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LOCATION FACTORS IN THE PETROCHEMICAL INDUSTRY WITH SPECIAL REFERENCE TO FUTURE EXPANSION IN THE ARKANSAS-WHITE-RED RIVER BASINS

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Preface

To anticipate the character and magnitude of future growth of regions and areas, it is necessary to analyze the ability of these areas to provide employment opportunities. A major and basic source of jobs is the manufacturing industry. As manufacturing expands into new locations, it creates new employment directly and indirectly.

Thus, it is as important for a region seeking to develop its resources as for industry itself to know what constitutes a profitable location. The requirements, markets, and technology of industry vary among its different types. A good location for one type of industry is not necessarily a good location for another type. The present study makes a contribution to knowledge concerning the locational forces to which the petrochemical industry—one of our more rapidly expanding industries—responds. At the same time, the analysis is a contribution to the whole field of locational theory.

The study resulted from participation by the Department of Commerce through its Area Development Division in the work of the Arkansas-White-Red River Basins Committee. This joint Federal-state group is submitting to the Congress the results of its five-year study and recommendations on the development of the land and water resources of this important region. It was the purpose of the Department, in participating in the study, to identify the industrial opportunities and growth potentials in the basin. The present study represents one part of the contribution of the Department to the work of the Committee. Because the locational problems of the petrochemical industry are considered in a national context, it was decided to make the study generally available.

Numerous persons have made this study possible. Within the Federal government personnel of the Area Development Division assisted in laying the groundwork for the study and seeing it through to its printing and publication. Victor Roterus, Chief of the Area Development Division, initiated the study, and Gustav E. Larson and David Brown correlated it with other economic studies of the Department of Commerce in the Arkansas-White-Red River Basins area. Arthur Schroder of the Department's Chemical and Rubber Division reviewed the text and made helpful suggestions. The detailed transportation cost analyses were made by Kenneth J. Zoeller and Frederick G. Kunz of the Transportation and Public Utilities Division, General Services Administration, under the direction of Frank L. Barton, Director.

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Mr. John F. O'Donnell of M. I. T. was of special assistance in guiding judgments on various matters.

Of course, none of these individuals or companies is to be held responsible for any errors in, and interpretations of, the data presented in this report.

The authors are also finally indebted to the competent research and secretarial services of Miss Ann-Marie G. Hellerstrom and Miss Alexia Hanitsch.

John C. Green

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Summary

Insight into the economic growth of countries and regions and projection of their patterns of development require careful study of the future geographic distribution of new as well as existing basic industries. Although the natural resources which provide the basis for the existence of a given industry may be relatively concentrated in one region, the subsequent industrial development need not be concentrated in the same region. The particular resource in question may be exported to other more or less distant regions for processing and manufacture, and provoke relatively little industrial development within the region of deposit.

It is the purpose of this report to examine the forces affecting the future geographic pattern of the petrochemical industry within the United States. Particular attention is given to the potentialities for development in the Arkansas-White-Red River basins, henceforth called the AWR region. This region is endowed with extensive supplies of natural gas, one of the basic sources of raw materials for the petrochemical industry.

The petrochemicals industry is interesting and significant to study from the standpoint of regional economic development. It is a relatively young industry with tremendous growth possibilities. Its ultimate raw materials are primarily petroleum and natural gas. These are concentrated in the Southwest and Gulf Coast regions. In contrast, the major markets for petrochemical end-products—plastics, synthetic fibers, detergents, synthetic rubber, solvents, and automotive chemicals—consist of the heavily industrialized areas of the Northeast.

From the standpoint of future availability, natural gas and its component hydrocarbons appear to be the best raw material source for methane-, ethylene-, and acetylene-based petrochemicals. Natural gas is not as favorable a raw material source for other petrochemicals. Since we are concerned with potential development in the AWR region, we therefore confine our analysis chiefly to petrochemicals based on methane, ethylene, and acetylene.

Plant costs, interest and related charges, maintenance costs, cooling water costs, and most process chemical costs are not expected to show much variation among regions. The costs of chlorine or its derivatives, however, are expected to vary significantly from region to region, and hence will affect the location pattern of new facilities for the production of chlorinated petrochemicals which consume large quantities of chlorine.

Labor costs and power costs, too, are not expected to exhibit major variations among regions, primarily because only relatively small amounts of labor and power are required for petrochemical production. Hence, for non-chlorinated petrochemicals there are no major locational pulls or pushes associated with any of the costs already mentioned.

Differences among regions in fuel, steam, and feedstock costs reduce to differences in transport costs of the equivalent volume of natural gas. These transport costs are subject to major variation among regions. A natural gas site, like Monroe, Louisiana, avoids them; while a Northeast location, like New York, must incur them. Likewise, transport costs on finished products exhibit major variation among regions. A natural gas site must incur them in shipping to major markets; market and gateway point locations in the Northeast can largely avoid them.

Another major set of cost differentials among regions may arise from differences in achievable size of plant or productive unit. Regions which are able to market large outputs can reap economies of scale and can have major advantages over regions which can market only a small output.

The location analysis for each of the large-volume, non-chlorinated petrochemicals considered is thus reduced to consideration of (1) transport costs on raw material and fuel gas; (2) transport costs on finished product; and (3) economies and diseconomies of scale. In the case of chlorinated petrochemicals, cost differentials on chlorine and its derivatives are an additional consideration.

The results of this study do not justify any blanket statement regarding petrochemical location which will cover the entire list of products considered. Some products, such as acrylonitrile and ethanolamines, are primarily raw material-oriented; others, such as ammonia and ethyl chloride, are primarily market-oriented when a large enough scale of operations can be achieved.

The major portion of expansion in natural gas-based petrochemicals capacity will be erected in natural gas areas. However, some expansion will occur at or near major metropolitan market areas and gateway points, particularly in the Ohio Valley because of its general advantage in chlorine production. The future pattern of petrochemicals expansion is therefore likely to be somewhat less oriented to the AWR and other natural gas producing areas than is current production.

It is estimated on a firm minimum basis that by 1975, petrochemical production capacity in the AWR region will have expanded by 6.049 billion pounds. This expansion is expected to require 2,210 laborers for operations and maintenance work.

