochemical production has grown extremely rapidly, especially since 1955, partly because of the growth of markets for organic chemicals, partly because of the increased availability of oil and gas raw materials, and partly because of the substitution of petroleum for the traditional organic material, coal. For example, in Germany coal-based organic chemicals constituted 90% of the organic chemicals produced in 1938, 82% in 1955.

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and less than 50% in 1961. In the United Kingdom in 1949, 490,000 metric tons of organic chemicals were produced of which 6% came from petroleum, and in 1962 about 2,310,000 metric tons were produced, of which 65% came from petroleum. Between 1954 and 1961 production of the basic chemical ethylene in Western Europe changed from 23% based on petroleum to 86.5%. In contrast the chemical industry in the United States has developed side by side with the petroleum industries; in 1950 almost 60% and in 1960, 85% of U.S. organic chemical production was from petroleum.

The results of this shift from coal to petroleum and the growth of organic chemical demand can be seen in Table 3, which although estimated on a narrower basis than the one used for petrochemical capacity and production statistics in this thesis, is comparable. Investment and production quadrupled in the five year period 1956-1961, a rate of growth which is unequalled by the chemical industry as a whole and industrial production in toto.

Table 3 also shows changes in the relative positions of the member countries of the O.E.E.C. These changes are also evident in the production of the chemical ethylene. In 1955-56 the ethylene capacity of the longer established


28Waddams, op. cit., p. 163.

### Table 3
INVESTMENT AND PRODUCTION IN THE PETROCHEMICAL INDUSTRY
O.E.E.C. COUNTRIES 1952-1962
(ORGANIC CHEMICALS ONLY)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total O.E.E.C. Production (millions of metric tons of carbon)</td>
<td>n.a.</td>
<td>0.30</td>
<td>0.47</td>
<td>0.81</td>
<td>1.68</td>
<td>2.00</td>
<td>2.50</td>
<td>80</td>
</tr>
<tr>
<td>Investment (millions of dollars)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austria</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>10.0</td>
<td>10.0</td>
<td>2</td>
</tr>
<tr>
<td>Belgium</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>17.0</td>
<td>19.6</td>
<td>34.6</td>
<td>40.0</td>
<td>1</td>
</tr>
<tr>
<td>France</td>
<td>33.0</td>
<td>46.0</td>
<td>50.0</td>
<td>84.2</td>
<td>208.7</td>
<td>253.7</td>
<td>315.0</td>
<td>34</td>
</tr>
<tr>
<td>Germany</td>
<td>59.0</td>
<td>68.0</td>
<td>128.0</td>
<td>263.0</td>
<td>453.0</td>
<td>523.0</td>
<td>590.0</td>
<td>12</td>
</tr>
<tr>
<td>Italy</td>
<td>36.0</td>
<td>44.0</td>
<td>51.0</td>
<td>123.0</td>
<td>271.5</td>
<td>347.5</td>
<td>450.0</td>
<td>10</td>
</tr>
<tr>
<td>Netherlands</td>
<td>9.4</td>
<td>9.4</td>
<td>13.0</td>
<td>23.0</td>
<td>60.0</td>
<td>70.0</td>
<td>100.0</td>
<td>5</td>
</tr>
<tr>
<td>Spain</td>
<td>0.0</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>113.0</td>
<td>122.0</td>
<td>170.0</td>
<td>265.0</td>
<td>406.0</td>
<td>461.0</td>
<td>520.0</td>
<td>15</td>
</tr>
<tr>
<td>Total O.E.E.C.</td>
<td>250.4</td>
<td>289.9</td>
<td>412.5</td>
<td>775.7</td>
<td>1419.3</td>
<td>1690.3</td>
<td>2025.5</td>
<td>80</td>
</tr>
</tbody>
</table>

Index of Chemical Production (1953 = 100)

| Year | 88 | 116 | 137 | 160 | 212 | 222 | 238 |

Index of Total Industrial Production (1953 = 100)

| Year | 94 | 110 | 126 | 136 | 157 | 161 | 170 |

petrochemical industry in the United Kingdom, about 115,000 tons, exceeded that of the rest of Western Europe combined (86,000 tons). By 1961, Germany had a capacity of 354,000 tons, Italy 160,000 tons and France 140,000 tons, while the United Kingdom had 400,000 tons of capacity. Germany now has the largest total investment in organic petrochemical facilities in Western Europe and was the largest producer in 1961.

Reasons for the Shift from Coal to Petroleum

Several reasons can be put forward for the shift in chemical raw materials supply from coal, coke and other sources to oil and natural gas. (1) Coal and coke prices have doubled in the last fourteen years, while the prices of petroleum products have remained relatively stable. For example, in the United Kingdom, using costs of raw materials to the coal gas industry as an illustration, with 1949 as an index number of 100, coal costs rose to 140 in 1954 and 188 in 1960, while coke costs rose to 135 in 1954 and 212 in 1960; using the price of heavy fuel oil as indicative of petroleum products, the cost index fell from 100 in 1954 to 97 in 1960. Although there was a temporary rise in heavy fuel oil prices during the Suez crisis. See "In Pursuit of Diversity," Petroleum Press Service, XXIX, No. 3, p. 106.
prices in Western Europe increased between 40% and 70% more than wholesale prices in general and crude oil prices in particular, so that chemical firms tended to look for alternative raw material sources. (2) This tendency was encouraged by long term coal shortages in some areas, and short term interruptions in supply in others, due mainly to labour problems. (3) Western Europe's oil refining capacity increased from 18,400,000 tons of crude distillation capacity in 1939 to 194,500,000 tons in 1960 and 235,000,000 tons in 1962. This development has permitted the shift to oil based feedstocks. (4) Natural gas has been discovered and developed in Western Europe. It is often made available to the chemical industry at lower rates than to fuel consumers. France and Italy accounted for 90% of the 94 billion cubic feet of natural gas used by the chemical industry in the European Common Market countries in 1960.

These and other influences have caused the change over from coal to petroleum raw materials at a time when demand for chemicals has grown at an extremely rapid rate.

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34This figure refers to consumption by both the organic and inorganic chemical industries. See L. H. Frampton, "European Economic Community . . . World's Largest Chemical Exporter," Petroleum Refiner, Vol. 42, No. 4 (April, 1963), p. 138.
2. The Pattern of Demand

Chemicals are mainly consumed by industry and agriculture. Many of the uses for petrochemicals are of recent origin, particularly plastics, synthetic fibres and synthetic rubbers. The rapid growth of these consuming industries in Western Europe can be seen in Table 4, and petrochemical demand has grown at a similar rate. One of the reasons for the rapid development of the synthetic industries has been the lower chemical prices made possible by the use of petroleum. For example, in the United Kingdom, vinyl chloride was $1.12 a ton in 1950 and $2.46 a ton in 1960, and acrylonitrile was $1.23 a ton in 1950 and $6.05 a ton in 1960.

<table>
<thead>
<tr>
<th>TABLE 4</th>
<th>PRODUCTION OF PLASTICS MATERIALS, SYNTHETIC FIBRES AND SYNTHETIC RUBBER IN THE O.E.E.C. COUNTRIES 1950-1961 (THOUSANDS OF METRIC TONS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastics Materials(^a)</td>
<td>348</td>
</tr>
<tr>
<td>Synthetic Fibres</td>
<td>9</td>
</tr>
<tr>
<td>Synthetic Rubber</td>
<td>0</td>
</tr>
</tbody>
</table>

\(^a\)Sales figures.

Figure 1 shows the distribution of plants engaged in the manufacture of plastics and synthetic fibres, and the main chemical producing areas in the major O.E.E.C. countries. It can be seen that the distributions of the plastics and fibres industries are similar to that of population, with concentrations in the new industrial areas, such as around the capital cities. In the United Kingdom, London has by far the greatest number of plastics plants, although the plant of Imperial Chemical Industries Limited (I.C.I.) at Wilton in Northern Yorkshire has a large capacity. Other centres which are likely to have large organic petrochemical demands are the Midlands and South Lancashire (where there is a long established chemical industry). On the continent of Europe there are concentrations of the plastics, synthetic fibre and chemical industries in an arc from Amsterdam to Liege, in the Cologne-Ruhr area, in Frankfurt am Main and Mannheim-Ludwigshafen, in and around Paris and at Milan. Secondary demand centres occur at Hamburg, in the Hannover-Brunswick area, on the Nord coal field of France, at Lyons, in Northern Switzerland and between Stuttgart and Munich. The German plastics industry is as large as those of France and the United Kingdom combined, and therefore the Cologne-Ruhr and Frankfurt-Ludwigshafen regions are particularly important as markets for certain organic petrochemicals. Inorganic petrochemicals are used as fertilizers.
Figure 1

MARKETS FOR PETROCHEMICALS IN WESTERN EUROPE
AS INDICATED BY THE CHEMICAL, PLASTICS AND SYNTHETIC FIBRE INDUSTRIES

KEY.

- NUMBER OF EMPLOYEES IN THE CHEMICAL INDUSTRY
  - 20/50
  - 75/100
  - (THOUSANDS)
- PRINCIPAL CHEMICAL PRODUCING AREAS
- PLASTICS PLANTS (INFORMATION ON ITALY NOT AVAILABLE)
- SYNTHETIC FIBRE PLANTS

WILTON
SOUTH LANCASHIRE
SOUTH WALES
LONDON
AMSTERDAM
ROTTERDAM
BRUSSELS
RUHR
COLOGNE
RHINE-MAIN
LUDWIGSHAFEN
MÜNCHEN
NORTHERN SWITZERLAND
LYONS
MILAN
MARSEILLE
in agriculture throughout Western Europe. However, in France and Italy a greater proportion of the inorganic fertilizers come from petroleum than in the other countries because natural gas is available there for ammonia production. In the United Kingdom and Germany, coal remains the basis of the inorganic chemical industry.

The O.E.E.C. countries export a total of $730,000,000 worth of organic chemicals a year, mainly to each other. In most countries exports of one type of chemical are balanced by imports of another type. However in Germany and the United Kingdom exports exceed imports, and the export market forms an important part of the demand for Western Europe's petrochemicals.

3. The Supply of Raw Materials

Only 6.6% of the feedstocks consumed by the organic petrochemical industry in Western Europe derive from natural gas, so that about 90% of the industry is based on imported raw materials, 70% oil and its liquid products and 20% refinery gas (Table 5). This dependence on imported raw materials has greatly influenced the distribution of the petrochemical industry.
<table>
<thead>
<tr>
<th>Country</th>
<th>Oil and Liquid Products</th>
<th>Refinery Gas</th>
<th>Natural Gas</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Consumption %</td>
<td>Consumption %</td>
<td>Consumption %</td>
<td>Consumption %</td>
</tr>
<tr>
<td>Belgium</td>
<td>43.1</td>
<td>100.0</td>
<td>0.0^a</td>
<td>0.0</td>
</tr>
<tr>
<td>France</td>
<td>339.6</td>
<td>61.5</td>
<td>154.3</td>
<td>28.0</td>
</tr>
<tr>
<td>Germany</td>
<td>1033.0^b</td>
<td>73.9</td>
<td>340.0</td>
<td>24.3</td>
</tr>
<tr>
<td>Italy</td>
<td>982.3</td>
<td>65.6</td>
<td>183.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Netherlands</td>
<td>184.9</td>
<td>29.0</td>
<td>452.9</td>
<td>71.0</td>
</tr>
<tr>
<td>Spain</td>
<td>23.0</td>
<td>100.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>1896.0</td>
<td>91.0</td>
<td>190.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Total e</td>
<td>4501.9</td>
<td>72.2</td>
<td>1320.5</td>
<td>21.2</td>
</tr>
</tbody>
</table>

^a Included with oil.   ^b Including 122,000 tons of crude oil.   ^c Estimated.
^d Not available, but small.   ^e Figures for Belgium, France and Italy refer to net consumption; Spain and United Kingdom, gross consumption; Germany, 70-80% net figures and the rest gross.

Natural gas is produced in large quantities only in Italy and France, and even in these two countries it accounts for less than one quarter of the raw materials consumed by the organic petrochemical industry. The main chemical use of natural gas is as a hydrogen source for the ammonia and inorganic fertiliser industries. Refinery gas, which is much more useful as an organic raw material was predominant in the formative years of Western Europe's petrochemical industry, but has been declining in relative importance since the early nineteen fifties, so that it now forms only 21.2% of the total. Large quantities of refinery gas have never been available in Western Europe. The reason for this is that catalytic cracking, which produces olefin-rich gases as well as maximising gasoline yields, forms only a small proportion of the refining capacity. Demands for oil products in Europe closely match the supply available from the simple distillation of crude, and therefore little additional processing (such as cracking) is needed. Moreover the cracking capacity that has been built is dispensed, so that while many petrochemical plants were originally based on refinery gases, it has usually been found necessary to draw heavily on other raw material supplies as plants have been expanded. The larger the petrochemical industry has grown, the less the reliance on refinery gases has become.

However the distillation of crude oils from the
Middle East and North Africa yields large quantities of naphtha as a by-product. By cracking this liquid olefin-rich gases are obtained and these gases are the main source of petrochemical feedstocks in Western Europe.

**Oil Refineries as a Source of Petrochemical Raw Materials**

Oil refining capacity in Western Europe has grown from 934,000 barrels per day of crude distillation capacity in 1950 to 4,546,000 barrels per day in 1962 (Table 6) as a result of an increased demand for fuel oils and gasoline and the change over from the pre-war practice of importing oil products from resource orientated refineries, to the post war situation in which crude oil is imported and refined domestically. The growth of the oil refining industry was remarkable between 1954 and 1960, particularly in Germany.

It has been shown that about 20% of the petrochemical raw materials used in Western Europe are refinery gases. As these gases are not economically transportable over long distances a site near an oil refinery is predetermined. This restriction on the location of petrochemical plants applies to more than 20% of the organic capacity.

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<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>14.3</td>
<td>113.9</td>
<td>100.1</td>
<td>138.0</td>
<td>175.9</td>
<td>161.5</td>
<td>187.0</td>
<td>288.7</td>
</tr>
<tr>
<td>France</td>
<td>363.1</td>
<td>456.4</td>
<td>491.1</td>
<td>636.1</td>
<td>713.2</td>
<td>842.7</td>
<td>914.7</td>
<td>922.5</td>
</tr>
<tr>
<td>Germany</td>
<td>111.9</td>
<td>140.5</td>
<td>262.5</td>
<td>302.5</td>
<td>406.6</td>
<td>846.2</td>
<td>876.7</td>
<td>968.3</td>
</tr>
<tr>
<td>Italy</td>
<td>102.5</td>
<td>257.5</td>
<td>453.7</td>
<td>546.0</td>
<td>722.9</td>
<td>818.6</td>
<td>851.1</td>
<td>800.7</td>
</tr>
<tr>
<td>Netherlands</td>
<td>97.9</td>
<td>195.5</td>
<td>237.0</td>
<td>261.0</td>
<td>349.0</td>
<td>459.0</td>
<td>463.0</td>
<td>463.0</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>244.6</td>
<td>540.8</td>
<td>618.4</td>
<td>631.8</td>
<td>917.9</td>
<td>949.3</td>
<td>1064.6</td>
<td>1103.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>934.3</td>
<td>1704.6</td>
<td>2162.8</td>
<td>2515.4</td>
<td>3285.5</td>
<td>4077.3</td>
<td>4357.1</td>
<td>4546.3</td>
</tr>
</tbody>
</table>

Many petrochemical plants use three or four different sources of raw materials, but must still be built near oil refineries if refinery gas is one of them. Furthermore, as many plants manufacturing intermediate chemicals use materials which are also not economically transportable (such as ethylene), this restriction effect is multiplied. Oil refinery location also has indirect effects on petrochemical plants using liquid raw materials for usually three to four times more feedstock is consumed than basic chemicals produced.

Because of these direct and indirect influences the location of oil refineries will be discussed in some detail.

The Distribution of Oil Refining Capacity

There are three alternatives in the location of an oil refinery in Western Europe. It may be located at a port (or on an oil field), it may be located at the main oil products market, or it may be built at some point in between. Figure 2 shows the concentration of refineries at major estuary ports. The Thames, Elbe, Rhine, Seine and Rhone mouths account for 46.3% of Western Europe's refining capacity with 27 out of the 96 plants (Table 7), although no one centre has more than 10% of the total capacity. A further 31.5% is located at other Western European ports. Only 22.2% is located inland and this includes 4.8% which is on the small oil fields of the continent.

One explanation for this estuary port orientation
Figure 2

OIL REFINING AND NATURAL GAS PRODUCTION IN WESTERN EUROPE 1962


KEY

OIL REFINING CAPACITY
(THOUSANDS OF BARRELS PER DAY)

FAWLEY

RUHR

PERNIS

STANLOW

MILFORD HAVEN

THAMES

PERNS

LE HAVRE-ROUEN

RUHR

COLOGNE

MILAN

MARSEILLE

GENOA

RAVENNA

AUGUSTA

Pipelines (Crude)

Natural Gas Production (Billions of Cubic Feet per Year)

3-10
50
100
150
200
250

Scale

0
100
200

MILES
### TABLE 7

**THE DISTRIBUTION OF OIL REFINING CAPACITY**[^1]  
**IN WESTERN EUROPE, 1961**  
**(GERMANY, FRANCE, BENELUX, ITALY AND UNITED KINGDOM ONLY)**

<table>
<thead>
<tr>
<th>Type of Area</th>
<th>No. of Refineries</th>
<th>% of Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal: Five Main Estuaries</td>
<td>27</td>
<td>46.3</td>
</tr>
<tr>
<td>Coastal: Other Ports</td>
<td>33</td>
<td>31.5</td>
</tr>
<tr>
<td>Cologne-Ruhr</td>
<td>10</td>
<td>11.8</td>
</tr>
<tr>
<td>Po Valley and Milan</td>
<td>16</td>
<td>5.6</td>
</tr>
<tr>
<td>Oil Fields</td>
<td>10</td>
<td>4.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>96</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

[^1]: Crude distillation capacity plus cracking, reforming and other types of processing.


is the juxtaposition of the points of entry for crude oil and the main oil products markets. London, Rotterdam, Antwerp, Marseilles and Hamburg may be cited as examples. For similar reasons a large proportion of refining capacity is also located at other ports such as Bordeaux, Genoa, Naples, Trieste, Fawley and Stanlow on Merseyside. These places are either large markets, or are near large markets, or are regional supply centres. The location of much of the refining capacity at these ports can therefore be simply
explained; however, there are a few points which need further discussion. Firstly, the importance of many ports in the oil refining industry is out of proportion to the sizes of their local markets. Marseilles has a far greater capacity than is justified by that city and its immediate surroundings alone. Secondly, some refineries are located at small ports which are not in themselves, nor are near, large markets. Many refineries in Italy, and the Heysham plant in North Lancashire are examples. Thirdly, in the case of the major inland German markets, the Ruhr and Cologne, refineries are market orientated, while in the case of the major inland French market, Paris, the associated refineries are coastal. These three points warrant further discussion.

Problems of Oil Refinery Location

The main factors influencing refinery location are the economies of large scale operations, and the relative advantages of transporting crude oil or products to the market areas. Economies of scale include lower initial capital costs per unit of capacity (and the fixed charges dependent on these costs), and lower variable costs, such as those which result from decreasing labour requirements with increasing scale. Refinery capital costs increase by a factor of 0.6 when plant is doubled in size.\(^\text{36}\) Refinery

\(^{36}\text{Ibid.}, \text{ pp. 87-88.}\)
operating costs have been estimated to be about $0.65 per barrel for a 100,000 barrels a day refinery, $0.90 per barrel for a 30,000 barrels a day refinery and $1.50 per barrel for a 10,000 barrels a day refinery.37

Transport costs for crude and products in Western Europe are given in Figure 3. Transport cost advantages are assumed to depend solely on the amount of crude needed to produce a given quantity of oil products, for the costs of transporting crude and products are very much the same when shipments are made in like amounts and by the same medium of transport. A simple refinery using Middle East crude (the source of 80% of Western Europe's imports) yields 20% as gasoline, 10% as premium kerosene, 62.5% as gas oil and fuel oil, and 7.5% is either used as refinery fuel or is lost in the conversion. An average yield of products from crude of 92.5% will therefore be used.

Even small refineries need large supporting markets; a company with a 33% share of the market in an area needs an average of 1,500,000 people to consume the products of a 10,000 barrels a day refinery in the United Kingdom, and more on the Continent. The number of cities capable of supporting large refineries is thus severely limited. On the other hand, costs of production are smaller for large scale refineries, so that if possible a company will

Figure 3
THE COST OF TRANSPORTING OIL IN WESTERN EUROPE.

MILES

CENTS PER TON MILE

M.T.P.Y. = MILLION TONS PER YEAR

DERIVED FROM: M.E. HUBBARD, "PIPELINES IN RELATION TO OTHER FORMS OF TRANSPORT." WORLD POWER CONFERENCE, MADRID 1960.
concentrate its capacity at one place.

Coastal refineries.—The common case in Western Europe is for regional markets to be divided between large concentrations of people and industry at tidewater and a more dispersed consumption pattern inland. London and south east England, Merseyside and Lancashire, Hamburg and the North German plain, Rotterdam and Antwerp and their hinterlands, Marseilles and the Rhone-Saone Valley, are examples. An oil company may either build a large refinery at the port and make small shipments of products inland, or it may build a medium sized plant at the port and smaller refineries wherever warranted inland. However, if the company chooses the latter alternative, it not only operates many small plants at a high cost, but also loses the benefits of large scale operations at its major refinery. One 100,000 barrels a day plant has an average processing cost at $0.65 per barrel; a 50,000 barrels a day and five 10,000 barrels a day refineries have an average processing cost of $1.15 per barrel, almost twice as much.

The only advantage of building small inland refineries is the possibility of using pipeline transport for bulk crude shipments. However, as shown by Figure 6, crude oil pipelines with capacities of 500,000 to 1,000,000 tons a year have no cost advantage over road and rail shipments of products, which are 7.5% smaller in bulk. Even when there is a significant difference between costs of transport
by pipelines and costs by road or rail, it is not usually large enough to offset the economies resulting from the large scale operation of a single coastal refinery. By building a 1,000,000 tons a year pipeline to a refinery 100 miles inland, a company might save 1¢ per ton mile or 12.5¢ per barrel over shipping products by rail. This is small compared with an economies of scale saving of $0.50 per barrel gained by building a single 100,000 barrels a day refinery at the coast.

The result of these and other influences has been that oil companies have located their refining capacity at the oil ports, particularly where these ports correspond with large urban and industrial markets, but also where the port was merely the place of access to an inland market.

Inland refineries.--There are two exceptions to this generalization. The first is the case of ten small refineries located on oil fields, a problem which needs no further discussion. The second is the case of large, concentrated inland markets which not only justify big refineries (and therefore have no scale disadvantage), but also can be served by crude oil pipelines in the 5,000,000 to 20,000,000 tons a year class, with costs of transport in the 0.15¢-0.40¢ per ton mile range.

In Germany such a large market exists in the Cologne-Ruhr region. The Wilhelmshaven to Cologne pipeline has a capacity at present of 10,000,000 tons a year and a
length of 240 miles; at about 0.25¢ per ton mile (Figure 3) it costs 60¢ to transport one ton of crude to the refineries at Cologne. By comparison the shipment of oil products by barge from refineries at Rotterdam or Hamburg costs about Dm. (Deutschmarks) 6.0 per ton ($1.50) or $1.40 for 0.925 tons.38 This saving in transport costs has led to the growth of the oil refining industry at Cologne and in the Ruhr since oil products demands in these areas reached a sufficiently high level to justify the Wilhelmshaven pipeline. This level was only reached recently, as in 1951 the total West German demand for the major refined products was only 7,000,000 tons a year. In 1958, 19,000,000 tons of products were consumed; in 1960, 28,000,000 tons were used and a second pipeline from Rotterdam to Cologne was completed by a different group of oil companies. Thus, in the last fifteen years, the oil refining industry in Germany has become more and more concentrated in the Cologne-Ruhr region while the relative importance of the North Sea German ports has declined.

Paris, in comparison, is served by a 150 mile products pipeline, the Trapil, from refineries near Le Havre and Rouen. Petite Couronne near Rouen is joined to Le Havre by a 48 mile long crude oil pipeline. Paris is a

concentrated market for gasoline which is large enough to justify the construction of a products pipeline from refineries at the two ports. Elsewhere in Europe the markets for individual refined products are not large or regular enough to justify the provision of products pipelines. Also 60% of the average Western European demand is for fuel oil, and residual fuel oil is not transported by pipeline, being more viscous than crude. Thus a products pipeline is not yet feasible in the case of the Cologne-Ruhr region, whereas such a line is possible in the case of the large Paris gasoline market. The Trapil was originally justified in 1953 on the grounds that it was cheaper than Seine barge transport and less liable to interruption, and it was also felt that the carrying capacity of the river for oil was approaching saturation. Its effect on the French refining industry has been to encourage location at Le Havre and Rouen, which is the reverse of the German distribution.

Generally, therefore, there are transport and scale advantages in locating refineries at the coast unless large inland fuel oil markets exist. There are other factors which also favour the choice of a coastal site. One of these is the large amounts of flat land which are required for oil refineries, a requirement that restricts the number

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of places suitable for development. Reclaimed land at estuary mouths can usually be bought at a reasonably low cost, and company docks can be constructed. Another site requirement, which is more important than in many industries, is the large amounts of low cost processing and cooling water needed in oil refining. At estuary sites this is available from the rivers and sea. Coastal location also saves one transshipment because the tanker can unload directly at the refinery. A final influence on refinery location should be noted. The use of super tankers for the transport of crude oil is increasing and not all oil ports can handle these ships. Thus deep water ports such as Milford Haven in Wales have prospered as refining centres despite their comparative isolation.