LOCATION FACTORS IN THE PETROCHEMICAL INDUSTRY WITH SPECIAL REFERENCE TO FUTURE EXPANSION IN THE ARKANSAS-WHITE-RED RIVER BASINS[1]

1. Introductory Remarks

A half century ago crude oil refining was practiced in the United States primarily to derive the product, kerosene. Only the most elementary distillation processes were utilized. Very little was known about the chemical composition of crude oil and its products and by-products. The same was true of natural gas although it had been burned as fuel on a small scale since the early 19th century.

The next decade, however, witnessed the emergence of a demand for motor fuel. Henceforth, the expansion of this demand was to constitute the most important single factor in the growth and development of the petroleum refining industry. Since the yield of gasoline from distillation of crude oil proved relatively inadequate to satisfy the rapidly mounting demand for motor fuel, research was undertaken to improve gasoline yields. Over the years new refinery processes, such as thermal and catalytic cracking, and thermal and catalytic reforming, were developed with this objective in mind. The quality of gasoline was upgraded. Concomitantly, knowledge relating to the chemical structure and behavior of the many different components of crude oil was amassed. It was discovered that in the various cracking processes certain of the crude oil components were transformed or synthesized into new components which were non-existent in the original crude. These new components were found to be effective in increasing the yield and quality of motor fuel. Also, it was gradually realized that these components were of the same type as those which were the basis of production of valuable chemical compounds (for example, ethyl alcohol), by natural methods such as fermentation and distillation of grain or wood.

This was the start of the petrochemical industry. Since natural gas contains many of the same components as crude oil, it qualifies independently as a major source of raw materials for the production of chemicals. Petroleum and natural gas sources have many advantages over other sources for conversion into chemical raw materials. And as a result of continuing research the number of actual and potential chemical compounds and products derivable from petroleum and natural gas raw materials has steadily increased until at the present time the list of possible petrochemicals is virtually unlimited.

To afford an indication of the number and complexity of petrochemical processes and products, Figure 1 has been constructed. It shows in the form of a flow sheet the basic petrochemical raw materials (crude oil and natural gas), selected important petrochemical intermediates (such as ethane, ethylene, ethylene oxide, and ethylene glycol), and general types of end products (such as antifreeze, synthetic fibers, and plastics). For example, take ethylene which may be captured directly from refinery gas or produced by cracking the ethane, propane, or mixtures of the two, available from refinery and natural gas. Ethylene yields among other products ethylbenzene, ethyl chloride, ethylene dichloride, ethyl alcohol and ethylene oxide which in turn yield end-products (such as solvents and antifreeze) or more advanced chemical intermediates (such as styrene and vinyl chloride).

2. Definitional Points

At the outset of our discussion it is well to attempt a definition of the term, petrochemical. The word itself only dates from 1944, although prior to that there had been numerous references to "petroleum chemicals" and the "petroleum-chemical industry."[2] Actually, the term "petrochemical" grew up through usage and in the process acquired a variety of meanings.

According to the *Encyclopedia of Chemical Technology* the term petrochemicals "denotes pure chemical substances commercially produced from petroleum or natural gas."[3] For our purposes we define petrochemicals as chemical elements and compounds (both organic and inorganic) which are recovered directly or derived indirectly in whole or part from petroleum or natural gas fractions. Thus we include those chemicals the raw materials for which may come principally from sources other than petroleum or natural gas, e.g. coal and coke. However, we exclude petroleum products such as gasoline, kerosene, lubricating oil and diesel fuel because they are not definite compounds or elements, but rather heterogeneous mixtures of several compounds. Also, we omit from analysis final or near-final products such as are listed in the right-hand column of Figure 1. From the standpoint of our study this omission is undesirable, since the location of the end products and chemical intermediates are closely interrelated. However, it is beyond the scope and resources of this study to consider final or near-final products, except for special circumstances.

Keeping the definition of a petrochemical in mind, we can turn to a brief discussion of the basic petrochemical raw material sources, i.e., petroleum and natural gas hydrocarbons.

A hydrocarbon is a molecule containing a given number of carbon atoms and a given number of hydrogen atoms. For example, ethane (C_2H_6) is a hydrocarbon containing 2 carbon atoms and 6 hydro-

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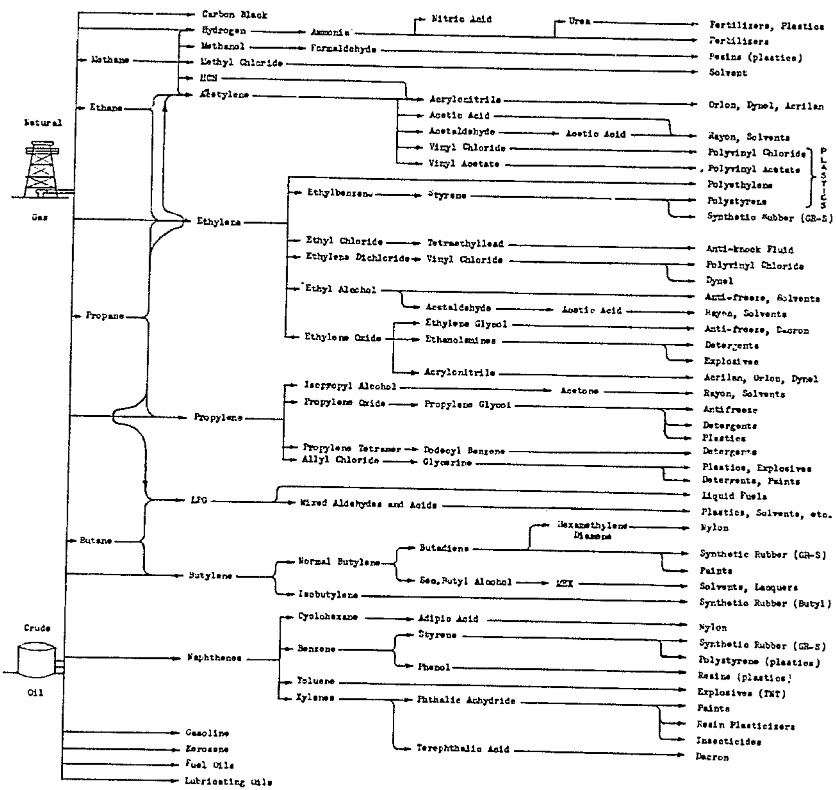
[1] The data of this report and our interpretation of these data drew heavily from a doctoral dissertation by Eugene W. Schooler, and from materials collected in connection with a study on the feasibility of an oil refinery—petrochemical—synthetic fiber complex for Puerto Rico. This latter study is sponsored by the Social Science Research Center, University of Puerto Rico.