As inland markets increase in size, two tendencies in oil refinery location will develop. Where crude oil pipelines are installed, cul-de-sac refineries will be built; for example, the new crude oil pipeline from Lavera, near Marseilles, to Karlsruhe, Strasbourg and Munich, has led to the location of refineries at these places. Where product pipelines are constructed, the present coastal distribution will be re-inforced; for example, in England the proposed common carrier pipeline to carry refined products between Essex, North London, Birmingham and

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41Estall and Buchanon, op. cit., pp. 221-222.
Lancashire, and the Fawley-West London line, would strengthen the Thames estuary, Stanlow and Fawley areas' hold on the refining industry. While both crude and product pipelines will probably eventually be built, the question of which will achieve dominance will depend on the relative strengths of gasoline and fuel oil demands.

Natural Gas as a Source of Petrochemical Raw Materials

The two main fields, Lacq and the Po Valley, account for over 80% of Western Europe's present natural gas production, although the use of the large new reserves at Groningen in the Netherlands will soon decrease this proportion. A gas pipeline network connects the fields of the Po Valley with the major cities of the region, while Lacq and the small St. Marcet gas field are connected to Paris, Lyons and Nantes by a 560 mile long, three pronged pipeline system.

Of approximately 15.5 billion cubic metres (547 billion cubic feet) of natural gas produced in the O.E.E.C. countries in 1961, 44% came from Italy, 39% from France, 10% from Austria, 4% Germany and 3% the Netherlands. Government organisations control most of the gas reserves and production of Europe; at Lacq, Societe Nationale des Petroles and in Italy, Ente Nazionale Idrocarburi (E.N.I.).

\[42\] For a discussion of these pipeline proposals, see Manners, *op. cit.*, p. 162.
In Italy chemical producers are given lower prices than consumers of gas for fuel purposes.

4. The Distribution of the Petrochemical Industry

The distributions of the petrochemical industry and the oil refining and gas industries in Western Europe are similar. Most of the petrochemical centres (Figure 4) are orientated towards refinery and natural gas field raw material sources. Thus the main problem is not why the industry is located at raw material sources, but which raw material sources are the most intensively used and why one is used more than the others. The coastal refining areas account for 78% of Western Europe's capacity to process crude oil, yet these areas have only 38% of the organic petrochemical capacity, although there is a further 15% at other coastal sites which are not directly associated with oil refineries. On the other hand, the Cologne-Ruhr region with only 12% of the refining capacity, has 22% of the organic petrochemical capacity of Western Europe.

Four factors which have been particularly important in the development of the petrochemical industry in Western Europe will now be discussed. It is not suggested that these are the only factors which have influenced the location of petrochemical plants, nor that they have all affected the location of every plant. However it is suggested that these are the most important influences.
Figure 4

ORGANIC PETROCHEMICAL CAPACITY BY AREA IN WESTERN EUROPE MID 1962

KEY
ORGANIC PETROCHEMICAL CAPACITY

50 000 200 400 600 800 1000 1500 2000
(MILLIONS OF POUNDS PER YEAR)
CIRCLES REFER TO CAPACITIES OF PLANTS WITHIN DOTTED LINES

SOURCE OF DATA: THE OIL AND GAS JOURNAL, SEPTEMBER 1962 AND OTHER SURVEYS.
The Effects of Raw Material Supply: Oil Refineries

The similarity between the distributions of oil refineries and gas fields, and petrochemical plants, apparent from a comparison of Figures 2 and 4, leads the geographer to look for relationships between the two.

Reasons for the Location of Petrochemical Plants at Refining Centres

The fact that many petrochemical plants are linked with oil refineries was mentioned in the discussion on oil refinery location. Some petrochemical plants are only refinery extensions in that materials are processed a little further before being passed on to other industries. For example, three plants at Donges in Western France process aromatic hydrocarbons from the refinery of Antar Petroles de l'Atlantique into more easily transportable liquid aromatics, such as benzene, toluene and xylenes. However, most plants are separate entities which gain considerable economic benefits by siting next to oil refineries.

Advantages of a refinery site.--Among the reasons for the siting of petrochemical plants next to refineries is the fact that the refining industry is the market for such chemical products as gasoline additives and anti-knock compounds. Small factories at Antwerp, La Mailleraye and Gonfreville in Basse Seine, L'Estaque near Marseilles and Paimboeuf near Donges are examples of this tendency to
locate near markets formed by the oil refining industry. Also petrochemical plants have similar site requirements to oil refineries, large amounts of low cost flat land and bulk water supplies. Often oil companies own large tracts of land around their refineries on which their petrochemical plants are built. By doing this the company can operate both types of plant in conjunction and obtain economies of scale; for example, the refinery often provides the steam, water and power requirements of the chemical plant. There are external economies to be gained by locating at refinery concentrations, and there is also the "snowballing effect" of a number of refineries, chemical plants and cognate industries attracting others.

Additional advantages of a waterside refinery site.—A petrochemical plant near a coastal, ship canal or riverside refinery obtains additional economic benefits. International oil companies which build plants at such sites are able to draw raw materials from their other refineries more easily. For example, Shell-St. Gobain at Berre near Marseilles use liquid feedstocks from Shell's Pernis refinery as petrochemical raw materials. Coastal refineries in particular usually have good port facilities, and this was stated to be one of the advantages of Shell's chemical plants at Stanlow and Shell Haven in England.43

There is a certain amount of traffic flow between

petrochemical plants which is made easier and cheaper by the availability of water transport, such as the movement of styrene from the plants of Forth Chemicals Ltd. at Grangemouth in Scotland and Shell Chemical Company at Carrington in England, to the International Synthetic Rubber Company at Fawley. In the case of the Rhine river, Rheinische Olefinwerke at Wesseling near Cologne, which is a joint Deutsche Shell and Badische Anilin und Soda-Fabrik operation, supplies ethylbenzene to Badische Anilin's huge factory at Ludwigshafen, 250 miles down the Rhine. In industries such as chemicals, a great deal of specialisation takes place and inter-plant exchanges are made in large volumes. A final advantage is that chemical exports may be carried by tankers which call at coastal refineries, often travelling at cheap rates as deck cargo (particularly when a refining-chemical company owns its own tankers).

Location at Market Area Refining Centres

It is to be expected therefore that refinery concentrations attract a considerable part of the petrochemical industry. This is especially true when it is considered that the industrial areas which are the major markets for fuel oil produced by refineries are also markets for organic chemicals, and cities which consume large amounts of gasoline are, for example, markets for ethylene glycol anti-freeze, a petrochemical product. Thus both are
attracted towards the same places. However, as it was indicated in the discussion on markets, the synthetic industries are not evenly distributed in all the industrial areas of Western Europe, and similarly the petrochemical industry is not evenly distributed at all refinery concentrations. If a refining centre is near to an industrial area which specialises on the manufacture of plastics, detergents, synthetic fibres and other allied industries, then a petrochemical industry, beyond the size that is to be expected because it is a refining centre, has usually developed. Cologne and the Ruhr are refinery areas which also contain large plastics, detergent and fibre plants and also have a considerable petrochemical industry; Rotterdam and Antwerp are refining and petrochemical centres near an arc of plastics and fibre plants from Amsterdam to Liege; the Merseyside petrochemical plants are near the chemical industry of South Lancashire and Cheshire. London, however, is a prominent exception, for while there are both refineries and markets for organic chemicals in the conurbation only a limited amount of petrochemical production takes place.

This development also occurs when a refining centre has easy access to a market area, as Fawley has to London, or Basse Seine to Paris or the Rhone mouth to Lyons. Finally when a refining centre is the nearest available to a market, development may still take place. For example,
Bordeaux is the nearest refinery port to the large Michelin Tyre Company factory at Clermont Ferrand, and the company plans to build a synthetic rubber plant there.

The effect of isolation from chemical markets can be seen in the lack of large developments at the North Sea German ports, or Milford Haven in Wales, or Naples. As an example of this differential development the Cologne-Ruhr and Hamburg areas will be examined in detail.

Cologne or Hamburg?.—North Rhine-Westphalia is an extensive plastics, detergents, synthetic fibres, dyestuffs, paints and synthetic rubber producing region. It also has good access to other regional markets and to foreign consumers via the Rhine routeway. Compared with this is the geographical isolation of Hamburg. Since the post war division of Germany this port has been cut off from its traditional hinterland in Saxony, Berlin, Silesia and Czechoslovakia which in 1938 supplied 60% of its exports. This also affects its industrial potential.

Petrochemical raw materials are available at both Hamburg and the Cologne-Ruhr region from oil refineries. Oil products are cheaper at Hamburg, for no overland freight rates need be paid. However, because of the pipelines to Cologne, the difference in the prices of oil products in the two areas is small, no more than an

estimated pipeline rate on crude oil of $0.60 per ton. Furthermore, competition between coal and oil in the Cologne-Ruhr area tends to hold the prices of oil products down, and, as the major alternative use for petrochemical raw materials is for fuel, feedstock prices at Cologne are also low. Coal can be bought for Dm. 57 per ton ($14.25) in the Ruhr or about $0.53 per million British Thermal Units (MM. B.t.u.)\(^{45}\). This sets an upper limit on the prices of competing oil products, so that naphtha can be bought in bulk quantities on the Rhine for Dm. 90-100 per ton ($22.50-$25.00) or $0.52-$0.58 per MM. B.t.u.\(^{46}\) Fuel oil is listed at Dm. 85-86 per ton ($21.25-$21.50) or $0.53-$0.54 per MM. B.t.u. at Hamburg\(^{47}\) and Dm. 2 ($0.50) more in the Ruhr,\(^{48}\) a difference of about 1.25\(^{\frac{c}{\circ}}\) per MM. B.t.u. If it is assumed that refiners value their gas production at the equivalent of fuel oil,\(^{49}\) then 1.25\(^{\frac{c}{\circ}}\) per MM. B.t.u. is also

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\(^{45}\)Efficiency in use is not considered in converting coal, oil and other fuels into millions of British Thermal Units. The conversion factors are taken from H. V. Warren, "Some Pertinent Factors in Energy Studies," The Canadian Geographer, V, No. 1 (1961), p. 16.

\(^{46}\)Letter from Farbwerke Hoechst, Frankfurt am Main, February, 1963.


\(^{49}\)Which is a reasonable assumption as refinery gas sold will have to be replaced in the fuel economy of the refinery by other oil products.
the difference in refinery gas prices between Hamburg and the Cologne-Ruhr region. This raw material price differential would give a Hamburg plant an advantage of $1.13 per short ton in the cost of manufacturing ethylene from refinery gases, which in turn causes a difference of $0.94 per short ton in the cost of making ethylene glycol from ethylene, an advantage which is insignificant when it is considered that ethylene glycol sells for $264 per short ton in Germany. However, Hamburg is 260 miles away from Cologne by rail, and Cologne and the Ruhr must be considered the main domestic markets for petrochemical producers in Germany. It costs a Hamburg producer Dm. 45.90 per metric ton ($10.00 per short ton) to reach this market. There is therefore an advantage of $9.06 per short ton in locating in the Cologne-Ruhr region when the factors of raw materials prices and product transport costs are considered. The effect of this difference has been the rapid growth of the petrochemical industry at Cologne and in the Ruhr, compared with the more stunted growth of the Hamburg area.

5090 MM. B.t.u. of refinery gas being needed to produce one short ton of ethylene. See Appendix I, Table 1.

51670 pounds of ethylene being needed to produce one short ton of ethylene glycol. See Appendix I, Table 2.

52Letter from Deutsche Bundesbahn, Frankfurt am Main, March, 1963. This rate applies to shipments in twenty ton lots.
Cologne or Rotterdam?—The positions of Hamburg and Rotterdam, vis-a-vis Cologne, the Ruhr and other markets, are very much different. Rotterdam has gained in importance since the war at the expense of Hamburg and other European ports, and this is reflected in its attractiveness to industry. In the case of petrochemicals manufacture, the Netherlands has both refinery products and natural gas for use as chemical raw materials, at prices roughly the same as those of refinery products at Hamburg. The great advantage of Rotterdam, however, stems from its position; rail freight rates on ethylene glycol between Rotterdam and Cologne (a distance of 162 miles) amount to $6.65 per ton; polyethylene moves from Rotterdam to Duisburg at a rate of $5.60 per ton, a rate which is just over one half of that from Hamburg to the Ruhr. A chemical plant at Rotterdam (or Antwerp) has all the advantages, mentioned earlier, of coastal plants, is near to markets in the Netherlands and Belgium, and has good access to other European Common Market and overseas markets. It is possible to build very large plants at such a central place, like the $280,000,000 petrochemical plant being built by I.C.I. near Rotterdam. Such large plants can compete very effectively with smaller plants in such market regions as Cologne and the Ruhr.

The examples of Hamburg and Rotterdam illustrate

53 Ibid.
the influence of location relative to major markets on the development of the petrochemical industry at different refinery centres.

The Effects of Raw Material Supply: Natural Gas

The natural gas fields of the Po Valley and South Western France have attracted several large plants mainly manufacturing inorganic petrochemicals, but also making some organics. At Lacq 40% of the gas produced is used on the field in a 50,000 Kw. electricity generator, a 66,000 ton aluminium plant and a complex of chemical plants.\textsuperscript{54} In the Po Valley, gas is used for chemicals manufacture at Porto Marghera, Ravenna, Ferrara, Milan and Novara.

This tendency for plants to locate on gas fields rather than at the market (drawing gas from pipelines) results from a number of factors. Gas pipelines have only been built in the north of Italy,\textsuperscript{55} and longer distance lines in France are small by North American standards. Also there are restrictions on the use of gas for chemicals. In the Paris area for example, industries are not allowed to use Lacq gas in order to prevent the further growth of industry in the Metropolitan area, and foster the economic


development of the South West. Another reason for growth at the gas field rather than at the markets is that larger quantities of natural gas are consumed by a petrochemical plant than there are chemicals produced from it.

In Germany and the Netherlands the common practice is for short pipelines to be built from small gas fields to nearby chemical plants. Thus the gas field at Darmstadt in the Rhine-Main region is linked with plants at Darmstadt, Ludwigshafen and Frankfurt. So far the small reserves of gas available in Germany and the Netherlands have precluded the siting of expensive and immobile chemical plants on the fields. The Groningen discovery however is large enough to warrant the construction of plants at the field.

**Market Orientation**

In the last section the idea that petrochemical plants tend to be built at the nearest refinery centre to the major chemical markets was introduced. However a comparison of Figures 1, 2 and 4 shows that some petrochemical have been built at the markets even though there is no refinery or gas field in the immediate vicinity. Examples of this type of plant are petrochemical factories at Amsterdam, Paris, Lyons and the Frankfurt-Ludwigshafen area.

(although the last is also the result of other factors and derives some of its raw materials from the nearby Darmstadt gas field).

Transport Costs on Raw Materials and Products

Between 1954 and 1961 in the O.E.E.C. countries, an average of three to four tons of oil and gas raw materials were used for every ton of basic organic petrochemical produced. This favours the location of plants at refineries and gas fields rather than markets. However if transport charges on raw materials are a third to a quarter of those on chemicals, a market location may be possible. A chemical plant sited on a major waterway is able to take bulk shipments of liquid feedstocks from refineries by barge and obtain low freight rates. Chemical shipments are made partly by barge but smaller and more spasmodic shipments, and those to markets not on rivers or canals, move by truck and rail. In 1960 Farbenfabriken Bayer imported 3,000,000 tons of chemicals and there were 1,400,000 tons outgoing, 43% by barge, 30% by rail, and 27% by truck, the last two media officially with the same freight rates. In France water is little used for chemical shipment, because trucking and rail are often cheaper than 200-600 ton barges moving over longer canal and river distances. In the United Kingdom, I.C.I. use rail but are increasingly turning to truck; bulk shipments of chemicals to the Continent move by
ship and rail. Water transport rates for chemical feedstocks are the same or a little above those for crude oil given in Figure 3. Rhine barge rates for large shipments vary from about 1¢ per ton mile for 125 miles to 0.7¢ per ton mile for 400 miles. Over the same distances rail rates on 20 ton shipments of chemicals in Germany decrease from 5.5¢ per ton mile to 3.6¢ per ton mile, with similar rates for large autobahn trucks. In the case of a bulk rail shipment of low value chemicals 273 miles from Frankfurt to Berne this drops to about 3¢ per metric ton mile, (a rate almost identical to a similar shipment from Utica to New York). In France a 125 mile shipment of ethylene glycol by rail costs about 3.7¢ per ton mile, while feedstock shipments by barge cost about 1.3¢ per ton mile for a 215 mile shipment on the Seine and 3.2¢ per ton mile for a 100 mile shipment on the Rhone. In the Netherlands a 100 mile shipment along the major railways of 15 tons of styrene or polyethylene can be made for 3.14¢ per ton mile.


58 The barge rates quoted are derived from Figure 3. Rail rates from a letter from Deutsche Bundesbahn, Frankfurt, except the Frankfurt-Berne rate.

The Feasibility of Market Orientation

When it is considered that river distances are usually 50-70% greater than those by rail, and that barge shipments entail additional costs such as greater storage capacity needed at the plant, and the maintenance of private docks, it can be seen that only under exceptional circumstances is market orientation economically feasible, for a company producing basic chemicals from three times as much feedstock. One such exception is the extremely low cost routeway of the Rhine. As shown by Table 8 a plant at the Frankfurt market could transport four tons of raw materials by barge from Cologne at the same cost as a plant at the refining city of Cologne could ship one ton of chemicals to markets in the Rhine-Main region by rail. Under these circumstances a petrochemical plant at Frankfurt or Ludwigshafen based upon naphtha or crude oil would be economically attractive. However the case for the market oriented plant has been overstated, for the Rhine-Main region is a large chemical market, to which shipments of chemicals can be made regularly and in bulk by barge. If material orientated plants at Cologne make 50% of their shipments of chemicals to the Rhine-Main market by barge, at similar rates to those operating for feedstocks, the market orientated plant has a slight transport cost disadvantage; a company would need additional reasons for making chemicals from petroleum at a non-refining centre.
<table>
<thead>
<tr>
<th>Source and Destination of Shipment</th>
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<th>Form of Transport</th>
<th>Distance (miles)</th>
<th>Rate per Ton Mile (c)</th>
<th>Cost per Ton ($)</th>
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<td>Rail</td>
<td>100</td>
<td>3.14-5.0</td>
<td>3.14-5.0</td>
</tr>
</tbody>
</table>

Source: Derived from Figure 3 and information supplied by Deutsche Bundesbahn, Frankfurt.
on the Rhine. This condition is applicable to the Frankfurt and Ludwigshafen plants which will be further discussed in the next section.

On the Seine and Rhone rivers barge and rail freight rates are more evenly balanced, when the longer distances by river are considered. A plant on the Seine at Paris could use up to 1.9 tons of feedstocks per ton of chemical and compete with a refinery orientated plant shipping chemicals by rail, and on the Rhone 1.14 tons of raw materials per ton of product is the margin. In these circumstances while market orientated plants are possible, they are not economically attractive. Thus plants at Lyons and Paris use petrochemicals as raw materials (such as ethylene glycol, propylene and aromatics), with which there is a higher yield of products. These plants are also usually parts of larger establishments manufacturing plastics and synthetic fibres.

In the last case shown by Table 8, canal barge and rail transport have similar freight rates, so that there is no advantage to be gained by locating at a canal-side market, unless, as is sometimes the case, the petrochemical plant is part of a larger factory. This condition also applies to companies using rail to ship raw materials to petrochemical plants in the market regions. In Germany rail rates on bulk shipments of naphtha are 20%-30% less than rates on higher valued chemicals, over the same distances; this difference is not sufficient to make a market site economically
attractive.

Generally therefore there are economies to be gained by locating at the raw material source, with the possible exception of areas with low cost transport facilities. If competitors make small, less regular shipments of chemicals by more expensive media of transport from raw material orientated plants, the differential between the freight rates obtained by them and a plant located at the market and making regular, bulk shipments of raw materials by low cost media, may make a market location economically possible, if not attractive. Usually however there are supplementary reasons for market locations as will be seen in the next section.

The Influence of a Pre-existing Chemical Industry

When an industry turns from one main raw material to another there are a number of forces which impede associated geographical changes in the pattern of production. The large amounts of capital invested in immobile equipment, the trained labour force, and the external economies of establishment in a long developed industrial area tend to offset even radical changes in the methods of production. However the ability of an area to survive industrial change varies, largely with the geographical position of that area.
Germany

In the introduction to this chapter it was pointed out that the petrochemical industry is a very recent development, and that a well established pattern of production based on coal had existed long before petroleum was first used for chemicals. Germany's chemical industry was particularly strong, and until the end of the war was largely controlled by one cartel, I. G. Farbenindustrie. Since the war the companies formed from the cartel have remained very strong. I. G. Farben had four main centres of production based upon coal, lignite limestone and salt; these were Rhineland-Westphalia, where there were plants at Huels, Essen, Leverkusen, Dormangen and Troisdorf; Frankfurt where the main plant was at Hoechst; Ludwigshafen-Mannheim; and Central Germany-Saxony-Anhalt with plants at Merseburg, Wolfen and Bitterfeld. The Rhine-Ruhr chemical industry was based upon coal tar, coke, and gas, the first two of which were shipped down the Rhine by barge, and also coke oven gas from the Saar. In the Ruhr there were several large plants for making oil and chemicals from coal which were built during the Second World War, some of which are now oil refineries.

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61 Elkins, op. cit., p. 196.
Chemische Werke Huels and a joint company Bunawerke Huels, which make petrochemicals, are located at Huels near Recklinghausen, and not, as might be expected, at the largest refining city of the Ruhr, Gelsenkirchen. The companies use natural gas piped from the Bentheim field in Emsland, liquified petroleum gases and coke oven gas, to make organic chemicals, plastics and rubber.\textsuperscript{62} Their site is the same as that occupied by an oil-from-coal plant during the war.

The Rhine banks between Cologne and the Ruhr are lined with heavy industry, among them the chemical industry. I. G. Farben had plants at Leverkusen and Dormangen in the Cologne area. Farbenfabriken Bayer and B. P. (British Petroleum) now use naphtha from B. P.'s Dinslaken refinery (north of Duisburg) and other B. P. refineries, in their jointly owned petrochemical plant at Dormangen, and the Bayer rubber, plastics and detergent plant at Leverkusen consumes the bulk of its chemical production.\textsuperscript{63}

Rheinische Olefinwerke at Wesseling, near Cologne, owned by Shell and Badische Analin uses gases from a refinery with which Shell co-operates, and naphtha from


Shell's nearby Godorf refinery.\textsuperscript{64} Wesseling was the site of a wartime coal hydrogenation plant.\textsuperscript{65} Part of the plant's products are transported down the Rhine to Badische Analin's Ludwigshafen works, a huge plant located at the junction of the coal gas pipeline from the Saar with the Rhine, and now also using natural gas from the Pfundstadt field near Darmstadt, and crude oil. Farbwerke Hoechst at Hoechst near Frankfurt was also formerly a part of the Farben Rhine empire using Ruhr coal tar and other materials, and now importing crude oil, and drawing natural gas from Darmstadt. Caltex Oil Company plan to build a refinery and ethylene plant at Frankfurt partly to provide feedstocks to the Hoechst chemical works.

It can be seen from these examples that the distribution of the German petrochemical industry has been greatly influenced by the former pattern of production based on coal and coke products. Yet as has been shown in the two preceding sections, the Ruhr-Cologne region is the lowest cost petrochemical producing area in Germany. This is because of its pipeline access to the coast and its large established markets (which are also remnants of the coal-chemical industry). The location of petrochemical plants on the Rhine

\textsuperscript{64}"R.O.W. Plant Typifies Progress of Germany's Petrochemical Industry," \textit{The Oil and Gas Journal}, Vol. 58, No. 6, February 8, 1960, p. 121.

\textsuperscript{65}Petroleum Press Service, XXII, No. 10, October, 1955, p. 382.
is possible even where there are no refineries, because of the low bulk raw material shipment costs the river affords. The Rhine-Ruhr petrochemical industry is therefore a product of the older coal based industry and the combination of a good competitive position.

France

The French petrochemical industry is not as large as that of Germany, and is more dispersed. Since the war the outstanding characteristic of the industry has been the development of new chemical producing areas, Basse Seine, the Rhone Mouth and Lacq. Although such older chemical areas as Alsasce-Lorraine and the Nord coalfield contain a few petrochemical plants, the poor positions of these areas relative to oil refineries and the Paris market has meant that production has shifted to more favourable places, with the introduction of petroleum.66

United Kingdom

In the United Kingdom the distribution of the petrochemical industry is partly the result of the continued growth of the coal field chemical areas, and partly the development of new areas. Shell's Carrington works

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near Manchester, on the ship canal, is both a continuation of the Widnes-Runcorn-Warrington chemical area based on local coal, and salt (which Carrington also uses), and is also joined by pipeline to the refinery and chemical plants of the company at Stanlow, from which it draws its petroleum raw materials.

Imperial Chemical Industries at Wilton on Teeside occupies a 2000 acre site about a mile south of the estuary, near the Cleveland, Lackenby and Warrenby steelworks. The plant uses large amounts of naphtha, one million tons a year, which is brought by tanker from the Shell and B. P. refineries at Thameshaven and Grangemouth; Wilton is situated between the two. I.C.I. has operated a large plant at Billingham, north of the Tees, since 1918, founded on the Durham coalfield and local salt and anhydrite. The works manufactured ammonia products, chlorine, caustic soda and cyanide, and in the 1930's plastics, perspex, synthetic fibres and dyestuffs units were added. After the war, when the company built their new plant at Wilton, across the Tees, Billingham was a main market for its products, and the two plants were joined by a nine foot in diameter pipeline. In effect therefore they are operated as one plant, the largest petrochemical complex outside the United States, employing 25,000 people and obtaining considerable economies.

Dyestuffs, plastics and fibres are now produced at Wilton in a huge integrated plant, so that while the chemical works is two hundred and fifty miles away from the London market, it is able to ship valuable semi-finished products, which can stand higher freight rates by road and rail than basic or intermediate chemicals. The plant also produces premium gasoline. I.C.I. Billingham are now changing from coal to oil raw materials, a shift which is one facet of the general swing of industry from coal to oil in Western Europe, so that the major reason for locating at Teeside will have disappeared. Geographical momentum holds the industry in the same place.