[2] William F. Bland, "What is a Petrochemical?," *Petroleum Processing*, Vol. 7, April 1952, p. 491.

[3] *Encyclopedia of Chemical Technology*, Vol. 10, p. 177. Also see Bland, *op. cit.*

FIGURE 1. FLOW SHEET OF PRINCIPAL PETROCHEMICAL RAW MATERIALS, INTERMEDIATES AND END-PRODUCTS



gen atoms. Crude petroleum is a very complex mixture of many different kinds of hydrocarbon compounds which fall into three types: paraffins, naphthenes, and aromatics. Of these innumerable different hydrocarbons virtually all of the ones actually or potentially of interest in petrochemical production are ones containing a relatively low number of carbon atoms, viz., eight or less. In natural gas, the hydrocarbons are primarily paraffins with eight carbon atoms or less, the heavier hydrocarbons being of less importance.[4] There are commercially feasible processes for separating or isolating these low numbered hydrocarbons in both petroleum and natural gas.[5]

The classification into paraffins, naphthenes, and aromatics concerns the technical chemical arrangement of the different atoms and is not of direct interest to our study. However, the terms themselves should be familiar because organic chemicals are often grouped according to the name of their hydrocarbon source, e.g. paraffinic chemicals, naphthenic chemicals, and aromatic chemicals.

The most important type of hydrocarbons from the standpoint of petrochemicals are the paraffins. The paraffinic hydrocarbons as they appear naturally in petroleum and natural gas are relatively unreactive, chemically speaking. That is, it is difficult to subject them to the ordinary chemical process reactions, particularly those involved in the synthesis of organic chemicals. However, if paraffins are dehydrogenated or cracked, they lose some of their hydrogen atoms; the remaining atoms are rearranged, resulting in a new kind of hydrocarbon which is chemically very reactive. These new hydrocarbons, which do not appear naturally in petroleum or natural gas but are a result of cracking operations, are called olefins.[6] In a similar manner it is possible to crack paraffins and obtain acetylene, another type of hydrocarbon which is chemically very reactive. When paraffins, olefins, and acetylene are considered as one group, they are called aliphatics and the chemicals which are made from them are called aliphatic chemicals. The most important aliphatics from the standpoint of petrochemicals production are the following paraffins and their derivative olefins:

Paraffin	*Olefin*
Methane	--
Ethane	Ethylene
Propane	Propylene
Butanes	Butylenes

It is difficult at present to gauge the importance of petrochemical acetylene. Although acetylene can be used as a base for a wide variety of chemicals, it has been only very recently that potentially economic processes for producing acetylene from methane, ethane, or propane have been developed. If these processes permit the production of acetylene at a cost approximating that of the olefins, particularly ethylene, acetylene will assume great importance since many chemicals can be produced with either ethylene or acetylene as a base.[7]

Although higher paraffins (and olefins) can be separated, their use in chemical synthesis is quite limited.[8]

Naphthenic hydrocarbons are of relatively small importance directly to chemical production, although one naphthenic, cyclohexane, is of growing significance in the production of nylon intermediates. Perhaps the most important aspect of naphthenics is the fact that through certain catalytic reforming processes they can be transformed into aromatics,[9] which are expected to play a more and more important role in petrochemical production.

The production of aromatic chemicals has been until comparatively recently the exclusive province of coal and coke, but petroleum hydrocarbons seem destined to become increasingly important in this field. In World War I, the soaring demand for toluene for explosives coupled with the limited supply available from coal and coke byproduct operations led to the production of this aromatic from petroleum. Much the same thing happened in World War II with respect to toluene and another important aromatic, benzene. Postwar demands for toluene, benzene, and xylenes appear to be expanding far too much to be satisfied from coal and coke operations.[10] Thus it is likely that all three of these important aromatics will come more and more from petrochemical operations.

3. Current and Future Production of Petrochemicals

The growth of petrochemicals in recent years has been extremely rapid. Figures 2 and 3, which for these years chart respectively the production of synthetic aliphatic chemicals, and petroleum and natural gas crude products (aromatics, naphthenes and aliphatics) used for chemical purposes,[11] clearly illustrate this.[12] This rapid growth is projected into the future by experts in the field. Reports of the United States Tariff Commission,[13] the President's Materials Policy Commission,[14] and articles by Boyd and Backus,[15] and Kuhn and Hutcheson,[16] provide data on past and

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[4] Louis F. Fieser and Mary Fieser, *Organic Chemistry*, New York, 1950, pp. 88-89.

[5] Louis F. Hatch, "Petrochemical Reactions," *Petroleum Refiner* Vol. 32, May 1953, p. 144.

[6] *Ibid.*, p. 145.

[7] R.S. Aries and R.M. Criner, "Acetylene—The Newest Petrochemical," *Petroleum Refiner*, Vol. 31, May 1952, pp. 129-130.

[8] Hatch, *op. cit.*, p. 145.

[9] For detailed descriptions of three different methods of producing petroleum aromatics, see: Davis Read, "Production of High-Purity Aromatics for Chemicals," *Petroleum Refiner*, Vol. 31, May 1952, pp. 97-103; W. H. Davis, J. I. Harper, F. R. Weatherly, "The Arosorb Process in Refinery Operations," *Petroleum Refiner*, Vol. 31, May 1952, pp. 109-113; and C. L. Dunn and G. F. Liedholm, "Shell Process Permits Recovery of Nitration-Grade Benzene and Toluene," *Petroleum Refiner*, Vol. 31, May 1952, pp. 104-108.

[10] The President's Materials Policy Commission, *Resources for Freedom*, Vol. IV, *The Promise of Technology*, Washington, 1952, p. 196.

[11] There is considerable, unavoidable double-counting and duplication in the U. S. Tariff Commission data.