Fawley and Grangemouth are new chemical producing areas. At Avonmouth near Bristol, I.C.I. are building a new petrochemical plant linked with Fawley by pipeline, a site typical of the new industrial areas of Europe.

The Netherlands

Finally the petrochemical plant built by Staatsmijnen, the Netherlands State Coalmine Company might be

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noted as an example of the coal based chemical industry on present petrochemical plant location decisions. The state company has sited on a new 25,000 ton ethylene unit, drawing naphtha down the Maas from Rotterdam, next to its existing ethylene-propylene works at Beek in South Limburg. This plant was originally based on local coal supplies. The Beek plant is similar to the Rhine chemical factories; when a plant is located on a low cost route way changes in raw material sources can easily be survived, and in fact turned to advantage.

The distribution of the petrochemical industry in Western Europe has been greatly influenced by the older coal based industry. Inertia and momentum have acted to hold the chemical industry in the previously existing producing areas. These forces have been more successful where low cost route ways enabled the new oil raw materials to be brought in at low cost, or where oil refineries were located in, or near, the older producing areas. Where these conditions did not exist the older areas have declined in relative importance, and new petrochemical areas have quickly sprung up, usually at coastal refinery centres.

The Influence of Political Decisions

The decision to locate a new plant at a certain place may be politically motivated, rather than result
from competitive economic forces. The establishment of such plants involves the subordination of considerations of competitive position to a more general aim, such as economic development of a region.

France and Italy

Both the French and Italian governments have indirectly influenced the distribution of the petrochemical industry by their control of the natural gas resources of the two countries. In France the rapid growth of the Lacq area was stimulated by the government's desire to develop the South West, and in Italy the sale of gas at cheap rates for chemical conversion has had a similar stimulating effect in the Po Valley. On the other hand state control of gas reserves has also had the opposite effect. The Montecatini company in rebuilding its chemical plants after the war first directed research into the utilization of Po Valley gas. There was however considerable political controversy as to whether or not Italy's gas resources would be completely nationalized, and it was therefore decided to also direct efforts into the use of crude oil fractions, with the aid of $15,000,000 from the Marshall plan. In spite of being able to buy gas at a very low price the company wished to remain independent of possible future political changes, and built a liquid cracker at its Ferrara plant. It has now opened a large plant at Brindisi,
based on crude oil imports, which is the direct result of research conducted in the 1940's and early 1950's.71

Through the Cassa del Mezzogiorno, the plan for the development of the South, the Italian government has directly influenced the growth of the petrochemical industry in the south of Italy and in Sicily. The Asfalti Bitumi Cementi Derivati company was persuaded to use heavy oil of a poor quality found on its land at Ragusa in Sicily for chemical production.72 E.N.I., the government corporation, has built an integrated oil treating, refining, electricity generating and petrochemical plant to use the heavy, sour crude oil found at Gela in Sicily. Funds have come from the European Investment Bank and the World Bank; this costly venture must be seen as part of a general policy of development.

Other Western European Countries

Elsewhere in Western Europe, while governments make loans to companies who are prepared to locate at certain specified places or refuse to give building permits to others or influence industry in other ways, the effect on the distribution of the petrochemical industry has been quite small. It should be noted however that the practice


72 Ibid., p. 130.
of giving interest free, or low interest loans can have a
greater effect on an industry such as chemicals in which
the cost of building plant and installing equipment forms
a large part of the costs of production, than it does on
a non capital-intensive industry.

5. New Capacity at Old Centres

Since the end of the Second World War, and particu-
larly since the middle nineteen fifties, oil and natural
gas have been providing an increasing share of the raw mate-
rials consumed by Western Europe's chemical industry. Oil
now supplies the major part of the organic chemicals
produced, and natural gas is being extensively used in the
manufacture of inorganic chemicals in France and Italy.
The use of petroleum has caused the growth of many new
chemical producing areas at coastal refining centres, and
at other coastal sites, especially where these areas have
good access to concentrations of the new synthetic in-
dustries.

Yet the increased relative importance of petroleum
raw materials has not caused an equivalent change in the
relative importance of some of the coal field areas
producing chemicals, for a pattern of production which has
evolved over decades does not disappear in a few years.
Some of the older chemicals-from-coal areas have large
petrochemical industries, and in particular the
Cologne-Ruhr region has maintained its dominance in the European chemical industry (although within the region a shift is discernable to a greater concentration in the West and around Cologne). The immediate and most apparent reasons for the continued development of the Cologne-Ruhr region are the large amounts of equipment which could be switched over from coal to petroleum, and the long establishment of the chemical and associated industries in the region. However there are also present day economic forces in operation which have encouraged the growth of the petrochemical industry along the Rhine. On the one hand are the direct causes of development and on the other the permissive economic conditions. Other areas have not adopted the use of petroleum as readily, even though the coal based chemical industry is well established, and have declined in relative importance. This has usually been because of a poor position, away from the sources of petroleum raw materials and major markets.

The shift from coal to petroleum in the West European chemical industry is an example of the spatially varying impact of technological and economic change on a well established pattern of production. The influence of the coal-chemical industry is not as apparent in Japan, where the petrochemical industry has developed entirely on the coasts. There is a great deal of similarity between the coastal plants of Western Europe and Japan as Chapter IV will show.
CHAPTER IV

JAPAN

The post war expansion of industry in Japan has been remarkable. Capacity and production have doubled every few years in a wide range of industries. The petrochemical industry is one of these growing industries. Although organic petrochemicals were produced for the first time only in 1957, by 1962 Japan reached the same level of capacity as France and Italy. If present plans materialise, Japan will be producing as much chemicals from petroleum as Germany and the United Kingdom by 1965.

An examination of the petrochemical industry in Japan is restricted by the limited availability of information. However enough material has been found for a conventional regional industrial study.

1. The Growth of the Petrochemical Industry

Japan's organic petrochemical output has risen from a value of 1.7 thousand million yen in 1957, to 24.0 thousand million yen in 1959, and an estimated 130.0 thousand million yen in 1962 ($372,000,000).73 There are a

number of reasons for this rapid growth:

1) Demand for chemicals in Japan has outstripped supply, so that in spite of the tremendous increase in production, imports have risen. For example in 1957, 18,000 tons of polyethylene were brought into Japan and in 1960, 23,400 tons were imported, principally from Germany, Italy and the United States. The main chemical consuming industries in which large increases in production have taken place are plastics, of which 101,000 tons were manufactured in 1955 and 578,000 tons in 1960, synthetic fibres which have risen in output from 15,800 tons in 1955 to 118,300 tons in 1960, and synthetic rubber which was first made in Japan in 1959 (1000 tons) and had grown to 51,000 tons by 1961.

2) Coal prices to the chemical industry have increased since the war making oil and gas raw materials comparatively cheap. In some cases the prices of organic chemicals have decreased due to the change over from coal to petroleum; ethylene oxide priced at 365 yen per kilogram in 1956 (when it was made from coal), had decreased in price to 170 yen per kilogram in 1961 (when it was made from petroleum). This has helped to hasten the growth of consuming industries.

3) The Japanese petrochemical industry has been able
to compete with foreign producers in spite of relatively high raw material costs and small scale plants. Two factors have aided the industry, the long distances between Japan and the Gulf Coast of the United States and Western Europe, and a tariff of 20% ad valorem on most intermediate chemicals during the infancy of the industry.

4) Refinery expansions and the development of domestic natural gas reserves have supplied petroleum raw materials in quantities which have permitted the large scale growth of petrochemical production.

5) The Japanese government via the Ministry of International Trade and Industry (M.I.T.I.) has helped the industry by granting aid and encouraging the adoption of the latest techniques.74 Tax exemptions and special facilities for depreciation have also been given.75

6) The large amounts of capital needed for the development of the petrochemical industry have been made available by the Zaibatsu, by domestic and foreign banks (such as the Bank of America, the Kommerz Bank of West Germany, and the Japanese Development Bank), and by the formation of agreements with oil and chemical companies in the United States.


2. The Supply of Raw Materials

Like its counterpart in Western Europe, the Japanese petrochemical industry is based mainly on liquid refinery products. About 90% of the capacity to produce basic organic petrochemicals uses naphtha, a joint product of fuel oil (which accounts for 65% of the output of refined oil products). Catalytic cracking capacity and refinery gas output are low, and the small amounts of gas which are available are dispersed, and only of minor importance. Furthermore, only 30% of the natural gas is "wet" so that the use of gas has so far been restricted to inorganic chemicals and methanol.

Japan's oil refineries were re-opened in 1950 after being closed for five years following the Second World War. Several small refineries are based on local oil fields on the north east coast of Honshu Island at Akita and Niigata. Most of the capacity however uses Middle East, Far East and Soviet crude, supplying 80%, 15.6% and 4% respectively of all oil imports. This capacity is concentrated along the south east coast (Figure 5), especially near Tokyo, Yokohama, Nagoya, Osaka and Kobe. The growth of refinery capacity, which now exceeds all the European countries with the exception of the United Kingdom, is shown in Table 9.

76Dentsu Advertising Limited, Japan Trade Monthly, loc. cit.
Figures 5 and 6
TABLE 9
GROWTH OF OIL REFINING CAPACITY IN JAPAN
(THOUSANDS OF BARRELS PER DAY)

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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Distillation Capacity</td>
<td>48</td>
<td>90</td>
<td>147</td>
<td>294</td>
<td>553</td>
<td>684</td>
<td>1096</td>
<td>1099</td>
</tr>
</tbody>
</table>

Source: "World Wide Oil," The Oil and Gas Journal, Vols. 49-59 (December, 1950-61).

Figure 5 also shows natural gas fields. Of the 731,400,000 cubic metres (2.58 billion cubic feet) produced in 1960, 82% came from Niigata and Akita prefectures in the north east, and about 10% from Chiba prefecture near Tokyo. Chemicals currently consume 70% of the gas production.

3. The Pattern of Demand

One of the main trends in Japan's industrial development has been the increasing dependence on foreign raw materials. The lack of large navigable rivers and the nature of the physical relief have led to the concentration of industry and population at the ports, and the few other areas of flat land available. Four main industrial areas have developed (see Figure 5). These are Keihin (from Tokyo to Yokohama), Chukyo (centred on Nagoya), Hanshin (Osaka and Kobe), and Kita-Kyushu (the northern part of Kyushu Island). The
"chemicals and related products industry," which includes, for example, plastics, like most Japanese industry is concentrated in the four areas. Tokyo and Osaka are the synthetic fibre centres. These two cities also produce the bulk of the synthetic detergents (77,900 tons out of a national total of 86,200 tons in 1960).\textsuperscript{77} The limited amounts of flat land available in Japan are attractive to all types of industry, so that the four areas outlined above are gradually reaching the saturation level. They also have problems of water shortage. Thus while oil refineries and petrochemical plants are attracted to the main industrial zones, which are the markets for oil products and chemicals, they are also partly driven away because of crowding, high land costs (especially for refineries and chemical plants which need a large site), and water supply problems. The trend for new plants, especially those built by recently formed companies which do not own tracts of land adjoining their present installations, is to choose a site as near the industrial zones as possible (such as the new refinery-chemical plant area at Goi, on the opposite side of Tokyo Bay to Yokohama), or to locate somewhere along the coast and to use water transport as far as possible.

4. The Distribution of the Petrochemical Industry

In the period 1955-1960, 82 thousand million yen ($228,000,000) was invested in organic petrochemical plants in Japan. In 1961 an additional 80 thousand million yen was added. While a part of this capital came from governmental and foreign sources, it was largely collected by the formation of Kombinants, combines of firms for the production of a commodity. Some kombinants were formed by the zaibatsu, such as Mitsui Petrochemical Company. Others are joint oil-chemical ventures, for example, the Nippon Oil Company's plant at Kawasaki; in this type of association, the refining company handles the cracking of naphtha, usually from its own plants, into basics, and the chemical members process the basic chemicals into intermediates. The inclusion of an oil company in a Kombinant has the effect of drawing chemical plants towards the refineries of that company.

Japanese industry is, generally, of a small scale. Of the working population in manufacturing, 49% is employed by firms with labour forces of fifty or less, compared with 20.4% in the United Kingdom and 16% in the United States.

79 Ibid., pp. 36-39.
Under the Kombinant system small chemical firms are able to gain economies available in the large scale operation of naphtha cracking plants. Each small plant, sited next to the cracker, specialises on the processing of one of its basic chemical products. This is a similar arrangement to the ethylene merchant system of the United States.

In 1962 there were five large producers of basic chemicals, mainly based on the cracking of naphtha, but also using some refinery gases and platformate. Two of these, Nippon Petrochemical Company and Toa Oil Company, supplied large numbers of affiliated plants at Kawasaki (Figure 6), an industrial area on reclaimed land between Tokyo and Yokohama. Nippon Petrochemical Company cracks naphtha piped from the Yokohama refinery of Nippon Petroleum Company, and also uses refinery gases as raw materials. It supplies a large number of satellite plants in the vicinity with basic chemicals, by pipeline. Toa Oil Company's plant came on stream in 1962 and uses naphtha. On the opposite side of Tokyo Bay at Mobara in Chiba prefecture, a large plant uses natural gas to produce methanol. A new naphtha cracker is being built nearby at Goi, on reclaimed land. The Tokyo Bay area contains 38% of Japan's organic petrochemical capacity. It is dominated by the two Kombinants at Kawasaki and is located both at the market, the Keihin industrial zone, and at the raw material source, the several large refineries at Kawasaki and Yokohama and the Chiba gas
fields.

Yokkaichi, near Nagoya, is the site of the Mitsubishi Petrochemical Company kombinant, a joint Mitsubishi-British Shell venture using naphtha, piped from a local refinery, to manufacture a variety of cracked products. These are supplied to a number of satellite plants belonging to the group, and the Nippon Synthetic Rubber Company, with which there is also an agreement. The area is near raw materials, and a major market, the Chukkyo industrial zone.

The Mitsui kombinant at Otake-Iwakuni uses local refinery gas, naphtha, and platformate as raw materials. Sumitomo Chemical Company at Niihama, Shikoku Island, uses naphtha brought by tanker from Tokuyama. Otake and Niihama are coastal areas midway between the Hanshin and Kita-Kyushu industrial zones. Two new cracking plants are being built at Tokuyama and Mizushima, and several smaller satellite chemical plants are also planned, so that the Inland Sea region will soon become Japan's second largest petrochemical producer. In 1962 the Otake, Tokuyama and Shikoku Island areas had 26.3% of the country's organic capacity.

Akita and Niigata are on natural gas fields on the north east coast of Honshu. Until late 1962 there were no long distance pipelines in operation in Japan, and nearly all of the gas produced in the region was consumed locally in chemical plants producing fertilizers, carbon black,
methanol, methyl chloride and hydrogen cyanide. Although Akita and Niigata have only 11% of Japan's organic petrochemical capacity, these areas have 70% of the inorganic capacity.

5. The Rising Son

Petrochemicals production, a mere offshoot of the coal-chemicals industry in the early nineteen fifties, is expanding rapidly because of increasing demand (especially from the plastics industry), the substitution of oil and natural gas for coal as chemical raw materials, investment by foreign banks and companies, and encouragement by the government. It is mainly located in or near the four industrial zones, which are the markets for its products, and, as these zones also attract the oil refining industry, the supply points of raw materials. This is similar to such oil refining centres as Fawley, Grangemouth, Rotterdam and Basse Seine in Western Europe, and to Philadelphia and the West Coast centres of Los Angeles and San Francisco in the United States, all of which are based partially or wholly on crude oil brought in by tanker. Like Western Europe, Japan has only small natural gas fields, and like Lacq in France, these are removed from the major energy markets. A high proportion of the gas is therefore consumed on the field, much being used by the chemical industry. However in contrast to Western Europe (where countries export
large amounts of organic chemicals), Japan's production is almost entirely used by the booming domestic plastics and fibres markets, and it is the products of these industries which are exported in great quantities. In both Western Europe and Japan, the market orientated oil refinery is the chief source of petrochemical raw materials; this may be contrasted with the United States, where the oil and gas fields of Texas and Louisiana are the dominant areas of petrochemical production.
CHAPTER V

THE UNITED STATES: A REGIONAL DESCRIPTION

The petrochemical industry is most highly developed, and operates on the largest scale in the United States. One centre, such as Baton Rouge, has a larger organic capacity than the whole of Japan, and the Gulf Coast has a larger capacity than all the Western European countries combined. Thus although the United States is examined in a similar manner to Japan, a more detailed treatment is afforded, and greater attention is given to the development of the petrochemical industry in each region.

Location factors discussed in this chapter are the "particular" type referred to in Chapter I, rather than general economic forces. In each region, whatever seems important to the explanation of the growth of the industry is noted. However because of the size of the industry in the United States most of the regional section of the chapter is taken up with descriptions. In Chapter VI the economic forces which have affected the distribution of the U. S. petrochemical industry are more thoroughly examined.
1. The Chemical Industry and the Growth of Petrochemical Production

Several major shifts have occurred in the distribution of the U. S. chemical industry, since its inception in the late eighteenth century. For the first hundred years of its existence the industry was limited to New England and the Philadelphia-Wilmington area where local raw materials were used to supply chemicals to the Eastern textiles, leather, paper, glass and soap manufacturers. Then in the latter part of the nineteenth, and in the early twentieth century a number of small chemical centres were built on the salt fields of Virginia (Saltville) and Michigan (Midland and Wyandotte) and at low cost power sources (Niagara Falls). During the First World War organic chemicals were produced on a large scale for the first time and in the war and inter-war years West Virginia, with its bituminous coal, oil and natural gas, and brines became the centre of the new industry. Finally since 1940 oil and natural gas have become the predominant raw material sources and the Gulf Coast of Texas and Louisiana is now the largest organic chemical producing region. However, both the older established segments of the chemical industry and the newer petrochemical industry have been influenced by past patterns of production, and there are, for example, petrochemical plants in the Philadelphia, Midland, Niagara Falls and West
Virginia areas as well as on the Gulf Coast.

Petroleum was first used as a chemical raw material in 1918 by a small company which was soon taken over by Standard Oil of New Jersey. In 1920 two companies, Standard Oil and Union Carbide of West Virginia, made seventy-five tons of chemicals from petroleum. During the next twenty years production increased slowly and was small compared with the output of the rapidly expanding coal-based chemical industry. In the late nineteen thirties the first plants were located on the Gulf Coast and during the Second World War the petrochemical industry experienced a period of "take off." Between 1940 and 1945 there was a rise of 500% in the volume of organic petrochemical production (Table 10), as a result of wartime chemical demands which could not be filled by the coal-chemicals industry. Since 1945 production has doubled every five years, partly because of a growth in demand for chemicals from the new synthetic industries, and partly because of the substitution of oil and gas for coal as raw materials. There has also been a sharp increase in inorganic petrochemical production recently. Petrochemicals now form one-third of the volume of all basic and intermediate chemicals produced in the United States, and 60% of their value.

<table>
<thead>
<tr>
<th>Year</th>
<th>1925</th>
<th>1930</th>
<th>1935</th>
<th>1940</th>
<th>1945</th>
<th>1950</th>
<th>1955</th>
<th>1961^a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic petrochemical production (billions^b of pounds).</td>
<td>n.a.</td>
<td>0.10</td>
<td>0.18</td>
<td>1.35</td>
<td>6.80</td>
<td>12.72</td>
<td>23.20</td>
<td>49.00</td>
</tr>
<tr>
<td>Inorganic petrochemical production (billions^b of pounds).</td>
<td>n.a.</td>
<td>0.38</td>
<td>0.45</td>
<td>1.04</td>
<td>1.15</td>
<td>3.42</td>
<td>9.00</td>
<td>16.00</td>
</tr>
<tr>
<td>Total petrochemical production (billions^b of pounds).</td>
<td>0.15</td>
<td>0.48</td>
<td>0.63</td>
<td>2.39</td>
<td>7.95</td>
<td>16.14</td>
<td>32.20</td>
<td>65.00</td>
</tr>
<tr>
<td>Investment in plant and facilities in U.S. ($ millions).</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>350</td>
<td>1200</td>
<td>2000</td>
<td>4000</td>
<td>8500</td>
</tr>
<tr>
<td>Investment in plant and facilities on Gulf Coast ($ millions)^a</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>450</td>
<td>900</td>
<td>2000</td>
<td>4700</td>
</tr>
</tbody>
</table>

^aEstimated ^b thousands of millions

2. Markets for Petrochemicals

The fact that most of the industrial and agricultural markets for petrochemicals are outside the Gulf Coast region has been repeatedly stressed by writers in the petroleum and chemical trade journals. Yet a surprisingly large market, especially for organics, does exist in the Southern states, for while they have only a small proportion of the total of U. S. industrial production, they have a large proportion of those industries which have high chemical demands such as synthetic fibres and rubbers.

The Distribution of the Market

Table 11 is an estimate of the demand for organic petrochemicals in the United States, by consuming industry;

<table>
<thead>
<tr>
<th>Industry</th>
<th>% Organic Petrochemical Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubber</td>
<td>22.5</td>
</tr>
<tr>
<td>Automotive and Aviation</td>
<td>19.1</td>
</tr>
<tr>
<td>Synthetic Fibres</td>
<td>16.9</td>
</tr>
<tr>
<td>Plastics</td>
<td>15.8</td>
</tr>
<tr>
<td>Synthetic Detergents</td>
<td>10.1</td>
</tr>
<tr>
<td>Surface Coatings</td>
<td>9.0</td>
</tr>
<tr>
<td>Explosives</td>
<td>2.2</td>
</tr>
<tr>
<td>Foods</td>
<td>2.2</td>
</tr>
<tr>
<td>Petroleum</td>
<td>1.1</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>1.1</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
</tr>
</tbody>
</table>

62% of demand is accounted for by four new synthetic industries, plastics, synthetic rubber, fibres and detergents. Table 12 shows the distribution by region of industries which most closely resemble those in Table 11, and for which adequate statistical information is available. In the case of synthetic detergents, only statistics on the "soap and other detergents industry" can be given, and for the "miscellaneous" category in Table 11, "all industrial production" is used in Table 12. The distribution of each industry is measured in terms of the percentage of value added by manufacture in each region. Where value added figures were only given collectively for a number of regions, which is often the case in the U. S. Census of Manufactures, estimates were made on the basis of the number of persons employed in each region. In the far right hand column of the table an index of petrochemical demand has been calculated by weighting each industry by its importance as a petrochemical consumer (i.e., synthetic rubber by 22.5, automotive and aircraft by 19.1, etc.), and taking the average of the weighted percentages in each region.

The Market Regions

Two types of region, in terms of petrochemical demand, are discernable from Table 12. In the North East and Mid West, the proportion of demand for petrochemicals is smaller than the proportion of industry in general, so
### TABLE 12

**DISTRIBUTION OF DEMAND FOR ORGANIC PETROCHEMICALS, UNITED STATES 1958**

*(ESTIMATED PERCENTAGE OF VALUE ADDED BY MANUFACTURE IN CONSUMING INDUSTRIES)*

<table>
<thead>
<tr>
<th>Region</th>
<th>Synthetic Rubber</th>
<th>Automotive and Air-Motive Rubber</th>
<th>Synthetic Plastic Fibres</th>
<th>Other Plastic Materials</th>
<th>Soap and Detergents</th>
<th>Paints</th>
<th>Explosives</th>
<th>Kindred Products</th>
<th>Food and Kindred Products</th>
<th>Petroleum Refining</th>
<th>All Indus-trial Demand</th>
<th>Petro-chemical Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>New England</td>
<td>0.0</td>
<td>1.5</td>
<td>0.7</td>
<td>8.2</td>
<td>6.2</td>
<td>3.4</td>
<td>3.3</td>
<td>4.2</td>
<td>0.3</td>
<td>7.4</td>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td>Middle Atlantic</td>
<td>2.5</td>
<td>10.5</td>
<td>3.8</td>
<td>30.4</td>
<td>23.0</td>
<td>26.0</td>
<td>28.6</td>
<td>20.4</td>
<td>9.9</td>
<td>24.7</td>
<td>14.1</td>
<td></td>
</tr>
<tr>
<td>East North Central</td>
<td>7.5</td>
<td>47.2</td>
<td>1.5</td>
<td>21.4</td>
<td>36.0</td>
<td>36.4</td>
<td>21.0</td>
<td>24.6</td>
<td>19.3</td>
<td>29.0</td>
<td>22.8</td>
<td></td>
</tr>
<tr>
<td>West North Central</td>
<td>0.0</td>
<td>8.5</td>
<td>0.0</td>
<td>4.0</td>
<td>13.3</td>
<td>6.7</td>
<td>11.1</td>
<td>12.6</td>
<td>5.7</td>
<td>6.3</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>South Atlantic</td>
<td>4.8</td>
<td>5.1</td>
<td>71.2</td>
<td>14.4</td>
<td>7.5</td>
<td>5.9</td>
<td>15.9</td>
<td>9.8</td>
<td>2.5</td>
<td>10.1</td>
<td>18.4</td>
<td></td>
</tr>
<tr>
<td>East South Central</td>
<td>18.6</td>
<td>2.3</td>
<td>22.8</td>
<td>7.2</td>
<td>0.2</td>
<td>4.0</td>
<td>8.4</td>
<td>5.0</td>
<td>1.7</td>
<td>4.5</td>
<td>10.4</td>
<td></td>
</tr>
<tr>
<td>West South Central</td>
<td>48.3</td>
<td>5.0</td>
<td>0.0</td>
<td>8.7</td>
<td>3.1</td>
<td>5.4</td>
<td>1.1</td>
<td>7.0</td>
<td>41.8</td>
<td>5.5</td>
<td>14.7</td>
<td></td>
</tr>
<tr>
<td>Mountain</td>
<td>0.0</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.8</td>
<td>5.6</td>
<td>2.7</td>
<td>4.6</td>
<td>1.6</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Pacific</td>
<td>18.3</td>
<td>19.8</td>
<td>0.0</td>
<td>5.7</td>
<td>10.7</td>
<td>11.4</td>
<td>5.0</td>
<td>13.7</td>
<td>14.2</td>
<td>10.9</td>
<td>11.6</td>
<td></td>
</tr>
</tbody>
</table>

| Total U.S.A. | 100.0          | 100.0                          | 100.0                    | 100.0                   | 100.0                | 100.0  | 100.0      | 100.0             | 100.0                    | 100.0                | 100.0                |

that the "Manufacturing Belt" containing 60% of the value added by manufacture in the United States, has 40% of the organic petrochemical demand, 17 in the East and 23 in the Mid West. In the South petrochemical demand is high, compared with the level of industrial activity, so that the South Atlantic, East South Central and West South Central regions with 20% of the U. S. value added by manufacture have 43.5% of its organic petrochemical demand. On the West Coast the proportion of petrochemical demand is similar to the region's percentage of value added by manufacture.

It should not be assumed, however, that the Gulf Coast's petrochemical industry is in the centre of a large Southern market. While the Southern states have a large total petrochemical demand, over one-half is represented by the synthetic fibre industry concentrated in Virginia and contiguous states, a distance of 1000 miles away from Houston by rail or 1600 miles by ship. If this demand region is included with those of the Middle Atlantic and New England states, the East Coast's proportion of U. S. organic petrochemical demand is increased to over 30%.

A further characteristic of the market regions is accessibility to the Gulf Coast region by low cost transport media. The East Coast can be reached by ship, the East North Central and East South Central regions are accessible by Mississippi and Ohio barge, and the West Coast can also be reached by ship. The Gulf Coast region is, therefore,
at the focal point of a three pronged water transport system, a position unrivalled by any of the other major regions.

Inorganic petrochemicals such as ammonia, ammonium nitrate and urea are used throughout the agricultural areas of the United States. Ammonia is also used by certain industries, and urea has a secondary use in the plastics industry. The other inorganic petrochemical produced from petroleum, carbon black, is used principally by the rubber industry.

3. Supply of Raw Materials

A wide range of liquid and gaseous petrochemical raw materials is available in the United States from domestic, and to a small extent foreign, sources. The U. S. petrochemical industry can draw from the universally obtainable refinery products and from natural gas and natural gas liquids which are only produced in large quantities in North America.

Refinery Products

Oil refinery by-products commonly used by the U. S. petrochemical industry include refinery gases, liquified petroleum gases (L.P.G.s) and certain other liquid products such as naphtha. A large number of minor products made by refineries are also used, such as kerosene, petroleum coke,
cresylic acid, waxes and fuel oil. In some cases crude oil is cracked to yield hydrocarbons for chemical manufacture.

Refinery Gas

The volume and composition of refinery gas production depends upon the refining process used. Catalytic cracking and reforming, processes which yield large quantities of gases suitable for chemical conversion, have been increasing in importance in the United States. In the period 1951-60 cracking capacity (mainly catalytic but also some thermal) and reforming capacity increased from 2,000,000 barrels a day to 3,500,000 barrels a day, while crude oil refining capacity increased from 7,200,000 barrels a day to 9,600,000. 82 This cracking and reforming capacity is designed to produce premium gasolines. Gasoline forms one-half of the oil products demand in the United States, compared with one-fifth in Western Europe and Japan. This accounts for the abundant availability of catalytic cracker gas in the United States compared with the more limited production of the other two regions.

Catalytic cracking capacity in the United States is distributed in approximately the same proportions as total refining capacity, although the East Coast has a slightly lower percentage of cracking capacity than of refining because

of a relatively high fuel oil demand. Refinery gas production can therefore be assumed to be distributed in a similar fashion to refining capacity, 30.5% of which is on the Gulf Coast, 14.8% on the East Coast, 20.3% in the Mid West and 15.7% on the West Coast (Table 13). As refinery gas is not transported long distances by pipeline, the consumption pattern is, of necessity, the same as that of supply.

TABLE 13
OIL REFINING, CRACKING AND REFORMING CAPACITY 1960
(THOUSANDS OF BARRELS PER DAY)

<table>
<thead>
<tr>
<th>Bureau of Mines Refinery District</th>
<th>Operating Refining Capacity</th>
<th>Per cent Operating, Cracking and Reforming Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Coast</td>
<td>1422.4</td>
<td>14.8</td>
</tr>
<tr>
<td>Appalachian No. 1</td>
<td>115.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Appalachian No. 2</td>
<td>111.5</td>
<td>1.2</td>
</tr>
<tr>
<td>Indiana, Illinois, Kentucky</td>
<td>1727.8</td>
<td>17.9</td>
</tr>
<tr>
<td>Minnesota, Wisconsin, N. and S. Dakota</td>
<td>133.9</td>
<td>1.4</td>
</tr>
<tr>
<td>Oklahoma, Kansas, Missouri</td>
<td>811.2</td>
<td>8.4</td>
</tr>
<tr>
<td>Texas Inland</td>
<td>365.3</td>
<td>3.8</td>
</tr>
<tr>
<td>Texas Gulf Coast</td>
<td>2156.3</td>
<td>22.4</td>
</tr>
<tr>
<td>Louisiana Gulf Coast</td>
<td>777.2</td>
<td>8.1</td>
</tr>
<tr>
<td>Louisiana Inland</td>
<td>132.5</td>
<td>1.4</td>
</tr>
<tr>
<td>New Mexico</td>
<td>27.7</td>
<td>0.3</td>
</tr>
<tr>
<td>Rocky Mountain</td>
<td>332.4</td>
<td>3.4</td>
</tr>
<tr>
<td>West Coast</td>
<td>1515.9</td>
<td>15.7</td>
</tr>
<tr>
<td>United States</td>
<td>9629.7</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Refinery Liquids

Propane and butane (L.P.G.s) are used as industrial and household fuel and as raw materials in the chemical and synthetic rubber industries. Production of L.P.G.s from refineries has risen from 33,000,000 barrels in 1951 to 77,600,000 barrels in 1960. It is also distributed in proportion to refining capacity, except that the refineries of Texas and Louisiana have higher L.P.G. yields than the average. The supply of other liquid refinery products used by the petrochemical industry may be assumed to vary with operating refinery capacity.

Oil Refinery Location

The concentration of almost one-third of U. S. refining capacity on the Gulf Coast, and the comparatively dispersed nature of the refining industry elsewhere, has had a significant effect on the distribution of the petrochemical industry. Much of the early plant capacity built in the South West was based upon refinery gases which were available there in quantities unrivalled by any other U. S. region.

The refining industry of the United States uses crude oil, predominantly from domestic sources, to manufacture products which are also largely sold in North America. About 53% of the crude oil intake of refineries

83Ibid., p. 85.
comes from the South West, 12% is from the Mountain states, 10% from California and 12%-13% imported. The major oil products markets are in the "Manufacturing Belt," with a secondary demand centre on the West Coast.

Gulf Coast or East Coast?

In a paper given to the Regional Science Association in 1956, R. J. Lindsay concluded that oil refineries serving the New York area market are able to operate at the lowest cost if located on the Gulf Coast. In his discussion of the factors leading to this situation Lindsay makes the assumption that tanker rates are the same for shipments of both crude oil and refined products. Between Galveston and New York the rate charged is $0.33 per barrel.

During the oil refining process a certain amount of the crude oil is lost, and because an East Coast refiner would have to pay freight rates on this wasted crude, he would be at a transport cost disadvantage to a competitor on the Gulf Coast. Specifically, in the case of a "Simple Refinery," an input of 28,570 barrels of crude per day yields 26,920 barrels of liquid products; after fuel is deducted, there is a loss of 1680 barrels per day. By locating on the Gulf Coast, 1680 multiplied by $0.33 or $555 per day can be saved. In the case of a "Complex

84See Lindsay, op. cit., pp. 304-316.
Refinery,\textsuperscript{85} 3000 barrels a day are lost giving a saving of $1000 a day to the Gulf Coast refiner.

There are also lower fuel and power costs on the Gulf Coast, although chemicals needed in the refining process are higher in cost. The result is that by locating a "Simple Refinery" on the Gulf Coast, $487-$514 a day can be saved compared with location on the East Coast. A "Complex Refinery" can produce at $1797-$2056 per day less.

South West or Middle West?

In the case of the Great Lakes market, Lindsay compares the relative advantages of locating a refinery in West Texas or Chicago. Crude oil can be shipped from Texas to Chicago by pipeline or by pipeline and barge, and the lighter oil products such as gasoline and distillate fuel oil can also use these media. However for the more viscous residual fuel oil, rail transport has to be substituted for pipelining when a refinery is located in West Texas. Rail transport costs are 27.5\$ per barrel per 100 miles compared with 1.75\$ per barrel per 100 miles for barge and between 1.70\$ and 1.93\$ per barrel for gasoline and crude oil by pipeline. Thus the necessity (for the raw material orientated refinery) of shipping residual fuel oil by rail gives the Chicago refinery a cost advantage.

When fuel and labour costs are also accounted for

\textsuperscript{85}A plant with a wider range of refining processes.
the advantages of Chicago over West Texas amounts to $1875 per day for a "Simple Refinery" of a capacity of 28,570 barrels a day, and $10,941 for a "Complex Refinery." 86

There is, therefore, a tendency for refineries based on domestic crude oil, and supplying the East Coast market, to locate on the Gulf Coast. Refineries serving the Mid West have mainly been built at the market, rather than at the oil field, although a part of the Mid West's supply of oil products is shipped from the Gulf Coast. When lower cost imported crude oil is used, the East Coast has an advantage over the Gulf Coast in supplying the New York area market, and a certain number of refineries have been located in the market region. However, there are restrictions on the amount of crude oil imported, which also limits the number of refineries located at the market.

South West or South East?

The southern East Coast is a greater disadvantage to the Gulf Coast than the New York area, for while the South Atlantic region as a whole has about 13% of U. S. oil products demand, it is scattered and few industrial and population concentrations exist to support large refineries. It is cheaper therefore to ship products by tanker from Gulf Coast refineries in the order of 150,000-200,000 barrels a day of capacity, than to build a series of 20,000-30,000

86 Ibid.
barrels a day refineries along the Southern East Coast.87

Other Regions

The central U. S. regions, apart from the Mid West, are served partly by the Gulf Coast and partly by local refineries using crude oil from the South West, Mountain States, and small fields scattered throughout the whole central area. In the Mountain region states, local crude oil supplies are refined to meet the small, scattered demand found there. On the West Coast, Californian crude is supplemented by imports from the Mountain states and from abroad to support a regional refining industry.

Significance of the Location of Oil Refineries

About 60% of the oil products consumption of the East Coast and 15% of that of the Mid West are supplied by refineries in Texas and Louisiana, and in particular by the Gulf Coast. Apart from the Gulf, the U. S. refining industry is dispersed with no single region having more than 21% of the national capacity. Within the major regions no area compares with the Houston-Texas City-Baytown or Beaumont-Port Arthur-Lake Charles or Baton Rouge refinery agglomerations.

For a moderate sized petrochemical complex based on

87 For further discussion on this topic, see S. M. Livingston, "Economics of Refinery Location in the United States," Proceedings of the Fifth World Petroleum Congress (New York: Fifth World Petroleum Congress Inc., 1959) Section IX, Paper 9, p. 81.
refinery gases, a large refinery capacity is needed at one place. This requirement is only met at a small number of major cities: Philadelphia, New York, Chicago, St. Louis, Los Angeles and San Francisco. Elsewhere the refining industry is too dispersed to support more than one or two small plants at any one place.

Natural Gas and Natural Gas Liquids

Petrochemical raw materials derived from natural gas in the United States include the gas itself, which is mainly methane, and natural gas liquids composed of the heavy fractions extracted from raw gases on the field. Natural gas liquids used on a large scale by the petrochemical industry are propane, butane and ethane (L.P.G.s).

Natural Gas

Natural Gas production is highly concentrated in the South West with 68% of the U. S. total coming from Texas and Louisiana, and 76% from the West South Central region (Table 1½). This production comes partly from fields along the coast of the Gulf of Mexico, the largest fields being around Houston and in the extreme south, and partly from West Texas, the Panhandle and Hugoton fields in the north of the state, and smaller fields in northern Louisiana.

88In a few cases these liquids are extracted from pipeline natural gas although this involves the treatment of large volumes of gas.


<table>
<thead>
<tr>
<th>Region</th>
<th>Gross Natural Gas Production (billions of cubic feet)</th>
<th>Estimated Production of L.P.G.s (^\text{a}) (millions of gallons)</th>
<th>Sales of L.P.G.s to Chemical and Synthetic Rubber Industries (millions of gallons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New England</td>
<td>0</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Middle Atlantic</td>
<td>124</td>
<td>355</td>
<td>89</td>
</tr>
<tr>
<td>East North Central</td>
<td>90</td>
<td>665</td>
<td>189</td>
</tr>
<tr>
<td>West North Central</td>
<td>717</td>
<td>380</td>
<td>1</td>
</tr>
<tr>
<td>South Atlantic</td>
<td>215</td>
<td>395</td>
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<tr>
<td>Pacific</td>
<td>830</td>
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<td>135</td>
</tr>
<tr>
<td>United States</td>
<td>15088</td>
<td>11705</td>
<td>3558</td>
</tr>
</tbody>
</table>

\(^{a}\)From natural gas and refineries.

Natural gas used by industry accounted for 838 billion cubic feet out of a total U. S. consumption of 12,509 billion cubic feet in 1960. Sales to the chemical industry constituted 11% of total industrial sales. The pattern of consumption is very much different from that of oil products. Although the Middle Atlantic region has 25% of U. S. manufacturing (value added 1960) it used only 5% of the gas consumed by industry in 1960. The East North Central region with 29% of U. S. manufacturing used 9% of the gas. By comparison the West South Central, with only 5.5% of the manufacturing, consumed almost 50% of the natural gas used by industry. Natural gas is a comparative newcomer in the energy market of the "Manufacturing Belt" and is also relatively expensive there because of high transport costs by pipeline.

Natural Gas Liquids

The West South Central region produced 70% of the L.P.G.s from natural gas in 1960, and 66% of the total L.P.G. production from gas and oil refineries (Table 14). It also consumed 77% of the L.P.G.s used by the chemical and synthetic rubber industries, a higher percentage than the proportions of these industries located in the South West. L.P.G. sales have increased from 4.2 billion gallons in 1951

to 9.5 billion in 1960, while in the same period sales to the chemical industry have risen from 0.8 billion gallons to 3.0 billion.

Overland transport costs for L.P.G.s are quite high except by pipeline; for example, propane costing 4¢ per gallon at a gas processing plant in Texas would cost 12¢ per gallon in New York if shipped by rail. An increasing number of tankers are being built or converted to carry L.P.G.s, and recently a pipeline has been constructed, specifically to carry the liquids, from Houston to Danville, Virginia.

Petroleum Products for Petrochemicals

There are, therefore, economic advantages to be gained in locating oil refineries on the Gulf Coast of the United States and 31% of U. S. refining capacity is located there. The remainder of the industry is dispersed, in similar fashion to the Western European refineries. Thus the Gulf Coast is the only area in the world with a large concentrated supply of refinery gases and liquid by-products which can be used in the petrochemical industry. In addition natural gas and the liquids extracted from it are also


concentrated in the South West, and as transport charges on these products are generally high, consumption has been restricted so that prices in the producing areas are low. The conditions for the growth of chemical manufacturing appear to be ideal, with respect to raw materials, on the Gulf Coast.

4. The Major Regions

The dominant characteristic of the distribution of the U. S. petrochemical industry is the concentration of plants on the Gulf Coast. From virtually nothing in 1940 (Figure 7, 1940) the proportion of the capacity of the industry located on the Gulf Coast rose to about 40% in 1945 and over 55% in 1961 (Figure 8). At the same time the older established chemical areas have declined in relative importance, as shown by a comparison of the number of plants in the Delaware Valley, Michigan and West Virginia in 1940 and 1951, with the total for the United States. Table 15 is an indication of the distribution of inorganic petrochemical capacity, of which less than one-third is in the West South Central region.

A number of major producing regions are identifiable from Figure 8. The Middle Atlantic, East North Central, South Atlantic, West South Central and Pacific regions will be described in turn, and reasons for the growth of petrochemical production will be suggested for each region.
Figure 7

DISTRIBUTION OF PETROCHEMICAL PLANTS IN THE UNITED STATES
1930, 1940, AND 1951.

1930

1940

1951

• PETROCHEMICAL PLANTS.

SOURCE: W.E. KUHN & J.W. HUTCHESON,
PETROLEUM PROCESSING, OCTOBER
1932; GIVEN IN ISARD AND SCHOLER

MILES.

J.R.P.
Figure 8

ORGANIC PETROCHEMICAL CAPACITY BY AREA IN THE UNITED STATES MID 1962.
SOURCE OF DATA: THE OIL AND GAS JOURNAL, SEPTEMBER 1962 AND OTHER SURVEYS.

KEY

ORGANIC PETROCHEMICAL CAPACITY (MILLIONS OF POUNDS PER YEAR). CIRCLES REFER TO CAPACITIES OF PLANTS WITHIN DOTTED LINES.
<table>
<thead>
<tr>
<th>Region</th>
<th>% of total U. S. capacity (Estimated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New England</td>
<td>0.5</td>
</tr>
<tr>
<td>Middle Atlantic</td>
<td>3.0</td>
</tr>
<tr>
<td>East North Central</td>
<td>9.5</td>
</tr>
<tr>
<td>West North Central</td>
<td>18.0</td>
</tr>
<tr>
<td>South Atlantic</td>
<td>11.5</td>
</tr>
<tr>
<td>East South Central</td>
<td>16.0</td>
</tr>
<tr>
<td>West South Central</td>
<td>29.0</td>
</tr>
<tr>
<td>Mountain</td>
<td>0.5</td>
</tr>
<tr>
<td>Pacific</td>
<td>12.0</td>
</tr>
<tr>
<td>United States</td>
<td>100.0</td>
</tr>
</tbody>
</table>

The Middle Atlantic Region

There are three concentrations of plants in this region, the Delaware Valley (around Philadelphia), Jersey City, and the Buffalo-Tonawanda area of New York State (Figure 8).

Delaware Valley

Philadelphia is a large urban-industrial market in itself, as well as being close to the New York conurbation. Within Greater Philadelphia, 700 plants either produce or consume petrochemicals, and at Wilmington, nearby, is the huge chemical complex of the DuPont Company. There are six large oil refineries on the Delaware between Philadelphia and Marcus Hook providing a source of raw materials. Among the other advantages of the valley are the availability of sites with water frontage (on the New Jersey side of the river), a forty foot dredged channel as far as Trenton and abundant fresh water from the Delaware river. Petrochemical plants have been built at Philadelphia, Claymont and Delaware City on the eastern side of the river and Gibbstown, Paulsboro, Woodbury, Westville and Burlington in New Jersey. A pipeline system carrying ethylene, propylene,


hydrogen and other basics and intermediates has been built, interconnecting refineries and chemical plants.  

The Sun Oil Company which operates one of the largest refineries in the area has built ethylene, ethylene oxide and polypropylene plants, and has established a small 'merchant' ethylene system. In this system, consumers of ethylene do not manufacture it themselves, on a small scale, but buy it from other larger oil and chemical companies. Sun Oil's developments have been the main stimuli behind a recent wave of plant building in the Delaware Valley, but other large companies do not appear to find the area as attractive. For example, the Gulf Oil Company was considering starting a second merchant ethylene system in the Delaware Valley, but is now building a 400,000,000 pounds a year ethylene plant at Cedar Bayou, near Houston. Thus while the foundations for a major petrochemical complex exists, large scale growth in the long established chemical area of Philadelphia has been slow in starting. Some of the reasons for this will be suggested in Chapter VI.

New Jersey

In Jersey City and Newark there are a number of refineries serving the New York area market. There are also several petrochemical plants in the area, with a concentration in the Linden-Perth Amboy district in the south of

94"Delaware Pipelines in Place," The Oil and Gas Journal, Vol. 59, No. 51, December 18, 1961, p. 56.
Newark. Here the Enjay Chemical Company (a part of Standard Oil) supplies ethylene to four plants making polyethylene, ethylene oxide and ethylene glycol. Apart from competition from Gulf Coast producers, the main drawbacks to development are the lack of large sites and such other difficulties inherent in a densely populated region as the high costs involved in laying chemical and feedstock pipelines.

Western New York State

Tonawanda is an electrochemical centre, but two petrochemical plants have also been built there, one using naphtha, and the other, Allied Chemical Corporation, producing polyethylene from liquified ethylene shipped from Sarnia, Ontario by Imperial Oil. There are also petrochemical plants at Buffalo and Niagara Falls.

The Delaware Valley (which includes states in both the Middle Atlantic and South Atlantic regions) has a total organic capacity of about 5% of the United States total, over one-quarter of which has been built since the beginning of 1960 (mostly by the Sun Oil Company and its subsidiaries). It is the largest single petrochemical producing area in the Eastern United States and the most likely for further development.

The East North Central Region

There are several plants scattered across Western Pennsylvania and Ohio, but the only significant feature of the industry in this area is the production of specialised synthetic rubbers around the tyre capital of Akron. Most of the conventional synthetic rubber used is imported from the Gulf Coast.

Michigan

In this state, Herbert Dow began to extract bromine and chlorine from brine at Midland, Michigan in 1896. At Wyandotte, in the south of the Detroit conurbation, the Pennsylvania Salt Manufacturing Company started chlorine-caustic soda production soon after. These two old salt field chemical areas are now petrochemical centres, with the Dow Company at Midland and nearby Bay City, and Pennsalt Chemicals Corporation at Wyandotte. Both companies also have large plants on the Gulf Coast.

Chicago

Despite large plastics and synthetic rubber consuming industries, Chicago has only a small petrochemicals production, even though the refineries at Whiting and East Chicago have a combined capacity of 500,000 barrels a day (which is sufficient to support a large petrochemical complex). The several small to medium sized plants that have been built are sited at Whiting, East Chicago, Chicago and
Joliet; American Oil Company plan to build a 200,000,000 pounds a year ethylene-propylene plant in the area, when enough intermediates producers can be attracted.  

Wood River, the refining centre opposite St. Louis has a number of small petrochemical plants. However, in both Chicago and St. Louis, Gulf Coast competition is strong, for these areas are linked directly with the Gulf by water, and rail rates are also fairly low.

Tuscola

At Tuscola near Decatur natural gas drawn from pipelines is processed to recover ethane, propane, butanes and natural gasoline. Ethanol, ethyl chloride and polyethylene are made from the ethane fraction. Theoretically the Tuscola plant is located at one of the best places available in the Mid West. It is equidistant from the Chicago and St. Louis markets, at the junction of two major gas transmission lines from which it draws raw materials, at the intersection of two railroads and highways, and has one river for fresh water intake and another for plant effluent discharge.  

The Tuscola plant is similar to another extraction unit built at Gabe, Kentucky on the Tennessee Gas Transmission pipeline

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for ethane, propane, butanes and pentanes production.

The economic argument for this type of market area plant is that natural gas weighing 2400 cubic feet per 100 pounds costs 3¢ per 100 pounds per 100 miles (i.e., 1.25¢ per 1000 cubic feet per 100 miles) to transport by pipeline from the gas field to the market. Rail transport costs 8¢-17¢ per 100 pounds per 100 miles, and barge and tanker costs range between 1.5¢ and 4.0¢ per 100 pounds per 100 miles for distances which are 20%-100% longer than those involved when pipelines are used. Thus by locating a petrochemical-extraction plant on a pipeline at or near the market, transport cost savings are made, especially if rail transport must be used for chemical shipments between raw material orientated plants and markets.

However, most of the heavy hydrocarbons (i.e., propane, butane, etc.) contained in natural gas are extracted before it enters the trunk pipeline, so that processing plants located in market areas must process extremely large quantities of gas to produce small amounts of L.P.G.s. It is doubtful whether marginal transport cost savings defray the high processing costs involved in extraction plants in market areas.

The study of Isard and Schooler on the location of

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99 Isard and Schooler,
the petrochemical industry assumes that the Tuscola type of plant is the main alternative to plants located on the gas fields of the South West. However, it remains an exception rather than rule for organic petrochemical plants in market regions, to draw raw materials from natural gas pipelines.

The South Atlantic and East South Central Regions

Petrochemical plants in Delaware and Maryland were dealt with in the section on the Middle Atlantic region. The only other large producing area in this region is the Great Kanawha Valley of West Virginia, which is the largest single petrochemical centre outside the Gulf Coast (Figure 8). Several scattered producing areas also exist along the Ohio Valley.

The Great Kanawha Valley

Charleston is the capital of the Kanawha chemical valley and plants are distributed along the river on a number of flats. The Union Carbide Chemicals Company has its main plant on Blaine Island and the surrounding districts of Charleston, at the juxtaposition of coal, natural gas and oil. Institute, the site of a wartime synthetic rubber plant, is now also occupied by a second huge Union Carbide organic chemicals factory. Goodrich-Gulf operate the synthetic rubber plant. The Union Carbide Chemicals Company has grown from a small local firm, Rollin Chemical Company, founded in 1913 to make barium oxides and salts at South
Charleston. It began to make petrochemicals in 1920, and while it has built plants at Texas City, Seadrift and Brownsville on the Gulf Coast, at Whiting in Indiana and Torrence, California, its operations remain centred on the Kanawha Valley. Local oil and gas supplies are supplemented by feedstocks derived from transcontinental pipelines which pass through West Virginia, so that the Kanawha petrochemical centre is an example of area originally based upon coal and petroleum from local fields and now importing raw materials from other regions. As such it is similar to the Ruhr in Western Europe. Like its European counterpart, a location just off a main river system which leads to major markets, has been an important factor in its survival of the petroleum "take over" in the organic chemicals industry.

The Du Pont ammonia department at Belle, to the south of Charleston, was located there because of the availability, at a low cost, of the raw material coal. Natural gas is now also used. Nitro, downstream from Charleston, was the site of a government explosives plant during the First World War, and there is now a small petrochemical plant there also.