[12] For a brief historical sketch of the petrochemical industry see *Encyclopedia of Chemical Technology*, Vol. 10, pp. 184-88.

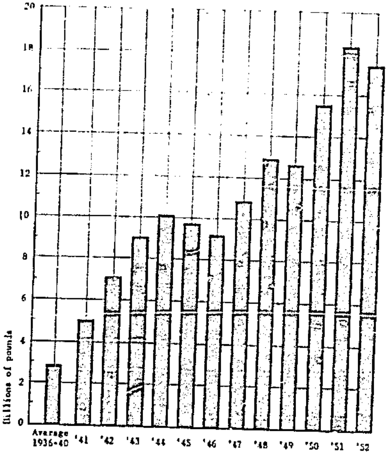
[13] United States Tariff Commission, *op.cit.*

[14] The President's Materials Policy Commission, *op.cit.*

[15] James A. Boyd and Claude A. Backus, "Petrochemicals Expanding 14% Annually," *Petroleum Engineer*, Vol. 25, April 1953, pp. C-3 to C-8

[16] W. E. Kuhn and J. W. Hutcheson, "Ethylene Petrochemicals," *Petroleum Processing*, Vol. 7, October and November 1952.

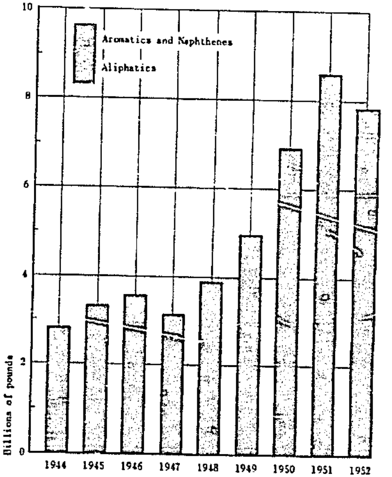
FIGURE 2
United States Production of Synthetic Acyclic* Organic Chemicals (Intermediates and Finished Products), 1936-1952



*The term acyclic corresponds approximately to the more familiar classification, aliphatic.

Source: U.S. Tariff Commission, *Synthetic Organic Chemicals, United States Production and Sales*, Annual Reports.

FIGURE 3
United States Production of Petroleum and Natural Gas Crude Products (Aromatics, Naphthenes & Aliphatics) for Chemical Conversion, 1944-52



Source: U.S. Tariff Commission, *Synthetic Organic Chemicals, United States Production and Sales*, Annual Reports.

current production of various petrochemicals and on future requirements. Suffice it to indicate briefly data and statements pertaining to the several major types of hydrocarbon raw materials and to individual chemicals derived from each type.

The total production of petroleum and natural gas hydrocarbons for chemical conversion in 1951 was 8.6 billion pounds, of which 7.0 billion pounds were aliphatic hydrocarbons and derivatives.[17] Although these figures reflect considerable double counting, they still show the dominant position held by aliphatics in the petrochemical field. Of the aliphatic hydrocarbons used, the four olefins (ethylene, propylene, normal butylene, and iso-butylene) together with methane constitute the most important raw materials for chemical production.

One estimate of olefin consumption for 1951 gives a total of 4.3 billion pounds, of which ethylene made up 41%; propylene, 27%; n-butylene, 27%; and iso-butylene, 5%.[18]

Methane (Natural Gas): The largest consumer of methane (natural gas) other than as a fuel is carbon black, of which 1,300 million pounds were produced in 1950. However, carbon black is being produced from oil to an ever increasing extent, and its production from natural gas is expected to decline to 715 million pounds by 1975. Ammonia appears destined to become the new leader in the methane chemicals field with production rising from 3,140 million pounds in 1950 to 10,400 million pounds by 1975. Methanol is another major methane chemical. Its production was 902 million pounds in 1950 and is expected to reach 2,870 million pounds by 1975. The principal uses of methanol are in the production of anti-freeze and formaldehyde. Other important but lesser volume methane chemicals are methyl chloride, methylene dichloride, carbon tetrachloride, carbon disulphide and hydrogen cyanide. The production of hydrogen cyanide is expected to expand very rapidly.

Ethylene: Total requirements for ethylene are estimated at 1,536 million pounds in 1950; 3,700 million pounds in 1960, and 7,000 million pounds in 1975. The largest consumer of ethylene is ethyl alcohol, the production of which is expected to grow from 165 million gallons in 1950 to 700 million gallons in 1975. The fastest growth in the consumption of ethylene is expected from polyethylene (for plastics) and acrylonitrile (for synthetic rubber and fabrics). Their combined consumption of ethylene was only 80 million pounds in 1950 but is expected to reach 2,200 million pounds by 1975. Other important ethylene chemicals are ethyl chloride, ethylene dichloride, and vinyl resins.

Propylene: Total production of propylene in 1950 was 882 million pounds. Estimated requirements for 1960 are 2,043 million pounds and for 1975,

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[17] United States Tariff Commission, *op.cit.*, p. 5.

[18] Boyd and Backus, *op.cit.*, p. C-6.

3,563 million pounds. This growth will be reflected by that of the primary propylene chemical, isopropyl alcohol, and its major derivative, acetone. Both these products are widely used industrial chemicals and their growth will tend to parallel the general industrial growth of the country. Other important propylene chemicals are glycerin, propylene glycol, propylene tetramer, and cumene.

Butylenes: The production of butylenes in 1950 totaled 1,020 million pounds. Requirements are expected to reach 4,700 pounds by 1975. The most important butylene chemical is butadiene, of which 615 million pounds were produced in 1950. Butadiene is used to make the major type of synthetic rubber, GR-S rubber. Other butylene derived chemicals are the secondary and tertiary butyl alcohols. Further, butylenes are used extensively in polymerizing and up-grading gasoline, although such uses are not strictly "petrochemical" in our sense.

Acetylene: As already indicated, the extent of future production and use of petrochemical acetylene is uncertain. However, if petroleum and natural gas acetylene does become economically feasible and comparable in cost to ethylene, it is estimated that acetylene requirements will be 859 million pounds by 1955 and 3,914 million pounds by 1975. It must be pointed out that part of these requirements will be supplied from carbide acetylene, although the general opinion seems to be that expansion from this source is limited because of large requirements of cheap power.[19]

Plastic materials such as vinyl resins are expected to be one of the largest users of acetylene. Of nearly equal importance as users will be acetaldehyde, acetic acid, and acetic anhydride, all of which are consumed principally by the cellulose acetate and rayon industries. Acetylene is likely to be used extensively also in the production of acrylonitrile, an important synthetic fiber material.

Aromatics: Benzene is the most important aromatic hydrocarbon. In 1950, 1,357 million pounds were produced. It is estimated that requirements will be 3,630 million pounds by 1960, and 6,651 million pounds by 1975. Most of the present requirements for benzene are supplied from the coal and coke industries. However, such by-product capacity is limited and it is likely that much of any future expansion in requirements will need to be satisfied from petrochemical benzene. (This statement also applies to the other aromatics, toluene and xylenes.) Styrene is the largest single consumer of benzene. In 1950, 539 million pounds of styrene were produced, and estimated requirements for 1975 are 2,635 million pounds. Styrene is used in making synthetic rubber and polystyrene plastics. Phenol is another major benzene chemical. Its production is expected to grow from 312 million pounds in 1950 to 1,250 million pounds in 1975. The most important use for phenol is in resins and plastics. Other important benzene chemicals are nylon, aniline, detergents, and maleic anhydride.

The other aromatic hydrocarbons, toluene and xylenes, will be less important quantitatively than benzene. The 1975 estimated requirement for toluene is 1,060 million pounds; for ortho-xylene, 686 million pounds; and for para-xylene, 756 million pounds. Toluene has been used mainly in the manufacture of explosives, but a new use which may become important is for the production of vinyltoluene, a partial substitute for styrene. Ortho-xylene will probably become increasingly important in the production of phthalic anhydride. Para-xylene can be used in the production of the synthetic fiber, dacron.

4. Observations on Feedstocks

Although Standard Oil Company of New Jersey as early as 1919 was producing alcohols from petroleum fractions, Carbide and Carbon Chemicals Corporation first developed in the early 1920's processes for synthesizing other chemicals from petroleum and natural gas hydrocarbons. Carbide and Carbon's experimental plant was at Clendenin, West Virginia, where it developed commercially feasible processes for converting hydrocarbon gases to glycol, acetone, ethyl alcohol, and other products. In 1925 a commercial plant was established at South Charleston, West Virginia. Within a few years other companies constructed similar plants in the East and in Michigan and other Midwestern states and in Texas.[20]

The big growth in the petrochemicals industry has taken place in the last fifteen years, especially during and after World War II. Although the initial processes developed by Carbide and Carbon utilized natural gas as a source of hydrocarbon raw materials, the first source of large volumes of unsaturated hydrocarbons such as ethylene and propylene was refinery waste gases. Thus, the major portion of the growth in petrochemicals production took place on the Gulf Coast, where there was large refinery capacity. See Maps 1, 2 and 3. In the mild climate of the Gulf Coast, the demand for fuel oil was small; and if fuel oil was used as refinery fuel, the refinery off-gases had little if any use at all. Thus the refinery gases were available for petrochemical operations at very low cost. Furthermore, when the practice developed of synthesizing large quantities of such chemicals as ammonia and methanol from methane, the Gulf Coast area experienced further expansion because of the proximity of abundant supplies of natural gas. About 85% of present petrochemical capacity is situated in the Gulf Coast area and the current rate of growth in this area is still rapid.

In addition to refinery gases and natural gas (mainly methane), possible raw material feedstocks for petrochemicals production include crude oil, distillate stocks, light hydrocarbon streams from natural gasoline plants, liquefied petroleum gases, and catalytic reformate. In considering the supply of any of these raw materials which will be available for future expansion of chemical production, one must take account of two important factors. The first is the yield and value of the

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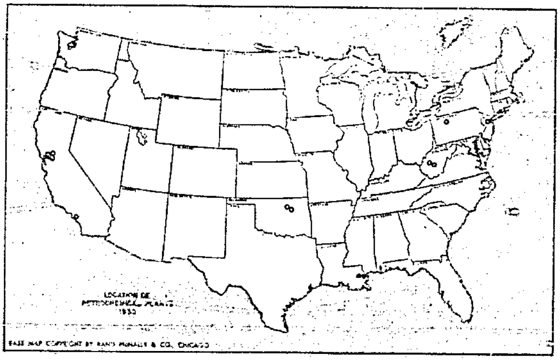
[19] Aries and Cziner, *op.cit.*, p. 127; and Theodore Weaver, "Economics of Acetylene by the Wulff Process," *Chemical Engineering Progress*, Vol. 49, Jan. 1953, p. 35.

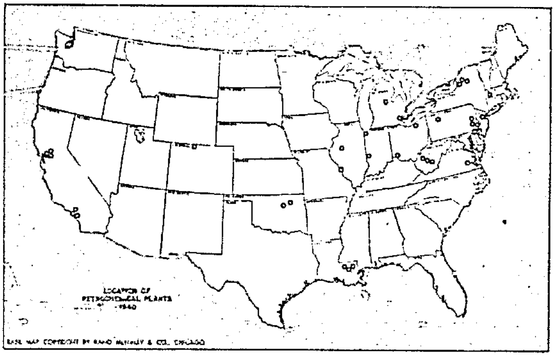
[20] For further discussion of Carbide and Carbon's early petrochemical activities see John R. Skeen, "Ethylene Glycol," *Chemical Engineering*, Vol. 56, May 1949, pp. 357-58.

MAP 1.



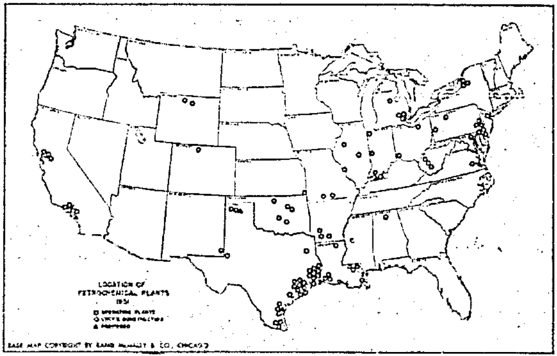
Location of
Petrochemical
Plants, 1930

MAP 2.