Ohio Valley

Along the Ohio river, from the Pennsylvania border to the junction with the Mississippi is a string of chemical centres. As these centres are mainly on the south side of the river, they are in the South Atlantic and East South Central regions; but like the Kanawha Valley, the plants serve the Middle Western and East Coast markets. In the West Virginia Panhandle, the Allied Chemical Corporation has two plants at Moundsville and there are other small factories using petroleum raw materials downstream at New Martinsville and Parkersburg. At Point Pleasant, the junction of the Kanawha and Ohio Valleys, the Celenease Chemical Company has a petrochemical plant. Ashland, at the junction of the Big Sandy and Ohio rivers, has two oil refineries (Ashland Oil Company) which supply feedstocks to petrochemical plants at Neal, West Virginia and Catlettsburg, Kentucky.102 Louisville, once again the site of a wartime built synthetic rubber plant, continues to produce rubber, and Owensboro, Henderson and Brandenburg are small towns with petrochemical plants on the Louisville-Evansville stretch of the river. Finally, Calvert City at the meeting point of the Tennessee and Ohio rivers, is a chemical centre based primarily on low cost electric power (for example, acetylene is produced via the power intensive calcium

carbide route), but a petrochemical complex is also developing. A 250,000,000 pounds a year ethylene unit is under construction by the Goodrich Chemical Company.

The Ohio and Kanawha petrochemical plants have often been built at old established chemical centres where large amounts of capital have been invested and ancillary services and markets have developed. However, these centres are also often at gateway points, where oil and gas pipelines enter the Mid West. For example, the Ohio-Mathieson Chemical Corporation's petrochemical plant at Brandenburg draws raw materials from the Tennessee Gas Transmission Company's extraction unit on the pipeline at Gabe, Kentucky, which is nearby. The total capacity of the Ohio-Kanawha plants amounts to about 10% of the U. S. organic petrochemical industry. In the whole of the Middle West from Buffalo to St. Louis and Bay City, Michigan to Charleston and Calvert City, is a total of 22-23% of U. S. organic petrochemical capacity, compared with less than 10% on the entire Eastern Coast and 7% on the West Coast.

In the southern states of the South Atlantic region there are two small organic petrochemical plants in South Carolina, and one larger plant at Pensacola in Florida where there is a synthetic fibre spinning factory.

103"Calvert City Complex Continues to Expand," Chemical Engineering Progress, Vol. 53, No. 4, April, 1957, p. 52.
The West South Central Region

The petrochemical industry in this region is divided between the Gulf Coast, a strip of land 100 miles in depth and 700 miles in extent from New Orleans in Louisiana to Brownsville in Texas, an inland oil and gas field area in the Arkansas, White and Red River Valleys, and the West Texas area between Big Spring and El Paso. On the Gulf Coast there are eight clusters of plants, each cluster being separated by distances of 50-100 miles, whereas in the inland areas plants are dispersed and separated by several hundreds of miles.

The Gulf Coast

On the Gulf Coast the raw material base of the chemical industry is made up of oil, oil products (both gaseous and liquid) from the largest single refining area in the world, natural gas and its liquid by-products, sulphur, salt (both from coastal salt domes and from the Permian Basin of West Texas), magnesium (from sea water), oyster shells and limestone. Among the factors, other than raw materials, that have influenced the development of the region have been the climate, which because it lacks extremes (except for hurricanes) decreases construction and maintenance costs, low wage rates, low power rates and low fuel costs. Also large tracts of non-industrial land were available along the Houston Ship Canal, and still are available along the
Intracoastal Waterway.

During the Second World War chemical companies expanded and decentralized their operations, and the government decided to manufacture rubber synthetically. Many of the new company plants and 50% of the government synthetic rubber capacity were located on the Gulf Coast. The phenomenal wartime growth of the Gulf Coast helped to form what one author has called "the self generating characteristics of rapid growth to create favourable psychological conditions for further growth."\(^{104}\) In fact it is fair to say that the expansion of the chemical industry on the Gulf Coast was so strongly in motion by the end of the war, that between 1945 and the later part of the 1950's, not only were there few major organic petrochemical plants built outside the Gulf Coast, but there was little discussion even, in the chemical and petroleum trade journals, of the possibilities of constructing plants elsewhere.\(^{105}\)

**Growth of the Gulf Coast.**—Prior to 1940 industry on the Gulf Coast was confined largely to oil refining. The first organic chemical facilities were built in 1933-34 when the Southern Alkali Corporation's soda ash, caustic soda and chlorine plant was located at Corpus Christi because of "the

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\(^{105}\)One of the few exceptions was the Tuscola plant and the discussion in the petroleum periodicals on this plant.
cheapest fuel (natural gas) at Tidewater in the United States. In 1935 a similar plant was built at Baton Rouge and later additions were made at Freeport and Houston. These plants attracted a great deal of interest to the Gulf region and a number of chemical plants were built either to use natural gas as a fuel (for example, the Dow Chemical Company's first plant at Freeport extracted magnesium and later bromine from sea water), or as a raw material. Baton Rouge in Louisiana was the first part of the Gulf Coast to attract petrochemical plants. Standard Oil of Louisiana built an ethyl chloride plant there in 1936, and the Ethyl Corporation followed soon after. In the next three years Shell Oil Company started petrochemical operations at Houston and Union Carbide located a plant at Texas City. Thus the Gulf Coast was just beginning to develop when demand for chemicals boomed as a result of the war. While capacity in areas such as the Kanawha Valley was expanded, the conventional coal based industry could not fill the inflated demand. In particular ammonia and ammonium nitrate (used in explosives), and butadiene and


styrene (used in synthetic rubber) were in short supply. In 1943 the first synthetic rubber plant was built by the U. S. government at Baton Rouge, partly for economic and partly for strategic reasons. Several similar plants followed, for example, at Baytown near Houston, $7,800,000 were spent on synthetic rubber facilities. More important, plants to supply chemicals to the rubber factories also sprang up; for example, $44,400,000 were spent on butadiene and butyl rubber facilities at the Humble Oil refinery at Baytown. Between 1940 and 1945, $1021,400,000 was invested in facilities for chemicals, coal and petroleum products in Texas and Louisiana, $728,400,000 of which came from the Federal government. Of the war facilities in chemicals, coal and petroleum products built by the U. S. government 43% by value were located in the South. Between 1940 and 1947 investment in Gulf Coast chemical plant facilities represented 26% of the national total investment in such facilities. This extraordinary growth has, in absolute terms, continued to the present day with investment in the petrochemical industry doubling every five years.

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109F. L. Deming and W. A. Stein, Disposal of Southern War Plants, Committee of the South Report, p. 16 et. seq. (n.d., n.p.).

110Ibid.

The Spaghetti Bowl.—On the Gulf Coast the oil refining, petrochemical and gas processing and pipeline industries are closely related. Many companies engage in two or three different activities. Petrochemical and chemical companies have integrated vertically both backwards into oil refining and natural gas production, and forwards into the manufacture of plastics or fibres. Oil companies, already established in the exploration and drilling for oil, pipelining, refining, shipping and marketing, have now extended into the chemical industry and even, in some cases, into synthetic rubber. Natural gas transmission companies have opened chemical plants. The three industries, oil, gas and petrochemicals, form one large complex supplying and consuming each other's products.

The pipeline connections between plants along the Gulf Coast have earned the region the name "the Spaghetti Bowl." Apart from crude oil, oil products, refinery gas, natural gas, and gas liquids pipelines, a network of chemical pipelines have also been built. The three Gulf Coast plants of Union Carbide are, for example, linked by pipeline.\footnote{H. C. Bozeman, "Pipeline Complex Serves a Petrochemical Complex," The Oil and Gas Journal, Vol. 60, No. 39 (September 24, 1962), p. 172.} An ethylene pipeline stretches from Lake Charles in Louisiana to Victoria in Texas, a distance of about 250 miles, connecting thirteen major ethylene producers (eight of which
are also consumers) to seventeen plants manufacturing ethylene derivatives. Huge salt domes are utilised for storage. The line carries two billion pounds a year of 99% pure ethylene, and this versatile, basic chemical is available on a basis which is as reliable as those of gas, electricity and water. This is the merchant system par excellence. Thus the Gulf Coast is unique in the petrochemical industry; there is no other region in the world which compares with it in size, degree of development, or complexity.

The Houston Area.—The Houston Ship Canal and the Intracoastal Waterway form axes along which plants are distributed. Waterside sites away from built up areas, on low cost land where taxes are lower and waste disposal problems at a minimum, have been mentioned as one of the major advantages of the Gulf Coast. About one-half of all new petrochemical plants and one-third of other post World War II chemical construction is concentrated along the Intracoastal Canal and the river systems of the Mid West. The large chemical companies have several chemical plants each, and a great deal of movement takes place between them, with water forming the main means of transport. Along the


Houston Ship Canal and in the surrounding parts of Houston, Pasadena, Baytown and Texas City are twenty-seven organic petrochemical plants with a combined capacity of one-third that of Texas and Louisiana. Not only does the Houston area have several of the largest refineries in the United States, but it is also able to draw supplies of natural gas and natural gas liquids from fields in the immediate hinterland which are also among the biggest in production and reserves in the United States. The Ship Canal is the focal point on which pipelines carrying petrochemical feedstocks converge, and is the capital of the U. S. petrochemical industry.

**Freeport.**--This city to the south of Houston is the site of the Dow Chemical Company's plants, which use natural gas and L.P.G.s to produce a wide variety of organic chemicals. Between Freeport and Houston, the Monsanto Chemical Company has recently built a 500,000,000 pounds a year ethylene plant at Chocolate Bayou. Sweeny, inland from Freeport, is dominated by the plants of the Phillips Chemical Company using L.P.G.s from a local gas field.

**Jefferson County and Lake Charles.**--Beaumont, Port Arthur, Orange and Port Neches are the main cities in the old established industrial district of Jefferson county, which has 17% of the organic petrochemical capacity of Texas and Louisiana in nineteen plants. The main raw materials used in this area are refinery products. Over the state border, at Lake Charles, are an additional seven
plants with 4% of the capacity of Texas and Louisiana. Continental Oil Company which recently built an alcohol plant at Lake Charles, near its Westlake refinery, gave the factors influencing its location choice as the availability of raw materials (by pipeline from the refinery), direct water transport to the North East, and the localizing factor of good local government relations.  

Baton Rouge and New Orleans.—Baton Rouge is between the oil and gas resources of the Gulf South and the markets of the Middle West to which it is connected by the Mississippi and Ohio rivers. This city and the outlying centres of Geismar (Wyandotte Chemicals Corporation) and Plaquemine (Dow Chemical Company) form the third largest petrochemical centre in Texas and Louisiana. One of the largest plants is that of Enjay Chemical Company which uses gases from the Humble Oil Refinery (Enjay is the chemical division of Humble Oil and Refining) to produce ethylene which is used within the plant and by four other concerns in Baton Rouge. By comparison Dow at Plaquemine makes its own basic chemicals from L.P.G.s. There are also a number of plants in and around New Orleans, including, for example, the American Cyanamid Company plant at Fortier which makes acrylonitrile from acetylene (from natural gas) which it supplies to the synthetic fibre plant.

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at Pensacola, Florida.\textsuperscript{116}

**Southern Gulf Coast.**—The main petrochemical centres on this part of the Gulf Coast are Seadrift, Victoria, Corpus Christi, Bishop and Brownsville. Corpus Christi, the largest, was first chosen as a site for chemical plants because of the availability there of cheap natural gas, the Palagana Salt Dome and a supply of oyster shells from the Gulf of Mexico.\textsuperscript{117} The three organic petrochemical plants now located at Corpus Christi mainly use oil products as raw materials, while Bishop, thirty miles inland, is on a natural gas field and the two plants of Celenese Chemical Company in the area are based on locally produced natural gas and L.P.G.s. On the Mexican border, the Brownsville area contains three organic plants, two of which are owned by Delhi Taylor Oil Corporation and the other by Union Carbide. Oil fractions are the principal raw materials.

Inland Texas and Louisiana

In West Texas, the Permian Basin contains six organic plants located around Big Spring and Odessa. The attraction of the area is low cost natural gas and L.P.G.s,


however, there are a number of disadvantages. There is an additional freight penalty (compared with the Gulf Coast) of $0.25-$0.50 for every 100 pounds of chemicals shipped out of the Basin. Another difficulty is the shortage of water; the Odessa Butadiene Company has to recover water for their plant from the Odessa city sewage effluent.

Amarillo, on the Llano Estacado of Northern Texas is the centre of four organic plants located on gas fields at Borger and Pampa, and built principally by the Phillips Chemical Company. The majority of the plants, however, are inorganic petrochemical producers making fertilisers and carbon black.

In Louisiana the only inland petrochemical centres of note are Shreveport and Monroe.

The Pacific Region

Of the thirty-seven organic plants in this region, thirty-five are in California, either in the San Francisco or Los Angeles conurbations.

San Francisco

The oil refineries and petrochemical plants of this

118 Labine, op. cit., p. 124.

area are sited along the southern shores of San Pablo Bay and the deep water channel of the Sacramento River, between Richmond and Antioch. Refineries operated by Tidewater Oil Company and Standard Oil are the main sources of feedstocks. Although there is a considerable demand in the city for ethylene derivatives (such as ethylene glycol, polyethylene, etc.), a minimum sized plant of 100,000,000 pounds a year is not yet justified, and the same situation applies to a propylene plant and other facilities. Thus the development of the petrochemical industry is hindered by the size of the market.

Los Angeles

This is a very much bigger market in spite of the restrictions imposed by the lack of a local synthetic fibre industry. The oil refining and petrochemical plants are sited in the south of the conurbation between El Segundo, Torrence and Long Beach. Shell Oil has had a plant at Dominguez since soon after the founding of the petrochemical industry.

The main period of growth of the industry occurred during World War II. A government synthetic rubber plant was built at Torrence, and associated facilities were also constructed at the same time.\textsuperscript{120} By the end of the war a

large ethylene unit of 290,000,000 pounds a year was operating, although it was closed down in 1947. Expansion has been relatively slow since the war in spite of the continued operation of the synthetic rubber plant, now owned by Shell Chemical Company. A small complex, linked by ethylene and propylene pipelines now exists.

5. Gulf Coast: Primary Production Centre

The outstanding characteristic of the U. S. petrochemical industry is the size and complexity of the massive manufacturing machine of the Gulf Coast. Some of the particular location factors involved in the formation of this vast complex have been recognised, and it has been intimated that the availability, at a low cost, of great amounts of raw materials has been of fundamental importance. In the following chapter a more penetrating examination of the predominant raw material orientation of the U. S. petrochemical industry is made.

CHAPTER VI

ECONOMIC FACTORS IN THE GROWTH OF THE GULF COAST PETROCHEMICAL INDUSTRY

The Gulf Coast produces well over one-half of the organic petrochemicals of the United States; this is a radical change from the pre-war pattern of production in which the East Coast, Mid West and Kanawha Valley areas were the major manufacturers. This shift in the distribution of the industry raises two questions. Firstly, what factors have led to the attraction of such a large capacity to the Gulf Coast, in such a short time? Secondly, what are the prospects for the continuation of the region's growth?

Decisions on the location of plants in the United States are made within an economic system in which the maximisation of profit is the object of private enterprise. Thus statements about "raw material availability" or "access to markets" are inadequate unless accompanied by evidence of regional cost advantages or disadvantages in raw materials and product transport. The region in which the least costs of production, and transport to a given market, can be attained provides the best potential for the largest profit.

Petrochemicals are sold predominantly to industry, so
that packaging and servicing part of the manufacturing process is relatively unimportant. Thus to account for the dominance of the Gulf Coast region in petrochemical production, the costs of assembled raw materials and other inputs are estimated in this oil and gas area, and in three important markets, the East Coast, Mid West and West Coast. Then the influence of transport costs between the Gulf Coast and the three markets is introduced. Total costs of production and transport are then compared for the four regions.

A hypothesis is developed that the stronger the cost advantage a region has in the production of a chemical, the greater is the propensity for capacity to be concentrated there.

1. Inputs

The inputs of a petrochemical plant are: (1) raw materials such as refinery gas, natural gas or L.P.G.s, (2) fuel, steam and electric power, the prices of which are closely related to regional fuel prices, (3) cooling and process water, (4) labour for the direct operation of the plant, for supervision, maintenance and office work, (5) supplies, equipment and spare parts necessary to keep the plant running, and (6) capital. Capital enters into production costs by way of fixed charges on the money invested in the plant, such as depreciation and interest. It will be assumed that capital is equally available in all parts
of the United States, so that regional variations in the charges dependent on investment will be based only on differences in the amount of money needed in each region to build a certain sized plant and install a given quantity of equipment.122

**Petrochemical Raw Materials**

The prices of oil and gas raw materials to the petrochemical industry are related to the fuel values of these commodities. On the Gulf Coast, gaseous raw materials have values equivalent to the cost of replacement by low priced natural gas. For example, off gases sold by a refinery to a chemical company must be replaced in the internal fuel economy of the refinery, and the cost of this replacement is the cost of an equivalent amount of natural gas. If the chemical company is not prepared to pay this replacement cost it is not profitable for the refinery to sell its gas. If the chemical company is willing to pay more than the replacement cost, refineries will compete to gain the gas contract and the price will fall. On the East Coast the lowest priced replacement fuel available is Bunker C or Number 6 Fuel Oil with a price which is over twice as much as that of natural gas on the Gulf Coast.

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122 No allowance is made for economies of scale, although it is recognised that companies are able to build larger plants on the Gulf Coast which serves all the major markets. However, some economies of scale cannot be excluded for they enter into the prices of inputs to a degree which cannot be exactly determined.
However, the price differential for liquid raw materials between the two regions is smaller, because transport charges (by tanker) between the two are low.

Figure 9 shows fuel prices in four regions between 1940 and 1960. Each of these regions will be considered in turn.

Gulf Coast

On the Gulf Coast the prices of refinery and natural gases have been estimated at the average price of natural gas to industrial consumers. In Texas this was 10.7¢ per Million British thermal units (MM. B.t.u.) in 1940, 8.8¢ in 1950 and 19.0¢ in 1960. Average gas prices to large scale chemical plants, which were published by the American Gas Association for a number of years, appear to be much the same as the average for all industries; for example, in 1950 the average price for chemical consumers was also 8.8¢ per MM. B.t.u.\(^{123}\) However, this gas price is an average for users who had established contracts with suppliers when prices were extremely low in the war and immediate post war years. After 1950 natural gas prices increased sharply (Figure 9). For a new petrochemical producer locating on the Gulf Coast in 1950, an estimated price of 12¢ per MM. B.t.u. for natural and refinery gases is used, and for

U.S. FUEL PRICES

Figure 9

Cents per Million B.T.U.

Year

1940 42 44 46 48 50 52 54 56 58 60

East Coast Fuel Oil
Illinois Natural Gas
Gulf Coast
Fuel Oil
California Natural Gas
Gulf Coast Natural Gas

Source: U.S. Minerals Yearbook, and "Petroleum Facts & Figures".

J.R.P.
similar reasons a price of 20¢ per MM. B.t.u. is used for 1960 (Table 16).

TABLE 16

ESTIMATED PRICES OF RAW MATERIALS IN FOUR REGIONS

<table>
<thead>
<tr>
<th>Raw Material</th>
<th>Gulf Coast 1950</th>
<th>Gulf Coast 1960</th>
<th>East Coast 1950</th>
<th>East Coast 1960</th>
<th>Mid West 1960</th>
<th>West Coast 1960</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refinery Gas</td>
<td>12</td>
<td>20</td>
<td>40</td>
<td>44</td>
<td>40</td>
<td>37</td>
</tr>
<tr>
<td>(¢/MM. B.t.u.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Gas</td>
<td>12</td>
<td>20</td>
<td>--</td>
<td>48</td>
<td>40</td>
<td>37</td>
</tr>
<tr>
<td>(¢/MM. B.t.u.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Butane (LPG,</td>
<td>3</td>
<td>4.5</td>
<td>n.a.</td>
<td>6.6</td>
<td>5.6</td>
<td>5.3</td>
</tr>
<tr>
<td>¢/MM. B.t.u.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For liquids there is a readily available and easily (i.e., cheaply) reached market outside the Gulf Coast, so that prices are higher. Bunker C was 30¢ per MM. B.t.u. on the Gulf Coast in 1950 and is now 38.8¢ per MM. B.t.u. L.P.G. prices shown in Figure 9 are those of propane at Baton Rouge; however, the prices of butane which will be used for production cost estimates in this chapter will be the average values of L.P.G.s at natural gas processing plants. In 1950 L.P.G.s were an average of 3¢ per gallon (33¢ per MM. B.t.u.) and in 1960, 4.5¢ per gallon (50¢ per MM. B.t.u.) at gas processing plants in Texas and Louisiana.
Market Regions

Raw material prices are higher in the three market regions, especially for gaseous hydrocarbons.

East Coast.--On the East Coast, Philadelphia prices are used as representative. The main petrochemical raw material available is refinery gas with a replacement value equivalent to Bunker C. Between 1948 and 1952 there were fluctuations in Bunker C prices, and a representative figure of 40¢ per MM. B.t.u. is used, although the actual average price in that year was 36¢ per MM. B.t.u. By 1960 Bunker C prices had risen to 44¢ per MM. B.t.u. Natural gas prices on the East Coast vary between states, and New Jersey is used as typical of the region. In 1960 the average price of natural gas to industrial consumers was 48¢ per MM. B.t.u. Butane is about 6.6¢ per gallon (73¢ per MM. B.t.u.) and propane is quoted at 9.4¢ per gallon (10¢ per MM. B.t.u.) in Philadelphia.

Mid West.--Chicago is used as representative of the Mid West. Number 6 fuel oil sells for 56¢ per MM. B.t.u. in Chicago whereas natural gas has an average price to industrial consumers of 40¢ per MM. B.t.u. in Illinois.

\[124\] This is slightly less than the price given in C. A. Stokes and C. D. Thurmond, "The Influence of Raw Material and Energy Costs on World Chemical Competition," Paper read to the American Institute of Chemical Engineers, December 6, 1961 (Mimeographed).

Natural gas and refinery gas prices in Chicago are taken as the average Illinois gas price of about 40¢ per MM. B.t.u. in 1960. Butane was 5.6¢ per gallon in Illinois in 1960.

**West Coast.**--In California natural gas and fuel oil prices are closely related. In 1940 fuel oil was 14¢ per MM. B.t.u. and gas 13.3¢, in 1950 fuel oil was 26.2¢ and gas 22.1¢ and in 1960 fuel oil was 36.2¢ and gas 39.4¢ per MM. B.t.u. An approximate price for natural and refinery gas of 37¢ per MM. B.t.u. in 1960 is used, and for butane the average L.P.G. price is 5.3¢ per gallon (59¢ per MM. B.t.u.) at gas processing plants in California.

Gaseous petrochemical raw materials, therefore, cost 20¢ per MM. B.t.u. on the Gulf Coast and between 37¢ and 44¢ in the market regions. Natural gas prices have a ceiling of 18.75¢-22.5¢ per MM. B.t.u. below those of the East Coast, and 12.5¢-15.0¢ below the Mid West which is set by the cost of transporting gas to these regions by pipeline (1.25-1.50¢ per M.c.f. /100 miles). Without this large differential in feedstock costs the large scale development of the Gulf Coast petrochemical industry would not have taken place. For instance if natural gas was less expensive to transport than fuel oil, gas prices on the Gulf Coast would be higher because gas demand in the industrial regions of the United States would be much larger. If the basic fuel price on the Gulf Coast was set by fuel oil, there would be a maximum difference in fuel and feedstock prices of 5.7¢ per MM. B.t.u.
between the Gulf and East Coasts (the cost of transporting 1 MM. B.t.u. by tanker between the two regions) and, theoretically, 6.2¢ per MM. B.t.u. between the Gulf Coast and the Mid West (the cost of transporting 1 MM. B.t.u. of fuel oil by Mississippi barge).\textsuperscript{126} This difference in feedstock prices would not be sufficient to offset transport costs on chemicals to markets and there would be no economic advantage to be gained by locating on the Gulf Coast. It can therefore be said that the development of the petrochemical industry on the Gulf Coast is a direct result of its low cost natural gas, which in turn is caused by high gas transport costs to distant markets.

Utilities: Fuel, Steam, Electric Power, Water

The amount of utilities used in the conversion of raw materials into chemicals varies according to the commodity concerned. Although there are exceptions, organic chemicals usually need greater quantities of utilities than inorganic chemicals.

The prices of fuels to petrochemical plants are assumed to be the lowest for the region concerned. Thus on the Gulf and West Coasts and in the Mid West natural gas prices are used, and on the East Coast Bunker C is the cheapest (Table 17).

\textsuperscript{126}Transport charges on fuel oil by tanker are 33¢ per barrel from Galveston to New York. By barge fuel oil costs 1.75¢ per barrel per 100 miles plus a loading and unloading charge of 1.0¢ per barrel. See Lindsay, \textit{op. cit.},
### TABLE 17

**UTILITY PRICES IN FOUR REGIONS**

<table>
<thead>
<tr>
<th>Utility</th>
<th>Gulf Coast 1950</th>
<th>Gulf Coast 1960</th>
<th>East Coast 1950</th>
<th>East Coast 1960</th>
<th>Mid West Coast 1960</th>
<th>West Coast 1960</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel (¢ per MM. B.t.u.)</td>
<td>12</td>
<td>20</td>
<td>40</td>
<td>44</td>
<td>40</td>
<td>37</td>
</tr>
<tr>
<td>Steam (¢ per thousand pounds)</td>
<td>18.6</td>
<td>32.0</td>
<td>58.5</td>
<td>65.0</td>
<td>58.5</td>
<td>56.0</td>
</tr>
<tr>
<td>Electric power (¢ per K.w.h.)</td>
<td>0.6</td>
<td>0.6</td>
<td>0.7</td>
<td>0.7</td>
<td>0.8</td>
<td>0.9</td>
</tr>
<tr>
<td>Cooling Water (¢ per thousand gallons)</td>
<td>1.8</td>
<td>1.8</td>
<td>2.4</td>
<td>2.4</td>
<td>2.5</td>
<td>2.2</td>
</tr>
</tbody>
</table>


Steam costs vary with fuel prices, about 1400-1600 B.t.u. being required to raise one pound of steam (the exact amount depending on boiler efficiency, water temperature and the steam pressure required). The costs used in each region are given in Table 17 and are derived from a recent study of ammonia production by the M. W. Kellog Company; however, the steam costs for 1950 and the Mid West in 1960 have been estimated from information of fuel costs.