Location of
Petrochemical
Plants, 1940

MAP 3.



Location of
Petrochemical
Plants, 1951

Source: W.E. Kuhn and J.W. Hutcheson, "Ethylene Petrochemicals," *Petroleum Processing*, Volume 7 October 1952, p. 1102.

chemical products that can be derived from the raw material; the second is the economic attractiveness of uses for the raw material other than as a chemical feedstock. In general, of several raw materials in equal abundance, those whose chemical derivatives are of high weight yield and high unit value, and whose alternative uses are of a low order of economic attractiveness, will tend to furnish the largest source of supply for future increases in petrochemicals production. Obviously, when the total available amounts of the various raw materials are of different magnitudes, this too will affect the absolute amounts of each to be used for chemical conversion. However, the general statement just made would still be valid in determining differences in the rates of growth in chemicals production from the various feedstocks.

In the remainder of this section each of the above mentioned raw materials is examined with respect to its possible future use as a chemical feedstock, with particular attention given to the influence of its alternative uses.

Natural Gas: As has been indicated, large amounts of natural gas have been utilized in the production of such chemicals as ammonia and methanol. However, natural gas has many advantages as a fuel and this has led to a continuous expansion of long-distance pipeline facilities from the Southwest natural gas fields to the large fuel markets of the North and East. So long as such a trend continues, the supply of cheap natural gas for chemical conversion will become more and more limited, since there obviously is some ultimate limit to the reserves of natural gas in the Southwest. And even though new reserves are constantly being discovered, the possibility of reaching the large fuel markets by means of existing or potential pipelines will enable the owners of the gas fields to command higher prices for their gas.

It should be noted that there is a limit to the possible rise in the price of gas (other than the institutional limits imposed by public rate making bodies). The Northeast has large supplies of coal. Since the future will undoubtedly witness further progress in coal gasification processes, this promises to make available in large quantity a type of gas which will possess the same attractive qualities as natural gas for use as fuel. If such a situation does develop it would appear that in the long run the price of natural gas will tend to become stabilized, but at a level higher than that which prevailed in earlier years near gas fields and which gave rise to the great expansion in the production of natural gas chemicals.

Light Hydrocarbon Streams: Consider next the use of light hydrocarbon streams from natural gasoline plants. It is necessary that natural gas be processed to remove the heavier hydrocarbons before it is placed in a pipeline. The presence of these easily liquefiable hydrocarbons in the raw gas tends to cause "freezeups" in the pipeline, thereby increasing costs of operation and maintenance. In the process of removing the heavier hydrocarbons, or natural gasoline, from natural gas, the capture of certain amounts of lighter hydrocarbons such as ethane and propane is unavoidable. These must be removed to a large extent before the natural gasoline can be sold. Thus ethane-rich streams from the "de-ethanizer," and propane-rich streams from the "de-propanizer" of the natural gasoline plant become available. Since the activities of natural gasoline plants will increase with the increased long distance pipelining of natural gas, the supply of these light hydrocarbon streams will also increase. So far as chemical production is concerned, the ethane streams will probably be more favorable than the propane streams. The only alternative disposal for the ethane would be to pump it back into the natural gas pipeline to be used as fuel, whereas the propane stream could be used to produce the high quality fuel, liquefied propane. Liquefied propane, because of its liquid form and ease of transport, possesses an advantage over natural gas for certain uses and conditions.[21] Furthermore, one of the most important of the petrochemical intermediates and one which is likely to experience a very high rate of growth is ethylene; and although both ethane and propane can be used as raw materials for its production, the yield from ethane is normally substantially greater than from propane.

It must be realized that there exists a strong possibility that the future demand for ethylene will be great enough so that ethane from natural gas will advance from its principal status of a natural gasoline by-product to that of at least a joint product with natural gasoline and/or LPG, as it has already done to some extent. In such a situation, the costs of capturing ethane increase as greater percentages are stripped, and the heavier propane is necessarily obtained in conjunction with the lighter ethane. Hence this might make available increasing amounts of propane for ethylene production. However, at lower levels of demand, an examination of the factors of availability, yield, and alternative uses indicates that ethane will be preferred to propane as a raw material for ethylene production.

Crude Oil: The use of crude oil, distillate stocks, liquefied petroleum gases, and catalytic reformate as raw material feedstocks for chemical production is limited by the existence of economically attractive alternative uses. Crude oil is the basic raw material for a wide variety of petroleum products, ranging from high octane aviation and motor fuel to residual fuel oil. And although it is true that the use of crude oil as a raw material feedstock for chemical production results in large volumes of by-product stocks which can then be processed into conventional petroleum products, still the amount of high-value, premium grade petroleum products that must be foregone is quite significant. This means that crude oil is a costly chemical raw material.

Light Distillate Stocks and LPG: The lighter fractions or distillates obtained from initial refinery processing of crude oil are the preferred feedstocks for gasoline production. Their availability as petrochemical raw material is accordingly severely limited until more valuable chemicals may be made from them and marketed.

Liquefied petroleum gas (LPG) is a general term for a group of products which includes liquid butane, liquid propane, and mixtures of the two. LPG, especially propane, has to some extent been

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[21] E.g., use for domestic fuel in rural areas not served by pipelines; and possible future use as motor fuel by fleets of trucks or buses.

used for chemical production, particularly in areas in the North and East which do not have oil refinery capacity or other sources of gaseous hydrocarbons. As has already been indicated, propane is a relatively expensive raw material both because of the steadily growing demand for it as an industrial and domestic fuel and because its price at the minimum must cover the costs of extraction, liquefying, and shipping. Thus, although the potential future quantity of propane and other LPG is very large, it does not now promise to constitute more than a relatively minor fraction of future petrochemical feedstocks.[22]