Electric power prices and cooling water costs are taken from the same source as steam costs.

pp. 307, 313.
Labour

Direct labour requirements for the operation of petrochemical plants are low in comparison with other industries.

On the Gulf Coast wage rates are lower than in the three market regions, although the differential between the regions is decreasing. Labour costs for the petrochemical industry given in Table 18 have been estimated by taking the average of hourly earnings in the petroleum and chemical industries. In 1950 the U. S. average was $2.08 per hour and by 1960 this had risen to $3.45 per hour. Regional wage rates were then estimated from information on relative gross hourly earnings by geographical area given in a paper by K. J. Nelson (see Table 18).

<table>
<thead>
<tr>
<th>TABLE 18</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ESTIMATED LABOUR COSTS IN FOUR REGIONS</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Gulf Coast 1950</th>
<th>Gulf Coast 1960</th>
<th>East Coast 1950</th>
<th>East Coast 1960</th>
<th>Mid West Coast 1960</th>
<th>West Coast 1960</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Labour, including fringe benefits ($/hour)</td>
<td>1.90</td>
<td>3.40</td>
<td>2.16</td>
<td>3.60</td>
<td>3.90</td>
<td>3.90</td>
</tr>
</tbody>
</table>

The petrochemical industry is capital intensive and small variations in the costs of plant construction can have a large effect, through depreciation and interest charges, on production costs. On the Gulf Coast the oil refining and petrochemical industries are highly developed and construction facilities for plants in this type of industry are long established; for example, a pool of labour exists which is experienced in the building of refinery and chemical plants, and installing the complex equipment used in these industries. Construction labour wage rates are lowest on the Gulf Coast and highest on the East and West Coasts. \(^{127}\) The Gulf and West Coasts, however, have the advantage of less extreme climates so that plants can be built in the open with little hindrance from adverse weather conditions. Also, until recently, chemical plants in the Mid West and on the East Coast were heavily protected against the weather which increased construction costs. This has now changed and plants are increasingly exposed in the North, apparently with few detrimental effects. Based on construction labour wage rates, the prices of building and the paper by K. J. Nelson, relative construction costs have been estimated and are given in Table 19. No consideration is given to the

price of land.

TABLE 19

ESTIMATED RELATIVE CONSTRUCTION COSTS
IN FOUR REGIONS

<table>
<thead>
<tr>
<th></th>
<th>Gulf Coast 1950</th>
<th>Gulf Coast 1960</th>
<th>East Coast 1950</th>
<th>East Coast 1960</th>
<th>Mid Coast 1960</th>
<th>West Coast 1960</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of Constructing a given sized petrochemical plant, (Gulf Coast 1960 = 100)</td>
<td>75</td>
<td>100</td>
<td>90</td>
<td>109</td>
<td>103</td>
<td>101</td>
</tr>
</tbody>
</table>

2. Regional Comparison of Production Costs for Selected Chemicals

The various petrochemical products have different raw material, utility, labour and capital requirements which must be taken into account in an examination of regional advantages and disadvantages in the industry. Seven major petrochemical products are discussed in detail in this chapter, and partial estimates of production costs are made for a further ten chemicals. Production cost comparisons are made by way of a series of tables which have been placed in Appendix I.

Ethylene

Table 1 of Appendix I is an estimate of the cost of
producing ethylene on the Gulf Coast and in the East Coast, Mid West and West Coast market regions. This chemical is the most important building block in the industry and a wide variety of intermediates can be made from it. The table is discussed in detail in the Appendix to demonstrate the methods used in the construction of this and successive cost estimates.

In 1950 the Gulf Coast could produce ethylene for about $2 per 100 pounds less than the East Coast, largely because of exceptionally low raw material prices. By 1960 this differential had decreased by $0.40 per 100 pounds, and there were smaller production cost differences between the Gulf Coast and the Mid West and West Coast market regions. Between 75% and 80% (depending on the region involved) of the Gulf Coast's production cost advantage is due to lower raw material and fuel prices.

These ethylene costs are used as the raw material prices for products made from ethylene in subsequent tables. It should be mentioned, however, that ethylene can be made from a number of raw materials beside refinery gases, and costs of production vary with raw material source as well as region.

Ethylene Glycol

This intermediate chemical is consumed as an anti-freeze in automobiles, as a raw material in synthetic fibre
production, and for a variety of other uses. Table 2 in the Appendix is an estimate of the cost of producing ethylene glycol from ethylene (Table 1).

Ethylene glycol which currently sells for $13.50 per 100 pounds in the United States, can be produced for $2.31 per 100 pounds less on the Gulf Coast than it can on the East Coast, a reduction of $0.32 per 100 pounds in the production cost advantage of the Gulf since 1950. The Mid West and West Coast regions are at smaller production cost disadvantages to the Gulf Coast. Between 65% and 80% of the advantage of the Gulf Coast is due to lower ethylene and steam costs.

**Acetaldehyde**

This chemical is produced in smaller quantities than the other six, and is derived from a number of raw material sources. It is used in the manufacture of synthetic fibres and solvents.

Table 3 of the Appendix is similar to Table 2 except that the raw material, utility and other requirements of acetaldehyde are smaller than those of ethylene glycol. This reduces the cost of production advantage of the Gulf Coast. Of this cost advantage, 80% is accounted for by lower ethylene costs.

**Butadiene**

Synthetic rubber is the main market for this mass
produced intermediate shown in Table 4. Butane prices are comparatively similar in all four regions and consequently the Gulf Coast's production cost advantage is small, 50% being accounted for by lower butane prices, 10-30% by utilities and the remainder is the result of the lower investment needed to build a plant in the South West.

Butadiene may also be made from the butylenes stream of refinery gases. When this raw material source is utilised the Gulf Coast's advantage is larger than with the use of butane.

**Synthetic Rubber (GR-\(S\).)**

The butadiene costs estimated in Table 4 are used in the calculation of synthetic rubber production costs in Table 5 of the Appendix. Synthetic rubber is often considered to be a petrochemical and has been included in this chapter to demonstrate the changes in cost advantages and disadvantages which occur when extremely complicated processes are used, and capital and utility inputs increase. The predominant use for synthetic rubber in the United States is the tyre industry, although there is a wide variety of other products manufactured from it.

Only 30-37% of the Gulf Coast's production cost advantage in synthetic rubber is due to lower butadiene and other raw material costs, 37-53% is accounted for by lower utility charges and the rest is lower depreciation, interest
and other costs dependent on investment.

**Methanol**

This is a low cost, versatile building block used in the manufacture of a number of other intermediate chemicals. Because of its low raw material requirement, it can be produced in the market regions at comparatively little cost disadvantage to the Gulf Coast.

In Table 6 it can be seen that 60% of the Gulf's lower production costs are due to natural gas and fuel prices, and 10-25% to lower utilities costs.

**Ammonia**

A number of fertilizers are made from ammonia, and this basic chemical is also consumed by industry. Table 7 is taken from a study by the M. W. Kellog Company, and only raw materials and utilities costs are considered. The small advantage of the Gulf Coast results from low raw material and other inputs.

**Other Chemicals**

Table 8 extends the analysis to cover a wider range of chemicals, although only raw materials and investment differentials are considered. The Gulf's advantage varies from $0.10 per 100 pounds for ammonium nitrate, which uses ubiquitous nitrogen from the air and small amounts of ammonia, to $2.93 per 100 pounds for acetylene, which
requires large quantities of natural gas for its manufacture.

By locating on the Gulf Coast firms can achieve lower production costs than in the market regions. The Gulf's advantage in production costs is greatest when large amounts of gaseous raw materials are consumed or when the process used is complicated and there are large capital and utility inputs. The Gulf's advantage is smallest when the process is simple or when raw material inputs are low.

Between 60% and 80% of the Gulf Coast's advantage in production costs usually derives from its low raw materials and fuel prices, and the rest is accounted for by lower investment costs.

It should also be noticed that the Gulf Coast production cost advantage was considerably greater in the initial phases of the growth of the petrochemical industry but is now decreasing slowly as raw material prices increase and advantages in investment costs decrease.

3. Transport of Chemicals

The cost of transporting chemicals from the Gulf Coast to the market regions is the main deterrent to petrochemical plant location in the South West.

Chemicals for which there is a large, regular demand can be shipped by barge, tanker and other water vessels between the Gulf Coast and the East Coast, Mid West and West Coast. However, for many petrochemicals demand is sporadic,
small and scattered so that rail and truck shipments must be made.

Rail Freight Rates

Most rail shipments in the United States move under commodity rates. Special equipment, which is often needed for chemicals, is either hired by the firm making the shipment, or, if it is owned by the chemical company, an allowance is paid by the railway. Truck rates are competitive with those of rail especially over short and medium distances and are not separately considered.

Extensive information on rail freight rates is available from the study by Isard and Schooler and this has been checked by reference to other published sources written in the 1953-55 period (see footnote to Table 9 in the Appendix). Rates range from 10.5¢ per 100 pounds per 100 miles to 17.0¢ per 100 pounds per 100 miles depending on the chemical concerned and the distance between the source and destination of the shipment.

A recent development in the United States is the "sea train" in which rail cars are loaded into ships on the Gulf Coast, carried to the East Coast, landed there and taken by rail to the consumer. Freight rates by sea train

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are usually about 70% of "all rail" rates.

**Barge Freight Rates**

The cost of transporting chemicals by barge varies from 0.2¢ per ton mile for large shipments by integrated barge\textsuperscript{130} to 0.5¢ per ton mile for the hire of barges under long term contracts. Special rates for bulk chemicals are from 0.25¢ per ton mile to 0.5¢.\textsuperscript{131} Chemicals shipped under pressure such as ethylene oxide and ammonia cost up to 0.8¢ per ton mile (Appendix, Table 9).\textsuperscript{132}

**Ship Freight Rates**

Tankers and other types of ships used for chemical shipments have freight rates which vary with the commodity, amount shipped, distance of shipment and other conditions. An easy to handle bulk chemical such as ethylene glycol can be transported from Texas to the northern East Coast for 0.37¢ per ton mile for a full tanker load or 0.42¢ per ton mile for a part load.\textsuperscript{133} Chemicals shipped under pressure cost 0.65¢ per ton mile in a 5000 ton tanker and 0.55¢ in a 10,000 to 12,000 ton tanker.\textsuperscript{134} Rates of 0.46¢ and 0.50¢

\begin{thebibliography}{9}
\bibitem{130} Nelson, op. cit., p. 10.
\bibitem{132} Isard and Schooler, op. cit., p. 20.
\bibitem{133} Tighe, op. cit., p. 4919.
\bibitem{134} Isard and Schooler, loc. cit.
\end{thebibliography}
per ton mile are used for normal shipments of non-corrosive and liquid corrosive chemicals. (Table 9 in Appendix I, 2.3¢ and 2.5¢ per 100 pounds per 100 miles.)

Other Costs of Water Shipments

The advantages of water transport are easily overestimated, for a number of considerations other than the rate per ton mile charged by shipping companies, affect the cost of using barges and ships. Water transport usually entails a greater storage capacity at the origin and destination of the shipment to allow for the accumulation and depletion of large loads. Inventory costs are higher by water because of the longer transit times involved, particularly when high valued chemicals are the cargo. Often a plant or a consumer is not directly served by water and the need to own or hire storage, and shipping or receiving, facilities at the wharfside is present; also it is expensive to make short distance shipments between tidewater or riverside, and the plant. Chartered or self-owned water transport is expensive when shipments are liable to fluctuations, whereas common carrier rail or truck transport companies will accept freight when it is available, and when it is not, no costs are involved.\textsuperscript{135} Insurance costs are also higher for barge and ship. To allow for some of these additional costs 5¢ per 100 pounds is added to rates per 100

\textsuperscript{135}Smith, \textit{op. cit.}, p. 223.
pounds per 100 miles to cover terminal charges and 2¢ per 100 pounds for insurance when water transport is used (see "Other Charges" Table 9).

4. Regional Comparison of Production and Transport Costs

The final step is to compare costs of producing chemicals from petroleum in the three market regions and costs of producing these chemicals at the source of raw materials and shipping them to the markets. In Appendix I, Table 10 summarizes the previous nine tables. The production cost advantage of the Gulf Coast is taken from Tables 1 to 8, the transport cost advantages of the market regions from Table 9. In the far right hand columns are the cost advantages or disadvantages involved in locating on the Gulf Coast, compared with the market regions.

Ethylene Derivatives

Ethylene itself is not considered in Table 10 because so far it has been transported long distances only in small amounts. Ethylene glycol can be produced on the Gulf Coast, and shipped to the East Coast and Mid West by rail, barge or tanker and to the West Coast by tanker, at a lower cost than these regions can produce it. Over 70% of U. S. ethylene glycol capacity is located on the Gulf Coast. The region's cost advantage is declining slowly as the 1950 and 1960
figures for the East Coast demonstrate, but this is being
counterbalanced by the increased use of tankers and barges
for large scale, low cost shipments. Rail costs have also
decreased (see footnote to Appendix I, Table 9). In the
production of a second main ethylene derivative, ethylene
oxide (much of which is further processed into ethylene
glycol), two main processes are prevalent. The oxidation of
ethylene uses larger amounts of ethylene than the chloro-
hydrin process (which is a reaction between ethylene and
chlorine) and therefore the Gulf Coast has a larger cost
advantage. Correspondingly the Gulf Coast has 80% of the
oxidation capacity and 67% of the chlorohydrin capacity of
the United States.

In the production of both types of polyethylene, the
Gulf Coast has a cost advantage over the market regions,
except when rail shipments are made to the West Coast. The
region has 75% of U. S. capacity even though it consumes
only 2% of the national production. Finally, ethylene
dichloride is used in the manufacture of vinyl chloride,
which is predominantly a Gulf Coast product, so that
although the Gulf has an advantage over the East Coast and
Mid West only when tanker and barge are utilized, it has
most of the ethylene dichloride capacity. In total the Gulf
Coast has 67% of U. S. ethylene capacity and about the same
proportion of its capacity for ethylene derivatives.136

136 Estimates of the percentage of U. S. capacity to
Methanol and Derivatives

Methanol, produced from natural gas, is shipped in bulk quantities by tanker and barge, usually to large consumers. Thus while the East Coast and Mid West can compete to fill small local demands, large demands in these market regions are most cheaply supplied by bulk water shipments from the Gulf Coast. The West Coast is most cheaply supplied by local producers whether rail or tanker is used. About 58% of U. S. methanol capacity is on the Gulf Coast although only 12% is consumed locally. Formaldehyde (used in the plastics industry) is the main chemical produced from methanol and because only forty-seven pounds of methanol is needed for one hundred pounds of formaldehyde the Gulf Coast is at a cost disadvantage to the market regions regardless of the transport medium used for the product. Thus the Gulf Coast region has only 10% of the national capacity, all of which serves local markets. The methyl chloride capacity based upon methanol is all located outside the Gulf Coast which is at a cost disadvantage to the market regions, except the East Coast when a tanker is used.

produce chemicals located on the Gulf Coast are made from tables appearing in a series of articles by R. F. Messing and J. W. Bradley, Chemical Engineering, Vol. 67, Nos. 13, 17, 18 and 26.
Butadiene and Synthetic Rubber

Butadiene is produced from butane and from butylenes (which are a part of refinery gases). When butane is the raw material the Gulf Coast is generally at a cost disadvantage; however, when refinery gases are used the reverse is true. Of the butadiene capacity based upon both materials 80% is on the Gulf Coast because the region also has 60% of the national butadiene consumption.

Synthetic rubber is most cheaply produced when plants are located on the Gulf Coast; the Gulf has 58% of the S.B.R. capacity of the United States. In spite of considerable disadvantages to Gulf Coast plants, synthetic rubber factories built between 1942 and 1945 have continued to exist at market region and gateway locations, although new capacity built since the war has been constructed in the South West. This market orientation of the production of a commodity which can be most cheaply made at the source of raw materials, may be explained by the fact that synthetic rubber plants are extremely expensive, and a pattern of production once established resists even powerful economic forces.

Acetylene and Acrylonitrile

Acetylene, like ethylene is not usually transported in bulk over long distances. Its production from natural gas is almost entirely on the Gulf Coast and therefore acrylonitrile from petrochemical acetylene is distributed
in the same manner. Acetylene outside the Gulf Coast is made by the calcium-carbide route, which does not involve the use of oil or natural gas, and acrylonitrile in the market regions is manufactured from non-petrochemical acetylene and via the ammonia-propylene, and ethylene processes which are not considered here.

Ammonia and Derivatives

Ammonia, ammonium nitrate and urea are produced in the market regions, for, as Table 10 shows, the Gulf Coast is at a cost disadvantage in the manufacture of these commodities. Thus a pattern of production which is the reverse of that for most organic petrochemicals has developed, only 29% of U. S. inorganic capacity being located in the West South Central region, part of which is carbon black.

Carbon Black

This inorganic petrochemical needs large amounts of raw materials (either natural gas or oil) and is therefore concentrated in cheap gas areas such as the inland parts of Texas and Louisiana.
5. The Effects of Comparative Cost Advantages and Disadvantages on the Four Regions

The thirteen organic petrochemicals considered in Table 10 of the Appendix may be considered representative of this part of the industry. Information derived from the table can be used in the formation of generalisations on an industry which is particularly diverse and which tends to prohibit generalisations.

There is a total of seventy-eight cost advantages or disadvantages to the Gulf Coast in the thirteen organic chemicals. Forty-two of these are advantages to the Gulf Coast, nineteen advantages to the West Coast, nine advantages to the Mid West and eight to the East Coast.

The West Coast

In the case of the West Coast whenever rail transport is used for organic chemicals the region can compete with the Gulf Coast, whereas when water transport is used it is at an advantage for only 54% of the chemicals. As regular, bulk shipments to the West Coast have only recently started it would appear that the petrochemical industry of the region has been able to develop virtually independently of Gulf Coast competition. In Table 20, the Pacific region is the most self-sufficient in organic petrochemicals, outside

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137 Both ethylene oxide and polyethylene are considered as two chemicals here.
### TABLE 20.
**COMPARISON OF THE DISTRIBUTIONS OF CAPACITY TO PRODUCE, AND DEMAND FOR, ORGANIC PETROCHEMICALS**

<table>
<thead>
<tr>
<th>Region</th>
<th>Estimated % of Organic Capacity</th>
<th>Estimated % of Demand</th>
<th>Capacity as a % of Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>New England</td>
<td>0.7</td>
<td>2.9</td>
<td>24</td>
</tr>
<tr>
<td>Middle Atlantic</td>
<td>6.7</td>
<td>14.1</td>
<td>47</td>
</tr>
<tr>
<td>East North Central</td>
<td>10.0</td>
<td>22.8</td>
<td>44</td>
</tr>
<tr>
<td>West North Central</td>
<td>0.9</td>
<td>4.8</td>
<td>19</td>
</tr>
<tr>
<td>South Atlantic</td>
<td>8.7</td>
<td>18.4</td>
<td>47</td>
</tr>
<tr>
<td>East South Central</td>
<td>4.4</td>
<td>10.4</td>
<td>42</td>
</tr>
<tr>
<td>West South Central</td>
<td>61.4</td>
<td>14.7</td>
<td>420</td>
</tr>
<tr>
<td>Mountain</td>
<td>0.1</td>
<td>0.3</td>
<td>33</td>
</tr>
<tr>
<td>Pacific</td>
<td>7.1</td>
<td>11.6</td>
<td>61</td>
</tr>
<tr>
<td>United States</td>
<td>100.0</td>
<td>100.0</td>
<td>--</td>
</tr>
</tbody>
</table>

the West South Central, although the degree of self-
sufficiency is not as high as might be expected. There
appears to be two reasons for this. On the one hand,
economies of scale increase the number of chemicals for
which the Gulf Coast is the optimum location. On the other
hand, there is a tendency for companies to build one plant
for each chemical demanded on the West Coast, but so far
demand has not reached a level which would justify two
plants, so that chemical imports from the Gulf are made to
temporarily fill the excess in regional demand over regional
supply.

This problem is, of course, caused by isolation; in
a more accessible region two plants would be built and the
proportion of supply which was in excess of local demand
would be shipped to other, nearby regions, even if a reduced
or, even, no profit was made on the shipment; on the West
Coast the high transport costs involved in reaching, say,
the East Coast, prohibits this arrangement. The fact remains,
however, that the West Coast, which is the most competitive
(with the Gulf Coast) of the market regions has the highest
proportion of demand filled by local supply.

The Mid West and East Coast

The Mid West region has nine cost advantages over
the Gulf Coast, all but two coinciding with the utilisation
of rail transport. A similar situation exists on the East
Coast which has eight advantages over the Gulf, seven of which occur as a result of the protection of high rail freight rates. The advantages of the Mid West and East Coast are, to some extent, exaggerated, because economies of scale, if considered, would increase the number of advantages to the Gulf Coast.

However, in spite of the small number of chemicals which the Mid West and East Coast market regions can produce at lower costs than the Gulf Coast, they have surprisingly large petrochemical capacities amounting to almost one-half of the level of their demands (see Table 20). This is the result of historical factors; before 1940 the petrochemical industry was highly concentrated in the Middle Atlantic and East North Central regions and in West Virginia. In 1940 twenty-one of the thirty-five plants producing petrochemicals were in these three areas (Figure 7, Chapter V). In the next eleven years when the economic advantages involved in locating on the Gulf Coast were the greatest (for example, natural gas prices actually decreased between 1940 and 1948 -- Figure 9), only six plants were added in the three areas, although the total number of plants in the United States increased to almost a hundred.

Between 1951 and 1962 the number of plants in the Middle Atlantic, East North Central and West Virginia areas has increased at a rate proportionate to the national increase. Thus these three old established areas have been declining
in relative importance in the petrochemical industry from a dominant position in 1940; this decline will probably continue for the next five years at least although a number of factors are working in favour of market region plants.

It can therefore be said that the present "over-capacity" of the North Eastern and Mid Western United States (vis-a-vis their comparative economic positions with the Gulf Coast) is a remnant of their former dominance in the industry. Because the petrochemical industry is expanding at such a rapid rate, plants are not usually closed down despite better economic opportunities elsewhere, so that a region, once established in this capital intensive industry, declines, in a relative sense, only slowly. If the industry had been subjected to a period of falling demands, there is no doubt that many plants in the older areas would have been shut, and companies would have operated their Gulf Coast plants at a higher level of capacity in compensation.

Other Market Regions

The discussion on the Mid West and East Coast regions also applies to the South Atlantic, within which the petrochemical industry is concentrated in West Virginia.

New England is at a greater cost disadvantage to the Gulf Coast than the New York-Philadelphia area, and has no traditionally large chemical industry. Thus the forces of momentum have never been set into motion. New England,
therefore, supplies a smaller proportion of its regional requirements of organic petrochemicals than the Middle Atlantic region.

West North Central has a good raw material base, with a large natural gas and L.P.G. production in Kansas and Missouri. Yet the small market for organics has not been attractive to companies. In the inorganic petrochemical industry by comparison, the large local consumption of fertilisers has stimulated the development of a considerable ammonia industry based primarily on the natural gas of the region.

In the East South Central region there is a growing market for organic petrochemicals in the synthetic fibre industry of Tennessee and Kentucky. The region is also near to the Mid West markets. The number of petrochemical plants in Kentucky has increased from three in 1951 to fourteen in 1962 and can be expected to increase further in the future.

West South Central

The West South Central region supplies local demand, principally from the synthetic rubber industry, and the whole of the rest of the country and export markets to varying degrees. Regions which do not have large long-established chemical industries, such as New England and the West North Central and Mountain areas, have between two-thirds and
three-quarters of their organic petrochemical requirements supplied by the Gulf Coast. Regions in which there is a well established chemical industry have retained the supply of almost one-half of their consumptions, and the East South Central region has gained a similar proportion. On the Pacific Coast the protection afforded by high freight rates and the local supply of raw materials at reasonably low costs, have, to some extent, decreased the effects of Gulf Coast competition, so that a higher proportion of regional demand is supplied by local plants.

6. Prospects For the Continued Dominance of the Gulf Coast

In the last twenty-five years the Gulf Coast petrochemical industry has expanded at a rate which is not approached by any other region. However, there are a number of new developments which may favour the growth of the industry outside the Gulf in the future, particularly in the market regions at gateway points.

The Gulf Coast offers lower costs of raw materials, fuel, labour and construction than the market areas. It relies on these lower costs to offset transport charges on finished products. Rising costs of raw materials, the greater use of liquid raw materials, and some technical innovations are working against the Gulf Coast, while developments in transport favour further Gulf Coast growth.
Rising Costs of Raw Materials

The costs of raw material and fuel on the Gulf Coast, set mainly by natural gas prices, are rising at faster rates than those of the market regions where fuel oil prices impose an effective limit on cost increases. Between 1960 and 1970 natural and refinery gases on the Gulf Coast are expected to rise in price by 10¢ per MM. B.t.u. to 30¢ per MM. B.t.u.; an increase of this order causes a rise of 60¢ per 100 pounds in the cost of manufacturing ethylene, for example, and this in turn increases ethylene glycol production costs by 50¢ per 100 pounds and polyethylene by 62-66¢ per 100 pounds. Reference to Table 10 of Appendix I shows that production cost increases of these amounts are sufficient to virtually eliminate the Gulf's cost advantages when rail transport is utilised. This seriously detracts from the region's attractiveness to the petrochemical industry. Similar increases in production costs can be expected on the Gulf Coast for other basics and intermediates.