Catalytic Reformate: The demand for higher and higher octane motor fuel by the automotive and aviation industries has necessitated the development of processes to upgrade ordinary or straight-run gasoline. One such process is catalytic reforming. In this process some of the naphthenic and paraffinic hydrocarbons are transformed or "reformed" into aromatic hydrocarbons. The end result is a higher grade gasoline. However, after the reforming step it is also possible to extract some of the aromatics from the "reformate." Thus, petroleum is a source of the important aromatic chemical raw materials, benzene, toluene, and xylenes. As in the case of crude oil and distillate stocks, this use of the petroleum stock competes with its use in the production of high grade motor fuel. Hence these aromatics become relatively expensive chemical raw materials. Nevertheless the opinion is widely held that the demand for aromatics will expand sufficiently to justify the production of very considerable amounts of petrochemical aromatics.[23]

Refinery Gas: It has been noted that the initial expansion in petrochemical production was made possible by the availability of low cost refinery gases. It is relevant at this point to discuss the supply of refinery gases with respect to future expansion of petrochemicals production. Several reasons have been advanced to support the viewpoint that the use of refinery gases for chemical feedstock is approaching its effective limit, particularly should the demand for higher octane motor fuel continue to dominate the scene:

1. The recent development of catalytic cracking and other processes (which incidentally require increased quantities of fuel) has tended to increase the proportion of gasoline and decrease the proportion of residual fuel oil obtained from crude oil. As a consequence, refineries use a larger proportion of their off-gases for their own fuel requirements.

2. The demand for higher grade motorfuel has led to the development of polymerization and alkylation processes. In these processes the ethylene, propane-propylene, and butane-butylene components of refinery gas are blended with gasoline to improve its quality.

3. Refineries in many instances recover part of the butane and propane components of their off-gas and process them to LPG.[24]

The net result of all these developments has been to change the status of refinery off-gas from a surplus by-product with little value to a more profitable raw material with several alternative uses. To the extent that such a change has taken place, the statements concerning the relative costliness of crude oil, distillate stocks, and catalytic reformate as petrochemical raw materials apply to refinery gases as well.

One must realize, however, that refinery gases normally are rather complex mixtures of hydrocarbons (and non-hydrocarbons), with different types of paraffins and olefins occurring in widely differing proportions. For this reason it is somewhat misleading to make a general statement concerning the use of refinery gases as raw materials for chemical conversion. It is quite likely that refinery gases will constitute much better sources for expansion in the production of some petrochemical intermediates than of others. For example, the olefins ethylene and propylene both occur directly in refinery gases, but the relative availability of propylene is usually substantially greater than that of ethylene. The demand for ethylene has already outrun the supply directly available in refinery gases. A substantial portion of present ethylene production comes from the cracking of ethane and propane. This trend will obviously be intensified in the future. On the other hand, the supplies of propylene in refinery gases are still adequate, and there is now little propylene production from the cracking of propane. Propylene from refinery gas is less expensive to produce than propylene from cracking propane. The former involves only one step, separation, while the latter involves two steps, cracking and separation. Thus the opinion is widely held that in spite of the alternative uses for refinery gas, it will probably continue to be the major source of supply of propylene. The same general considerations apply to the case of butylene. Although it is impossible to predict what actually will happen, it appears much more valid to assume that refinery gases will contitute a more favorable future source of supply of propylene and butylene than of ethylene.

Summary: The discussion in this section indicates the following points:

1. Natural gas (methane) will continue in the future to be used directly for the production of substantial amounts of such chemicals as ammonia and methanol, although increasing facilities for serving major fuel markets will restrict the availability of "cheap" natural gas for chemical conversion.

2. Light hydrocarbon streams, particularly ethane, obtained as by-products or joint products

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[22] However, as will be pointed out later, the production of LPG may exert a very important influence on the *location* of future petrochemical production.

[23] The President's Materials Policy Commission, *op.cit.*, p. 196; Boyd and Rackus, *op.cit.* p.C-5.

[24] For further discussion of limitations on the supply of refinery gases for chemical conversion, see Marcus Sittenfield, "The Economics of Petroleum Chemical Plant Location," *Chemical Engineering Progress*, Vol. 45, May 1949, p. 317; and B. R. Carney and Ronald E. Meyer, "Petrochemical Industry Looks to Liquefied Petroleum Gas," *Petroleum Refiner*, Vol. 32, April 1953, p. 123.

from natural gasoline and other natural gas stripping operations will be a favorable source of supply for ethylene and its derivative chemicals.[25]

3. Refinery gases, although faced with increasing limitations as a raw material source for general petrochemical production, owing to increasingly attractive alternative uses, will continue to constitute a major, possibly dominant, source of propylene and butylene. This is true largely because these olefins occur directly and in relatively large quantities in refinery gases. They require relatively inexpensive processing.

4. Crude oil, distillate stocks, liquefied petroleum gases, and catalytic reformate will be definitely limited as petrochemical source materials because of economically attractive alternative uses and/or relatively expensive processing and shipping costs.[26]

5. Considerations on Regional Availability of Raw Materials

The several possibilities for location of petrochemical processes include the following:

1. the construction of a plant at a raw material source and shipment of product to the market (where the market does not coincide with the raw material source), or to several markets;
2. the construction of a plant at a market (or at a focal point within a broad market area) and shipment of raw material to the plant (with local shipment of product to points within the broad market area);
3. the construction of a plant at a non-raw material, non-market site and shipment of both raw materials and product.

Refinery Derived Stocks and Crude Oil: Consider first the use of refinery gases as raw materials. The only practical method of transporting such gases is by pipeline, since they are not easily liquefiable; and although there are pipeline systems in Texas for the transportation of refinery gases over short distances, it is unlikely that long distance pipelines for this purpose will ever be established. The tremendous volume of gas which would need to be shipped to justify the construction and operation of a major pipeline would not be forthcoming. Therefore, it can be said that for all practical purposes, the location of a petrochemical operation using refinery gas as a raw material is tied to the location of the refinery, and is dependent on the complex of forces which affect refinery location and whose analysis lies outside the scope of this study.[27] However, certain fractions of refinery gas such as propylene and butylene (but not ethylene) can be separated and easily liquefied. In this form they can be shipped relatively easily. Hence petrochemical production based on these intermediates is not necessarily tied to the refinery location.