Only slight increases in raw materials and fuel prices are expected on the East Coast and West Coast, and in the Mid West. In these market regions fuel oil and

138 See, for example, H. K. Nieuwenhuis, "East Coast-Gulf Coast Refinery Growth and the Petrochemical Industry," Paper read to the Forty-Fourth National Meeting of the American Institute of Chemical Engineers, New Orleans, February, 1961 (Mimeographed), Figure 4.
coal prices are much the same as those of natural gas, so that an effective ceiling is imposed on gas prices. Fuel oil and coal prices are much more stable than those of gas, in the long run.

Greater Use of Liquid Raw Materials

Liquids such as L.P.G.s and naphtha are being used in greater and greater quantities as petrochemical raw materials. Even on the Gulf Coast, a large new ethylene unit at Chocolate Bayou, Texas, uses naphtha for a part of its output. It is claimed that the use of naphtha reverses the usual production cost advantage in favour of the Gulf Coast, for when naphtha is used for ethylene, fuel oil, fuel gas, gasoline, propylene and butadiene are by-products.\textsuperscript{139} As these have higher values in market regions than at the raw material source, the manufacture of ethylene is "subsidized" and is lower in cost. In one study, the claim is made that by using refinery gases, L.P.G.s and naphtha, ethylene can be made for $3.45 per 100 pounds in the Gulf Coast and $3.65 per 100 pounds in the Mid West, but if natural gasoline is also used costs fall to $3.03 on the Gulf Coast and $2.79 in the Mid West (not including profit and federal tax).\textsuperscript{140} While these costs are at least a little

\textsuperscript{139}J. Chrones and J. L. James, \textit{Economics of Ethylene Production from Light Naphtha} (London: Kellog International Corporation, n. d.), p. 10.

\textsuperscript{140}J. Chrones and A. R. Johnson, "Integrating Ethylene Production in a Medium Sized Refinery," Paper read to
optimistic, the tendency for the Gulf's cost advantage to at least decline with the greater use of liquid raw materials is well recognised and logical.

Technical Developments in the Industry

There have been a number of technical developments in the petrochemical industry which favour the growth of the market regions.

Small plants which have few scale disadvantages to large plants can now be built, and even portable factories for consumers with seasonally fluctuating demands are being considered. In the production of polyvinyl chloride, for example, the usual plant size has been between 25,000,000 pounds a year of capacity and 100,000,000 pounds a year. Now "package plants" of 6,000,000 to 25,000,000 pounds can compete, and these plants are being located next to plastics manufacturers in the market regions.\(^1\)

The use of pipelines for long distance bulk chemical shipments while increasing the Gulf Coast's advantage in basic chemicals, will encourage the growth of intermediates manufacture in the market regions. In one case, dodecene is being pumped through the Cherokee oil products pipeline the Western Petroleum Refiners Association meeting, Wichita, May, 1961, quoted by R. A. Lahine, op. cit., p. 120.

from Ponca City, Oklahoma to Wood River, Illinois. This type of intermediate shipment favours the Gulf Coast; however, ethylene is now being liquified and shipped by water and rail tank car as an experiment, and this, if successful commercially, will encourage ethylene glycol, polyethylene and other large ethylene derivatives producers to locate at the markets. Propylene, which should find greater uses in the future with the growth of the new polypropylene market, is easily shipped long distances, and bulk shipments from the Gulf Coast are already economically feasible.

Changes in the Transport of Chemicals

On the other hand some changes in transport are working towards further growth on the Gulf Coast. Integrated barges decrease the costs of making shipments of chemicals up the Mississippi. New chemical tankers, such as the S.S. Alchemist can carry a number of chemicals at the same time, so that small quantity shipments between the Gulf Coast and East Coast are now possible by water. Rail transport freight rates on some chemicals, between the Gulf Coast and the markets have fallen (see footnote to Table 9 of Appendix I).

The net effect of these developments will probably be a slowing down in the rate of growth of the Gulf Coast, and an increase in the amount of capacity located in the market regions.
7. Summary

The concentration of the organic segment of the petrochemical industry on the Gulf Coast is the result of the low production and transport costs gained by locating plants there. Gaseous raw materials costs are about one-half of those of the market regions because of exceptionally low natural gas prices which set their value. These low gas prices are, in turn, the result of high transport costs to distant mass markets. Fuel, steam and other utility charges are also low on the Gulf Coast. Generally, between 60% and 80% of the differential in production costs between the raw material region and the market regions, is due to the lower costs of raw materials and utilities. When liquid feedstocks are utilised the differential is decreased, and utility charges and those costs which depend on construction costs, assume a greater importance.

When bulk shipments of chemicals are made between the Gulf Coast and the major markets, transport costs are low because barges, tankers and other vessels can be used. Thus it can be seen that the Gulf is at its greatest advantage in the production of basic and intermediate petrochemicals which need large amounts of gaseous raw materials and which can be easily shipped in bulk quantities by water. The region is at a smaller advantage, or even at a disadvantage to the market regions, when small amounts of
liquid raw materials are required for the production of chemicals which are shipped, usually to scattered markets, by rail. The Gulf Coast, therefore, has a large proportion of the capacity to produce ethylene and its derivatives, methanol, acetylene (from natural gas) and synthetic rubber. It has a disadvantage in the production of formaldehyde, and, for example, methyl chloride (from methanol) which have low raw material requirements, and has only a small proportion of U. S. capacity in these chemicals. Also, ammonia and its derivatives, which combine hydrogen from natural gas with nitrogen from the ubiquitous air, are market orientated.

However, there are other factors which have influenced the distribution of the petrochemical industry. Chemical centres, long established on coal or salt fields have adopted the use of the new petroleum raw materials. To explain the existance of these centres it is usually necessary to survey the historical development of the chemical industry, but to explain why such plants continue to operate, economic and geographic factors must be considered. One reason, for the continued operation of these centres, is that chemical plants require a vast amount of capital investment, and that once a number of plants are built at a place, it is often cheaper to continue to use these plants rather than scrapping and building anew in lower cost regions. Also plants in the old established chemical valleys of the Ohio and Kanawha, and in Michigan,
are often at oil and gas gateway points to the Mid West, just as Sarnia the petrochemical centre in Canada, is at the oil gateway to Southern Ontario. Finally, such old centres have, in some cases, access to raw materials other than petroleum (such as salt), which compensates to some extent for the disadvantages which occur in oil and gas raw materials costs.

The large chemical companies which originally added petrochemicals to their other operations in the Mid West and on the East Coast provide a good example of the effects of comparative cost advantage. Companies such as Dow Chemical and Union Carbide, originally commenced petrochemical production alongside their coal field and salt field orientated plants in Michigan and the Kanawha Valley. However, as the industry grew plants were also built on the Gulf Coast, and these plants have subsequently been greatly expanded. The growth of the Gulf Coast petrochemical industry has been partly caused by an increase in the number of plants located there, but has been mainly caused by the expansion of a few extremely large plants belonging to major companies. Thus the average ethylene plant on the Gulf Coast has a capacity of 21\(\frac{1}{4}\),000,000 pounds a year, while for the rest of the United States the average is 13\(\frac{1}{4}\),000,000 pounds.

Because of increasing natural gas prices in the South West, the increased use of liquid raw materials, and some
technical developments in the industry, the growth rate of Gulf Coast petrochemical capacity must be expected to slow down in the near future. Large petrochemical complexes on the East Coast, probably at Philadelphia, in the Mid West, at Chicago and Toledo, on the West Coast at Los Angeles and San Francisco, and at gateway points such as Calvert City in Kentucky will develop. No rapid changes in the distribution of the industry will probably occur, however, for in the last quarter century this capital intensive manufacture has set in motion its own force of momentum on the Gulf Coast.
A similar locational pattern of petrochemical production has evolved in all the major regions of the western world. Within this pattern several types of plant locations have been identified, and a number of different methods of analysis have been tested. From this, several conclusions on the location of the petrochemical industry and on the utility of several methods of geographic analysis have been reached. This final chapter outlines these.

The Location of the Petrochemical Industry

There are four main types of place at which petrochemical plants have been built. These are (1) on oil and gas fields away from chemical markets, (2) at coastal and riverside refinery concentrations in market regions, (3) at other coastal and riverside points which are not necessarily markets and (4) at gateway points, which often correspond with old established coal-chemical areas.

Oil and Gas Field Plants

The principal advantage to be gained by locating a petrochemical plant on oil and gas fields, is the low cost of raw materials. However, when oil only is produced, the
raw material cost advantage over other areas is generally small, because oil is easily and cheaply transported by pipeline or water. Natural gas is between three and six times as expensive to transport for equal energy contents and equal weights. As oil products and natural gas compete in the energy markets, and have similar prices for equal B.t.u. amounts, the price of natural gas on the fields is usually much lower than that of oil products. Also natural gas has only been used, on a large scale, since the last war, and the combination of the two factors, high transport costs (relative to oil) and recent utilisation have led to extremely low gas prices on such fields as those in Texas and Louisiana in the United States, and Alberta in Canada. This gas also sets the value of other gases, such as those produced by oil refineries, which are of greater use to the petrochemical industry.

In spite of low gaseous raw material costs, not all oil and gas fields have large petrochemical industries as an examination of the inland areas of Texas and Louisiana, or New Mexico, or Alberta142 shows. One of the main differences between these fields and those on the Gulf Coast, is that the Gulf has an oil refining industry serving some of the biggest markets in the world, while the other petroleum fields have small refining industries serving markets which are

predominantly local. This gives two advantages to the Gulf Coast. On the one hand it greatly increases the supplies of ethylene, propylene, butylenes and other basics from raw materials which have values equivalent to those of natural gas (i.e., from refinery gases). On the other hand, the presence of the refining industry leads to external economies such as those arising from the availability of certain services and the establishment of construction facilities geared to the refining-chemical type of work; it should also be mentioned that an oil company wishing to move into chemicals manufacture is more likely to build its new plant near its large oil refineries than to choose a virgin site. Another main difference between the Gulf Coast and the other petroleum fields (which is actually the major cause of the development of the refining industry on the Coast) is that the Gulf of Mexico, Intracoastal Waterway and Mississippi River can be navigated by ships and barges, whereas the other fields are landlocked. Transport costs on bulk shipments of chemicals by barge and ship are between one-quarter and one-sixth of those by rail. Thus the advantages gained in raw material costs by locating on the Gulf Coast are not counterbalanced by high transport charges on chemical shipments to the North Eastern and Mid Western U. S. markets; in the cases of the interior oil and gas fields, the high costs attendant on the use of rail transport, for all types of chemical shipment, outweigh savings
on raw materials. There are other disadvantages to interior plant locations, such as the shortage of process and cooling water in many areas, but the lack of oil refining industries and high costs of land transport can be regarded as the most significant.

Coastal and Riverside Refinery Plants

In non-oil and gas field regions, refineries are the main sources of raw materials for the petrochemical industry. When refinery gas is used, a site near an oil refinery must be chosen, for no long distance pipelines exist to transport this commodity. There are several other factors which "tie together" oil refineries and petrochemical plants, so that for many oil and chemical companies the decision on where to locate petrochemical facilities has been made between alternative refinery concentrations. Yet underlying the apparent freedom of choice of location between alternative refineries, is the basic necessity for a riverside or coastal position for the transport of crude oil to the refinery and chemicals from the associated petrochemical plants, for road and rail costs are high.

There are several factors influencing refinery-side petrochemical plant location, within the framework of the necessity of a low-cost transport medium. For many plants, the nearness of the refinery to major chemical markets appears to have been the principal immediate determinant;
Basse Seine is near to Paris, Yokohama and Kawasaki near Tokyo, the Delaware Valley is near to large North Eastern chemical markets. Not only are transport costs minimized when petrochemical plants are located near markets, but often refinery concentrations are larger and raw materials more abundantly available near urban-industrial agglomerations. The co-location of several oil refineries and petrochemical plants also gives external economies.

Other Coastal and Riverside Plants

The use of naphtha and crude oil as petrochemical raw materials to some extent discourages a refinery location, for a similar range of gasolines and fuels to the refinery, are produced. Thus when such liquids as naphtha are used, a location anywhere on a major waterway is possible from the point of view of raw material availability and cost. This has led to the location of petrochemical plants at established chemical centres on coasts and rivers, such as Wilton in England, and also to the development of new areas which have neither refineries nor pre-existing chemical industries, such as Brindisi in Italy. Where rivers flow to inland markets, and low cost raw materials transport is available, plants have been built despite the absence of oil refineries, such as those at Paris and Lyons.
Gateway Plants

At the peripheries of large interior market regions, where low cost raw materials transport media, water and pipeline, enter, a number of gateway point petrochemical plants have been built. In the United States the Ohio and Mississippi Rivers are used to transport crude oil, and where these rivers border on the large but dispersed Mid Western market, refineries and petrochemical plants have been located. Also the entry points of crude oil and natural gas pipelines are similarly marked by small refining and chemical centres. In Western Europe the Rhine River and the Wilhelmshaven and Rotterdam pipelines give an oil gateway position to Cologne, which is also a large petrochemical producer.

It is significant that the two long established coal based chemical areas, which have most readily adopted the use of petroleum raw materials, have gateway positions. The Kanawha and Ruhr petrochemical industries are surprisingly similar. Both have developed at major coal field chemical areas. Both are near major waterways, the Kanawha being a tributary of the Ohio which gives access to the Mid West, and the Ruhr a tributary of the Rhine which leads to the Netherlands, Southern Germany, France, Switzerland and overseas export markets. While both chemical industries have been adapted to the use of petroleum, both are being partly surpassed by other nearby centres which are directly
on the main transport routes, the Kanawha by Ohio River plants and the Ruhr by Cologne. Even so, in both cases, the large amounts of capital invested in chemical and synthetic products facilities, particularly during the Second World War, has created a force of inertia which ensures for these areas the continuation of the chemical industry.

There are other factors of comparatively minor importance which have influenced the distribution of the petrochemical industry. Governmental activity has, for example, stimulated the development of Southern Italy. In the United States the decisions of the government on the location of wartime synthetic rubber plants has affected subsequent development. Generally, however, deviations from the normal pattern of a raw material, oil refinery or gateway location have only taken place within the framework of the necessity for water or pipeline transport. It is noticeable that coal-chemical areas which are isolated from these media have not developed into petrochemical centres, and the lack of inland plants, other than those on pipelines and rivers is outstanding.

The petrochemical industry has developed partly in new petroleum producing and processing areas, partly in old established coal field chemical regions, and partly on new non-refining coastal margins. Common to all types of location is the overriding necessity of nearness to major water and pipeline systems, and it is this factor which is the
determining influence in the distribution of the petrochemical industry.

Conclusions on the Methods of Location Analysis Used

In the analysis of the location of the petrochemical industries of Western Europe, Japan and the United States, a rigorous use of available data on costs of production and transport appears most satisfactory in determining the causes of the growth of production in certain regions. Although as illustrated in Chapter III on Europe, historical methods are often needed, they can be supplemented by a more precise examination of costs. The traditional regional description illustrated in Chapters IV and V on Japan and the United States leaves something to be desired when explanations are sought. This can be supplied by use of the factor method. However, the comparative cost method of analysis provides the most accurate and thorough explanation.

The comparative cost method involves a comparison and discussion of each region, it examines each locational influence in detail, and can be used to show changes through time in both processes and the distributions of factors of production. As in the other methods, the end product of the analysis is a general statement on the influences affecting the location of industry. However, two immediate advantages spring to mind. Firstly, it allows an assessment of the
significance of each location factor which is not based on "intuition;" thus on the Gulf Coast, raw material and fuel costs account for between 60% and 80% of the production cost advantage over the market regions. Secondly, it leads to the discovery of forces which, without the use of this type of method, would either not be found or could only be hinted at. Thus in Western Europe, although the reasons for the orientation of plants towards oil refineries rather than markets might be guessed at, a comparison of costs enables the exact reasons for the orientation to be determined, and the causes of deviations from this orientation to be explained.

Even for industries which gain only small advantages by locating at certain places, a comparative cost study is necessary as a basis. It is of little use to launch into a discussion of the particular location factors involved in the siting of plants without first making an economic study, of the comparative cost type, to determine whether the industry is foot-loose, irrevocably confined to one place, or what degree of freedom of location between the two it has. Comparative cost studies give perspective to practical explanations of the actual factors involved in the location of plants.

It cannot be said that the comparative cost method gives a highly original explanation of location, for it follows the principles laid down by theorists from Weber
and Von Thunen to Isard. However, by putting into per­spective the practical reasoning used by economic geographers, it weaves isolated and particular studies into general state­ments which collectively may be called a "theory" of location. The task of economic geographers should be to adopt and develop the principles of comparative cost and other forms of analysis already in use by regional scientists, and to add to these by drawing upon the many excellent empirical studies contained in the geographical literature. The formulation of a geographic theory of industrial location is a matter of reorganising material which is currently available rather than the creation of a new way of thought.
APPENDIX I

COMPARATIVE COST TABLES
Table 1 is explained in detail to show the methods used in this and subsequent comparisons of production costs.

Basic information on investment, raw material and utility requirements is derived from W. Isard et al., quoted at the foot of the table, and for each chemical examined the same procedure is followed.

Regional investment costs are estimated from the relative construction costs given in Table 19 in Chapter VI, using a base of $8.3 million equals 100 equals Gulf Coast in 1960. Thus on the East Coast, construction costs are 9% higher than on the Gulf, or $8.3 million plus $0.7 million equals $9.0 million.

Refinery gas, utility and labour costs are simple multiplications of the amount of each required, in the production of 100 pounds of ethylene, by the price of each, given in Tables 16, 17 and 18 in Chapter VI. For example, on the Gulf Coast 4.5 MM.B.t.u. of refinery gas at 20¢ per MM.B.t.u. gave a raw material cost of $0.90.

A series of other costs can be estimated from this data, using techniques developed by chemical engineers. Supervision varies from a minimum of 10% to a maximum of 30% of direct labour costs in chemical plants depending on the technical complexity of the process and the design and layout of the plant. Following C. H. Chilton, who suggests a
proportion of 15 - 30% of operating labour costs, supervision is estimated at 15% of direct labour costs. Maintenance charges are usually estimated as a percentage of investment in the plant, varying from 2% per annum when corrosion and wear are at a minimum, to 10 - 15% when corrosion, extreme temperature and abrasion are experienced in the process. As labour accounts for one half of maintenance costs, a method of estimation which takes wage rate variations into consideration should be used in a regional comparison. Also the influence of climate, on, for example, paintwork should not be discounted. However no such estimating methods exist and a figure of 5% per annum of the investment per 100 pounds is used for all regions.

Costs of equipment and operating supplies can be estimated either as a percentage of operating labour (for example Chilton suggests 10%) or as a proportion of plant maintenance costs. Isard and Schooler using information from the U. S. Bureau of Mines, and R. S. Aries uses

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144 Isard and Schooler, op. cit., p. 23.


15% of plant maintenance costs to estimate equipment and operating supplies. This latter method is used here. Indirect production costs, a nebulous title covering an heterogeneity of expenditures necessary in running a plant (e.g. first aid and sanitary facilities, maintenance of roads and yards etc.), are estimated at 50% of the total cost of direct labour, supervision, maintenance and operating supplies. No separate cost estimate is made for payroll overhead (which is largely composed of the fringe benefits already included in direct labour costs), or general office overhead.

Depreciation is estimated at 10% per annum of the investment in plant, which is the usual rate in the chemical industry. Interest is 4% on the capital tied up in the plant. Local taxes are estimated at 2%, and insurance 1% of plant investment per annum. Interest, taxes and insurance in total are 7% of plant investment. \(^\text{14.7}\)

The total of these costs is the production cost of ethylene before profit and federal taxes are included. This is the price at which ethylene can be made available within a company for conversion into intermediates. When ethylene is sold outside the company a profit of at least 10% of the investment is usually made and corporate income and excess profit taxes, payable to the U. S. Bureau of Internal Revenue, are included in the price. Profit and federal taxes are

estimated at 20% p.a. of the investment, giving a selling price for ethylene in each region.

In Table 2, the ethylene costs before profit and federal tax given in Table 1 are used as raw material costs. The rest of the table is constructed in the same manner as Table 1.

In Table 8 cost advantages are only calculated for raw materials and investment.

Raw material cost advantages are found by multiplying the requirements shown in the Table, by the difference in price between the Gulf Coast and the market regions (from Tables 16 of Chapter VI, and 1 - 7 of this Appendix). For example, 9,500 cubic feet of natural gas are used for the production of 100 pounds of acetylene, and the Gulf Coast natural gas price is $0.28 per thousand cubic feet lower than that of the East Coast (Table 16 of Chapter VI); 9.5 multiplied by $0.28 gives a raw material advantage of $2.66 per 100 pounds.

For each 100 pounds per annum of capacity, an investment of $15.00 is necessary on the Gulf Coast and $16.35 on the East Coast (from the relative construction costs in Table 19 of Chapter VI). Depreciation, interest and other charges amounting to 20% of the investment must be paid for by each 100 pounds of output; 20% of the $15.00 on the Gulf Coast is $3.00, and 20% of the $16.35 on the East Coast is $3.27, giving the Gulf an investment advantage of $0.27 per 100 pounds.
The total of the two advantages is $2.93 per 100 pounds of acetylene. This calculation is repeated for each region and each chemical.

Table 10 is constructed from Tables 1 - 9. The production cost advantages of the Gulf Coast over the market regions are from Tables 1 - 8. The Gulf Coast transport cost disadvantage is from Table 9; rail, barge and tanker rates used depend on the chemical concerned, whether it is corrosive, whether it must be shipped in pressure tanks, how much is shipped, etc. In the right hand column the total cost advantage or disadvantage is found by subtracting the Gulf's transport cost disadvantage from its production cost advantage.

The first seven chemicals are those for which all inputs were considered in calculating the production cost advantage of the Gulf Coast. In the second part of the table, chemicals for which the Gulf's production cost advantage was worked out using raw material and investment costs only, are presented.
### TABLE 1

COSTS OF PRODUCTION FOR ETHYLENE FROM REFINERY GASES

<table>
<thead>
<tr>
<th>Region</th>
<th>Gulf Coast</th>
<th>East Coast</th>
<th>Mid West</th>
<th>West Coast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>1950</td>
<td>1960</td>
<td>1950</td>
<td>1960</td>
</tr>
<tr>
<td>Plant Investment ($ millions)</td>
<td>6.2</td>
<td>8.3</td>
<td>7.5</td>
<td>9.0</td>
</tr>
<tr>
<td>Mixed refinery $/100 lbs.</td>
<td>1.80</td>
<td>1.98</td>
<td>1.80</td>
<td>1.67</td>
</tr>
<tr>
<td>4.5 MM. B.t.u.</td>
<td>0.54</td>
<td>0.90</td>
<td>1.80</td>
<td>1.98</td>
</tr>
<tr>
<td>Fuel 1.03 MM. B.t.u.</td>
<td>0.12</td>
<td>0.21</td>
<td>0.41</td>
<td>0.45</td>
</tr>
<tr>
<td>Steam 250 lbs.</td>
<td>0.05</td>
<td>0.08</td>
<td>0.15</td>
<td>0.16</td>
</tr>
<tr>
<td>Cooling water 1,800 gallons</td>
<td>0.03</td>
<td>0.03</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Electric power 45 k.w.h.</td>
<td>0.27</td>
<td>0.27</td>
<td>0.31</td>
<td>0.31</td>
</tr>
<tr>
<td>Direct labour 0.018 man hours</td>
<td>0.03</td>
<td>0.06</td>
<td>0.04</td>
<td>0.06</td>
</tr>
<tr>
<td>Supervision</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Maintenance</td>
<td>0.15</td>
<td>0.21</td>
<td>0.19</td>
<td>0.23</td>
</tr>
<tr>
<td>Operating supplies</td>
<td>0.02</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Indirect production cost</td>
<td>0.11</td>
<td>0.15</td>
<td>0.14</td>
<td>0.17</td>
</tr>
<tr>
<td>Depreciation</td>
<td>0.31</td>
<td>0.42</td>
<td>0.38</td>
<td>0.46</td>
</tr>
<tr>
<td>Taxes, Insurance, Interest</td>
<td>0.22</td>
<td>0.29</td>
<td>0.26</td>
<td>0.32</td>
</tr>
<tr>
<td>Cost of production before profit and tax</td>
<td>1.86</td>
<td>2.66</td>
<td>3.76</td>
<td>4.22</td>
</tr>
<tr>
<td>20% return on capital</td>
<td>0.62</td>
<td>0.84</td>
<td>0.76</td>
<td>0.82</td>
</tr>
<tr>
<td>Selling price at plant</td>
<td>2.48</td>
<td>3.50</td>
<td>4.52</td>
<td>5.04</td>
</tr>
<tr>
<td>Advantage of Gulf Coast</td>
<td>-</td>
<td>-</td>
<td>2.04</td>
<td>1.64</td>
</tr>
</tbody>
</table>

## Table 2

COSTS OF PRODUCTION FOR ETHYLENE GLYCOL FROM ETHYLENE, 1960

<table>
<thead>
<tr>
<th>Region</th>
<th>Gulf Coast</th>
<th>East Coast</th>
<th>Mid West</th>
<th>West Coast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant Investment ($ millions)</td>
<td>6.0</td>
<td>7.5</td>
<td>6.75</td>
<td>8.2</td>
</tr>
<tr>
<td>Ethylene 83.5 lbs.</td>
<td>1.55</td>
<td>2.22</td>
<td>3.14</td>
<td>3.52</td>
</tr>
<tr>
<td>Chemicals &amp; Catalyst</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Fuel 0.15 MM.B.t.u.</td>
<td>0.02</td>
<td>0.03</td>
<td>0.06</td>
<td>0.07</td>
</tr>
<tr>
<td>Steam 800 lbs.</td>
<td>0.15</td>
<td>0.26</td>
<td>0.47</td>
<td>0.52</td>
</tr>
<tr>
<td>Cooling water 4,940 gals.</td>
<td>0.09</td>
<td>0.09</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Electric power 5 k.w.h.</td>
<td>0.03</td>
<td>0.03</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Direct labour 0.13 man hours</td>
<td>0.25</td>
<td>0.44</td>
<td>0.28</td>
<td>0.47</td>
</tr>
<tr>
<td>Supervision</td>
<td>0.04</td>
<td>0.07</td>
<td>0.04</td>
<td>0.07</td>
</tr>
<tr>
<td>Maintenance</td>
<td>0.57</td>
<td>0.71</td>
<td>0.64</td>
<td>0.78</td>
</tr>
<tr>
<td>Operating Supplies</td>
<td>0.09</td>
<td>0.11</td>
<td>0.10</td>
<td>0.12</td>
</tr>
<tr>
<td>Indirect production cost</td>
<td>0.48</td>
<td>0.67</td>
<td>0.53</td>
<td>0.72</td>
</tr>
<tr>
<td>Depreciation</td>
<td>1.14</td>
<td>1.41</td>
<td>1.27</td>
<td>1.55</td>
</tr>
<tr>
<td>Taxes, insurance, interest</td>
<td>0.80</td>
<td>0.99</td>
<td>0.89</td>
<td>1.08</td>
</tr>
<tr>
<td>Cost of production before profit and fed. tax</td>
<td>5.24</td>
<td>7.06</td>
<td>7.61</td>
<td>9.09</td>
</tr>
<tr>
<td>20% return on capital</td>
<td>2.28</td>
<td>2.82</td>
<td>2.54</td>
<td>3.10</td>
</tr>
<tr>
<td>Selling price at plant</td>
<td>7.52</td>
<td>9.88</td>
<td>10.15</td>
<td>12.19</td>
</tr>
<tr>
<td>Advantage of Gulf Coast</td>
<td>-</td>
<td>-</td>
<td>2.63</td>
<td>2.31</td>
</tr>
</tbody>
</table>

Ethylene costs from Table 1.
<table>
<thead>
<tr>
<th>Region</th>
<th>Gulf Coast</th>
<th>East Coast</th>
<th>Mid West</th>
<th>West Coast</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Plant size:</strong></td>
<td>33,000,000 pounds per annum (two stage).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Plant Investment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>($ millions)</td>
<td>1.675</td>
<td>1.83</td>
<td>1.73</td>
<td>1.69</td>
</tr>
<tr>
<td>$/100 lbs.</td>
<td>$/100 lbs.</td>
<td>$/100 lbs.</td>
<td>$/100 lbs.</td>
<td>$/100 lbs.</td>
</tr>
<tr>
<td>Ethylene(^a)</td>
<td>1.79</td>
<td>2.83</td>
<td>2.69</td>
<td>2.56</td>
</tr>
<tr>
<td>Hydrochloric acid</td>
<td>0.14</td>
<td>0.14</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>and catalyst</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steam 120 lbs.</td>
<td>0.04</td>
<td>0.08</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>Electric power</td>
<td>0.10</td>
<td>0.12</td>
<td>0.13</td>
<td>0.15</td>
</tr>
<tr>
<td>Direct labour</td>
<td>0.088 man hours</td>
<td>0.30</td>
<td>0.32</td>
<td>0.34</td>
</tr>
<tr>
<td>Maintenance</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Operating</td>
<td>0.26</td>
<td>0.28</td>
<td>0.27</td>
<td>0.26</td>
</tr>
<tr>
<td>Supplies</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Indirect</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production costs</td>
<td>0.33</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>Depreciation</td>
<td>0.51</td>
<td>0.56</td>
<td>0.53</td>
<td>0.51</td>
</tr>
<tr>
<td>Taxes,insurance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>interest</td>
<td>0.35</td>
<td>0.39</td>
<td>0.37</td>
<td>0.36</td>
</tr>
<tr>
<td>Cost of production before profit and fed. tax</td>
<td>3.91</td>
<td>5.16</td>
<td>4.98</td>
<td>4.89</td>
</tr>
<tr>
<td>20% return on capital</td>
<td>1.02</td>
<td>1.12</td>
<td>1.06</td>
<td>1.02</td>
</tr>
<tr>
<td>Selling price at plant</td>
<td>4.93</td>
<td>6.28</td>
<td>6.04</td>
<td>5.91</td>
</tr>
<tr>
<td>Advantage of Gulf Coast</td>
<td>-</td>
<td>1.35</td>
<td>1.11</td>
<td>0.98</td>
</tr>
</tbody>
</table>

\(^a\)Ethylene costs from Table 1. 67.1 lbs. Ethylene/100 lbs. Source of raw materials, investment, utility and labour requirements: "Ethylene Oxidation: Low Cost Route to Acetaldehyde Manufacture," Chemical Engineering, Vol. 68 No. 10 (May 15, 1961).
## TABLE 4

COST OF PRODUCTION OF BUTADIENE FROM BUTANE (L.P.G.), 1960

<table>
<thead>
<tr>
<th>Plant size: 100,000,000 lbs. per annum.</th>
<th>Bulk selling price in the U.S. $11.75 /100 lbs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region</td>
<td>Gulf Coast</td>
</tr>
<tr>
<td>Plant Investment</td>
<td>($ millions)</td>
</tr>
<tr>
<td></td>
<td>$/100 lbs.</td>
</tr>
<tr>
<td>Butane</td>
<td>191 lbs.</td>
</tr>
<tr>
<td>(estimated)</td>
<td></td>
</tr>
<tr>
<td>Labour</td>
<td>0.08 man hours</td>
</tr>
<tr>
<td>Supervision</td>
<td>0.04</td>
</tr>
<tr>
<td>Maintenance</td>
<td>0.70</td>
</tr>
<tr>
<td>Operating Supplies</td>
<td>0.11</td>
</tr>
<tr>
<td>Indirect production costs</td>
<td>0.56</td>
</tr>
<tr>
<td>Depreciation</td>
<td>1.40</td>
</tr>
<tr>
<td>Taxes, insurance, interest</td>
<td>0.98</td>
</tr>
<tr>
<td>Cost of production before profit and fed. tax</td>
<td>7.66</td>
</tr>
<tr>
<td>20% return on capital</td>
<td>2.80</td>
</tr>
<tr>
<td>Selling price at plant</td>
<td>10.46</td>
</tr>
<tr>
<td>Advantage of Gulf Coast</td>
<td>-</td>
</tr>
</tbody>
</table>

*a1 gallon = 4.86 lbs.

<table>
<thead>
<tr>
<th>Plant size: 160,000,000 lbs. per annum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk selling price in U.S. $23.00 /100 lbs.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Region</th>
<th>Gulf Coast</th>
<th>East Coast</th>
<th>Mid West</th>
<th>West Coast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant investment ($ millions)</td>
<td>24.0</td>
<td>26.2</td>
<td>24.8</td>
<td>24.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>&amp;/100 lbs.</th>
<th>$/100 lbs.</th>
<th>&amp;/100 lbs.</th>
<th>$/100 lbs.</th>
<th>&amp;/100 lbs.</th>
<th>$/100 lbs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butadiene</td>
<td>80 lbs. <em>a</em></td>
<td>6.12</td>
<td>7.20</td>
<td>6.76</td>
<td>6.60</td>
</tr>
<tr>
<td>Benzene</td>
<td>19 lbs. <em>b</em></td>
<td>0.76</td>
<td>0.76</td>
<td>0.76</td>
<td>0.76</td>
</tr>
<tr>
<td>Ethane</td>
<td>9 lbs. <em>c</em></td>
<td>0.07</td>
<td>0.14</td>
<td>0.14</td>
<td>0.13</td>
</tr>
<tr>
<td>Steam</td>
<td>2470 lbs.</td>
<td>0.79</td>
<td>1.60</td>
<td>1.44</td>
<td>1.38</td>
</tr>
<tr>
<td>Cooling water</td>
<td>28,600 gals.</td>
<td>0.52</td>
<td>0.69</td>
<td>0.72</td>
<td>0.63</td>
</tr>
<tr>
<td>Electric power</td>
<td>23 k.w.h.</td>
<td>0.14</td>
<td>0.16</td>
<td>0.18</td>
<td>0.21</td>
</tr>
<tr>
<td>Fuel 0.265 MM.B.t.u.</td>
<td>0.05</td>
<td>0.12</td>
<td>0.11</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Direct labour</td>
<td>0.16 man hrs.</td>
<td>0.54</td>
<td>0.58</td>
<td>0.62</td>
<td>0.62</td>
</tr>
<tr>
<td>Supervision</td>
<td>0.08</td>
<td>0.09</td>
<td>0.09</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>0.75</td>
<td>0.82</td>
<td>0.78</td>
<td>0.76</td>
<td></td>
</tr>
<tr>
<td>Operating supplies</td>
<td>0.11</td>
<td>0.12</td>
<td>0.12</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>Indirect production cost</td>
<td>0.74</td>
<td>0.81</td>
<td>0.81</td>
<td>0.79</td>
<td></td>
</tr>
<tr>
<td>Depreciation</td>
<td>1.50</td>
<td>1.64</td>
<td>1.55</td>
<td>1.51</td>
<td></td>
</tr>
<tr>
<td>Taxes, insurance, interest</td>
<td>1.05</td>
<td>1.15</td>
<td>1.09</td>
<td>1.06</td>
<td></td>
</tr>
<tr>
<td>Cost of production before profit and fed. tax</td>
<td>13.22</td>
<td>15.88</td>
<td>15.17</td>
<td>14.75</td>
<td></td>
</tr>
<tr>
<td>20% return on capital</td>
<td>3.00</td>
<td>3.28</td>
<td>3.10</td>
<td>3.02</td>
<td></td>
</tr>
<tr>
<td>Selling price at plant</td>
<td>16.22</td>
<td>19.16</td>
<td>18.27</td>
<td>17.77</td>
<td></td>
</tr>
<tr>
<td>Advantage of Gulf Coast</td>
<td>-</td>
<td>2.94</td>
<td>2.05</td>
<td>1.55</td>
<td></td>
</tr>
</tbody>
</table>

*Butadiene costs from Table 4. *b*At 4¢ per pound. *c*At 0.75¢ per pound Gulf Coast, 1.6¢ per pound East Coast, 1.5¢ per pound Mid West, 1.4¢ per pound West Coast. Source of raw materials, utilities and labour requirements: W. Isard and E. W. Schooler, *Location Factors in the Petrochemical Industry* (Washington: Office of Technical Services, U.S. Dept. of Commerce, 1955), pp. A-3, B-8.
## Table 6

**Costs of Production of Methanol from Natural Gas, 1960**

<table>
<thead>
<tr>
<th>Plant size: 120,000,000 lbs. per annum.</th>
<th>Region</th>
<th>Gulf Coast</th>
<th>East Coast</th>
<th>Mid West</th>
<th>West Coast</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Investment</strong> ($ millions)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>($/100 lbs.)</td>
<td>9.72</td>
<td>10.6</td>
<td>10.0</td>
<td>9.8</td>
<td></td>
</tr>
<tr>
<td><strong>Natural Gas</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,180 cu.ft.</td>
<td>0.24</td>
<td>0.57</td>
<td>0.47</td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td>Fuel 1.1 MM.</td>
<td>0.22</td>
<td>0.48</td>
<td>0.44</td>
<td>0.41</td>
<td></td>
</tr>
<tr>
<td>Steam 100 lbs.</td>
<td>0.03</td>
<td>0.07</td>
<td>0.06</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Cooling water</td>
<td>0.08</td>
<td>0.10</td>
<td>0.11</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td><strong>Electric power</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37 k.w.h.</td>
<td>0.22</td>
<td>0.26</td>
<td>0.30</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>Direct labour</td>
<td>0.06</td>
<td>0.07</td>
<td>0.06</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td><strong>Operating supplies</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indirect production cost</td>
<td>0.35</td>
<td>0.38</td>
<td>0.37</td>
<td>0.37</td>
<td></td>
</tr>
<tr>
<td>Depreciation</td>
<td>0.81</td>
<td>0.88</td>
<td>0.83</td>
<td>0.82</td>
<td></td>
</tr>
<tr>
<td>Taxes, Insurance,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interest</td>
<td>0.57</td>
<td>0.62</td>
<td>0.58</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td><strong>Cost of production</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>before profit and fed. tax</td>
<td>3.22</td>
<td>4.25</td>
<td>3.90</td>
<td>3.82</td>
<td></td>
</tr>
<tr>
<td>20% return on capital</td>
<td>1.62</td>
<td>1.76</td>
<td>1.66</td>
<td>1.64</td>
<td></td>
</tr>
<tr>
<td>Selling price at plant</td>
<td>4.84</td>
<td>5.88</td>
<td>5.56</td>
<td>5.46</td>
<td></td>
</tr>
<tr>
<td>Advantage of Gulf Coast</td>
<td>-</td>
<td>1.04</td>
<td>0.72</td>
<td>0.62</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Region</th>
<th>Gulf Coast</th>
<th>East Coast</th>
<th>Mid West</th>
<th>West Coast</th>
<th>Pacific North West</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Operating Costs ($/ton)</td>
<td>12.49</td>
<td>26.78</td>
<td>20.71</td>
<td>20.42</td>
<td>17.88</td>
</tr>
<tr>
<td>Advantage of Gulf Coast ($/100 lbs.)</td>
<td>-</td>
<td>0.72</td>
<td>0.41</td>
<td>0.40</td>
<td>0.27</td>
</tr>
</tbody>
</table>

### TABLE 8

**INVESTMENT AND RAW MATERIAL COST ADVANTAGES TO THE GULF COAST FOR VARIOUS CHEMICALS, 1960**

<table>
<thead>
<tr>
<th>Chemical (Process used)</th>
<th>Raw Materials Requirements per 100 lbs.</th>
<th>Gulf Coast Investment per 100 lbs. annual capacity ($)</th>
<th>$/100 lbs. Advantage of Gulf Coast over East Coast Mid West West Coast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetylene</td>
<td>Natural gas; 9,500 cu.ft.</td>
<td>15.0</td>
<td>2.93</td>
</tr>
<tr>
<td>Acrylonitrile</td>
<td>Acetylene, a 60 lbs.</td>
<td>48.0</td>
<td>2.62</td>
</tr>
<tr>
<td>Ammonium Nitrate</td>
<td>Ammonia, 22 lbs.</td>
<td>2.5</td>
<td>0.22</td>
</tr>
<tr>
<td>Carbon Black (Furnace Process)</td>
<td>Natural gas, 10,000 cu.ft.</td>
<td>6.5</td>
<td>2.92</td>
</tr>
<tr>
<td>Ethylene Dichloride</td>
<td>Ethylene, 32 lbs.</td>
<td>23.0</td>
<td>0.93</td>
</tr>
<tr>
<td>Ethylene Oxide (Oxidation Process)</td>
<td>Ethylene, 125 lbs.</td>
<td>12.5</td>
<td>2.27</td>
</tr>
<tr>
<td>Ethylene Oxide (Chlorohydrin Process)</td>
<td>Ethylene, 60 lbs.</td>
<td>8.8</td>
<td>1.47</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>Methanol, 47 lbs.</td>
<td>3.0</td>
<td>0.47</td>
</tr>
<tr>
<td>Methyl Chloride</td>
<td>Methanol, 70 lbs.</td>
<td>4.0</td>
<td>0.77</td>
</tr>
<tr>
<td>Polyethylene (High Pressure)</td>
<td>Ethylene, 110 lbs.</td>
<td>40.0</td>
<td>2.50</td>
</tr>
<tr>
<td>Polyethylene (Low Pressure)</td>
<td>Ethylene 103 lbs.</td>
<td>30.0</td>
<td>2.24</td>
</tr>
<tr>
<td>Urea</td>
<td>Ammonia 200 lbs.</td>
<td>4.5</td>
<td>1.52</td>
</tr>
</tbody>
</table>

*aUsing acetylene costs calculated for this table.*

### TABLE 9

**TRANSPORT COSTS FOR CHEMICALS IN THE UNITED STATES**

<table>
<thead>
<tr>
<th>Transport Medium, Transport Cost</th>
<th>Miles (approx.)</th>
<th>Range of Transport Cost $/100 lbs./100 miles</th>
<th>Other Charges $/100 lbs.</th>
<th>Total Transport Cost $/100 lbs.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rail (All chemicals)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Houston - New York</td>
<td>1600</td>
<td>10.5 - 15.0</td>
<td>0</td>
<td>1.68 - 2.40</td>
</tr>
<tr>
<td>Houston - Chicago</td>
<td>1000</td>
<td>12.2 - 17.0</td>
<td>0</td>
<td>1.22 - 1.70</td>
</tr>
<tr>
<td>Houston - Los Angeles</td>
<td>1400</td>
<td>11.0 - 14.5</td>
<td>0</td>
<td>1.54 - 2.03</td>
</tr>
<tr>
<td><strong>Barge</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Houston - Chicago</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non corrosive chemicals</td>
<td>2000</td>
<td>1.5</td>
<td>7</td>
<td>0.37</td>
</tr>
<tr>
<td>Liquid corrosive chemicals</td>
<td>2000</td>
<td>1.8</td>
<td>7</td>
<td>0.42</td>
</tr>
<tr>
<td>Pressure chemicals</td>
<td>2000</td>
<td>4.0</td>
<td>7</td>
<td>0.87</td>
</tr>
<tr>
<td><strong>Tanker</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Houston - New York</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non corrosive chemicals</td>
<td>1900</td>
<td>2.3</td>
<td>7</td>
<td>0.51</td>
</tr>
<tr>
<td>Liquid corrosive chemicals</td>
<td>1900</td>
<td>2.5</td>
<td>7</td>
<td>0.55</td>
</tr>
<tr>
<td>Pressure chemicals</td>
<td>1900</td>
<td>3.3</td>
<td>7</td>
<td>0.70</td>
</tr>
<tr>
<td>Houston - Los Angeles</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non corrosive chemicals</td>
<td>3000</td>
<td>2.3</td>
<td>7</td>
<td>0.76</td>
</tr>
<tr>
<td>Liquid corrosive chemicals</td>
<td>3000</td>
<td>2.5</td>
<td>7</td>
<td>0.82</td>
</tr>
<tr>
<td>Pressure chemicals</td>
<td>3000</td>
<td>3.3</td>
<td>7</td>
<td>1.06</td>
</tr>
</tbody>
</table>

*The latest detailed information on rail rates applies to the 1953-55 period. Rates have since decreased for bulk shipments of some chemicals. One recent paper (K. J. Nelson) has quoted an average rate for bulk rail shipments of 8.5¢/100 lbs./100 miles or $1.36/100 lbs. from Houston to New York, $0.85/100 lbs. from Houston to Chicago and $1.19 from Houston to Los Angeles.*

**Sources:**
<table>
<thead>
<tr>
<th>Chemical</th>
<th>Production Cost /$100 lbs.</th>
<th>Advantage or Disadvantage of Gulf Coast over Product East Mid West</th>
<th>Transport Cost /$100 lbs.</th>
<th>Disadvantage of Gulf Coast to Product East Mid West</th>
<th>Total Cost /$/100 lbs.</th>
<th>Advantage (+) or Disadvantage (-) of Gulf to Product East Mid West</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethylene Glycol, 1950</td>
<td>2.63</td>
<td>-</td>
<td>Rail</td>
<td>1.68</td>
<td>-0.95</td>
<td>-</td>
</tr>
<tr>
<td>Ethylene Glycol, 1960 (1100)</td>
<td>2.31</td>
<td>1.72</td>
<td>1.42</td>
<td>Rail</td>
<td>1.68</td>
<td>0.63</td>
</tr>
<tr>
<td>Acetaldehyde (870)</td>
<td>1.35</td>
<td>1.11</td>
<td>0.98</td>
<td>Rail</td>
<td>1.93</td>
<td>-0.58</td>
</tr>
<tr>
<td>Butadiene (1900)</td>
<td>1.61</td>
<td>0.89</td>
<td>0.63</td>
<td>Rail</td>
<td>1.93</td>
<td>-0.32</td>
</tr>
<tr>
<td>GR-S Rubber (2900)</td>
<td>2.94</td>
<td>2.05</td>
<td>1.55</td>
<td>Rail</td>
<td>1.77</td>
<td>+1.17</td>
</tr>
<tr>
<td>Methanol (2000)</td>
<td>1.04</td>
<td>0.72</td>
<td>0.62</td>
<td>Rail</td>
<td>1.68</td>
<td>-0.64</td>
</tr>
<tr>
<td>Ammonia (10800)</td>
<td>0.72</td>
<td>0.41</td>
<td>0.40</td>
<td>Rail</td>
<td>1.93</td>
<td>-1.21</td>
</tr>
<tr>
<td>Chemical</td>
<td>$/100 lbs. Production Cost</td>
<td>$/100 lbs. Transport Cost</td>
<td>$/100 lbs. Total Cost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>----------------------------</td>
<td>----------------------------</td>
<td>-----------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethylene Dichloride (1300)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>East</td>
<td>Mid</td>
<td>West</td>
<td>East</td>
<td>Mid</td>
<td>West</td>
</tr>
<tr>
<td>Production Advantage of Gulf Coast over</td>
<td>0.93</td>
<td>0.59</td>
<td>0.42</td>
<td>Rail</td>
<td>1.77</td>
<td>1.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Water</td>
<td>0.55</td>
<td>0.42</td>
</tr>
<tr>
<td>Ethylene Oxide via Oxidation process</td>
<td>2.27</td>
<td>1.82</td>
<td>1.47</td>
<td>Rail</td>
<td>1.93</td>
<td>1.38</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Water</td>
<td>0.70</td>
<td>0.87</td>
</tr>
<tr>
<td>Ethylene Oxide via chlorohydrin process</td>
<td>1.47</td>
<td>1.16</td>
<td>0.95</td>
<td>Rail</td>
<td>1.93</td>
<td>1.38</td>
</tr>
<tr>
<td>(Total E.O., 1300)</td>
<td></td>
<td></td>
<td></td>
<td>Water</td>
<td>0.70</td>
<td>0.87</td>
</tr>
<tr>
<td>Polyethylene via high pressure process (1100)</td>
<td>2.50</td>
<td>1.77</td>
<td>1.36</td>
<td>Rail</td>
<td>2.20</td>
<td>1.54</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Water</td>
<td>0.51</td>
<td>0.37</td>
</tr>
<tr>
<td>Polyethylene via low pressure process (250)</td>
<td>2.24</td>
<td>1.62</td>
<td>1.26</td>
<td>Rail</td>
<td>2.20</td>
<td>1.54</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Water</td>
<td>0.51</td>
<td>0.37</td>
</tr>
<tr>
<td>Formaldehyde (640)</td>
<td>0.47</td>
<td>0.36</td>
<td>0.30</td>
<td>Rail</td>
<td>1.93</td>
<td>1.38</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Water</td>
<td>0.55</td>
<td>0.42</td>
</tr>
<tr>
<td>Methyl Chloride (110)</td>
<td>0.77</td>
<td>0.55</td>
<td>0.45</td>
<td>Rail</td>
<td>2.40</td>
<td>1.70</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Water</td>
<td>0.70</td>
<td>0.87</td>
</tr>
<tr>
<td>Chemical</td>
<td>Production Cost $/100 lbs.</td>
<td>Advantage of Gulf Coast over Means of Product Transport Cost $/100 lbs.</td>
<td>Total Cost $/100 lbs.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
<td>----------------------------</td>
<td>--------------------------------------------------------------------------</td>
<td>-----------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Amount produced in U.S., 1961, in millions of pounds)*</td>
<td></td>
<td>East Mid West Coast Transport East Mid West Coast Advantages (↑) or Disadvantages (↓) of Gulf to East Mid West Coast</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Acrylonitrile (250)          | 2.62 1.14 1.08             | Rail 1.93 1.38 1.75  | +0.69 +0.10 +0.67 |
| Ammonium Nitrate (n.a.)      | 0.22 0.11 0.11             | Rail 2.07 1.50 1.90  | -1.85 +1.39 -1.79 |
| Urea (1500)                  | 1.52 0.85 0.81             | Rail 1.91 1.37 1.73  | -0.39 -0.52 -0.92 |
| Carbon Black (2030)          | 2.92 2.03 1.71             | Rail 1.68 1.22 1.54  | +1.24 +0.81 +0.17 |

*Production Figures refer to total amounts manufactured by all processes, and not solely the processes referred to here.

Source: Tables 1 - 9.
Aromatics. A group of hydrocarbons, of which the main constituents are benzene, toluene and xylenes, derived from oil.

Barrel. A standard measure of quantities of oil equivalent to 35 Imperial or 42 U.S. gallons.

Benzene. One of the main aromatics.

Bunker Fuel. Any oil fuel taken into the bunkers of ships.

Catalyst. A substance which by its presence can effect a chemical reaction without itself being changed.

Cracking. A process by which the yield of lighter products obtainable from oil can be increased by causing changes in the chemical structure. In the thermal process, the reaction is due to temperature alone; in the catalytic version a catalyst is employed.

Crude Oil. A material occurring naturally in the earth and consisting essentially of hydrocarbons.

Distillation. The process of separating substances of different boiling points by evaporation and condensation.

Fraction. Any derivative separated by distillation from petroleum.

Fuel Oil. Heavy distillates, residues or blends of oil used as fuel.

Gas Oil. A petroleum distillate.

Gasoline. A refined petroleum distillate within the boiling range of 30°C-200°C suitable as a fuel in an internal combustion engine.

Hydrocarbon. A mixture of carbon and hydrogen.

Liquified Petroleum Gas (L.P.G.). Hydrocarbons, gaseous at atmospheric temperatures and pressures, produced by oil refineries and natural gas processing plants and used as fuels and chemical feedstocks.
Naphtha. A petroleum distillate in the gasoline range.

Natural Gas. Hydrocarbon gases, usually mainly methane, often found in association with oil.

Natural Gasoline. A liquid composed mainly of pentanes produced from natural gas.

Olefins. The products obtained when paraffins are cracked.

Paraffins. The methane, ethane, propane, butane and pentanes group of hydrocarbons.

Petroleum. Used in this thesis to mean both oil and natural gas.
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