Much the same general considerations are valid in the United States for the production of aromatics from petroleum. The aromatics are in reality produced jointly with much larger quantities of gasoline and other conventional petroleum products.[28] Therefore the location of petroleum aromatics production will be determined by considerations relevant to the location of the major products of the refinery. However, since it is feasible to transport these aromatics, the location of plants producing aromatic derivatives is not dictated by the location of refineries

In the case of petrochemicals from crude oil, distillate stocks, and LPG, there would exist the possibility of location either at the raw materials source, at the market, or elsewhere, since these raw materials can be easily transported by rail, ship, or pipeline.

Light Hydrocarbons From Natural Gas: Finally, consider the production of petrochemicals based on light hydrocarbons stripped from natural gas. It has been indicated that raw natural gas must be processed to remove most of the C_5 and heavier hydrocarbons before the gas is placed in a pipeline, and that some ethane and propane are obtained as a by-product of this operation. The natural gasoline plants which process the raw natural gas often expand their stripping operations in order to recover substantially greater quantities of the propane and butane hydrocarbons in addition to the natural gasoline and C_5 + hydrocarbons. The propane and butane are liquefied and sold as LPG. The important point, however, is that as stripping operations are expanded to extract more propane and butane, increasing quantities of ethane are captured as a by-product.

Although it is necessary to remove natural gasoline at the gas field, some butane and propane may be left in the gas without affecting significantly the pipeline operating costs. Therefore it is possible that in the future more of the propane and butane will be stripped at or near the market in order to avoid high freight costs on LPG. In such a situation ethane would be available both in the Southwest at the natural gas fields as a by-product (as a result of natural gasoline stripping) and at these fields and various other locations as a joint product along with butane and propane.[29] Thus ethane based petrochemicals pro-

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[25] Although it is difficult to compare the relative attractiveness of dry natural gas (methane) and natural gas ethane, owing to the great difference in absolute supplies, the following figures given by R. L. Bateman, an official of Carbide and Carbon Chemicals Co., are of interest. In 1952 the average sales price of aliphatic chemicals (of which ethylene and thus ethane are major raw materials) was 15¢/lb; in contrast the average sales price of inorganics (of which natural gas ammonia and its derivatives are important representatives) was 2.5¢/lb. "Petrochemicals in the Postwar Years," *Petroleum Processing*, Vol. 8, October 1953, pp. 1537-1539.

[26] For further discussion and data on availability estimates see President's Materials Policy Commission, *op.cit.*, Chap. 13; and Eugene Ayres, "Raw Materials for Organic Chemicals," a paper presented at the American Chemical Society annual meeting in Chicago, September 6-11, 1953.

[27] Theoretically, petrochemical market demands, transport rates, and associated considerations could influence refinery location, making it necessary to discuss the location of both refinery and petrochemical activities in the same framework in order to achieve meaningful results. As a practical matter, however, the proportion of total refinery output represented by refinery gases is so small as to render insignificant the effect of their use for chemical conversion upon the location of the refinery.

[28] Read, *op.cit.*, pp. 102-103.

[29] If, in the extreme case, all the butane and propane (LPG) were stripped at market points and not at natural gas fields, ethane would not be available at natural gas fields except as a by-product of natural gasoline stripping. (For the most part, butane and propane must be stripped before sizeable quantities of ethane are obtainable.) In this case the volume of ethane available at

(Continued)

duction could locate either in the Southwest or elsewhere along pipelines. It is true that present institutional arrangements have a restrictive influence upon market location, because much of the intermediate weight (LPG) hydrocarbon content of raw natural gas is stripped at the source along with the heavier or natural gasoline components. Since a pipeline company secures its natural gas stocks from many different sources, and since these sources produce gas streams of varying degrees of initial "richness," the company has been unable, or unwilling, in the past to pay a premium for richer gas streams. Among other factors the streams would have been mingled in the pipeline and the cost of stripping LPG hydrocarbons from the composite stream would have been greater than the costs of stripping the rich streams at the source. Further, there are technical problems in measuring the quality of any stream, although these difficulties are not insoluble. Accordingly, under present institutional arrangements the pipeline company pays the producer a price which covers only a gas of an agreed upon minimum BTU content. Therefore it is to the advantage of the producer to engage in stripping operations himself so long as the stripped gas contains the minimum BTU content, and so long as the revenue he can obtain from the additional LPG (and ethane) more than covers the additional stripping costs.

These current institutional arrangements reflect conditions which developed when pipeline transportation of natural gas was in its infancy. In the meantime there have been improvements in size and efficiency both of pipelines and stripping operations. These improvements together with those on the horizon will result in lower transport cost for gas and in increased economies in large stripping plants. This has and will lead to an increase in the attractiveness of a large-scale market-oriented stripping operation, as will be apparent later. Therefore although current arrangements restrict pipeline transportation of the rich hydrocarbon content of natural gas, it is nonetheless relevant to consider whether or not major location at the market could take place on a pure cost basis without reference to institutional arrangements. If such a location is sufficiently profitable we can expect at least some changes in contract conditions, as have taken place in the past in other industries.

We are fully aware that monopolistic and oligopolistic behavior, leadership patterns, and other factors may oppose change. However, consideration of these factors is outside the scope of this study. Our aim is to identify directions in which the future location pattern is likely to change (and perhaps as a by-product, the type of institutional changes that might be desirable). We fully realize that future location pattern and institutional arrangements are closely interrelated and that the degree to which the ideal pattern (from a pure cost standpoint) is realizable, is partially dependent on the flexibility of institutional arrangements.

However rigid these institutional arrangements may be, a certain amount of ethane, propane, and heavier hydrocarbons is available from lean natural gas which has already been subjected to some stripping at the source. We have already indicated that the demand for ethylene is at present strong enough to change the status of ethane from that of a by-product to that of a joint product in stripping operations. This is another way of stating that under certain conditions it is profitable to subject lean natural gas to further stripping operations for the purpose of extracting more of the ethane, along with additional amounts of heavier hydrocarbons. Such treatment of lean gas can clearly take place at or near the market end of a pipeline even under present conditions. Two examples of such an operation are the Tennessee Gas Transmission Company's hydrocarbon extraction plant in Kentucky and the Panhandle Eastern Pipeline Company's similar plant in Illinois. Informed persons have observed with reference to the Kentucky plant that neither the natural gasoline-LPG operation nor the ethane and subsequent chemical operation would be economically feasible alone. This reinforces our statements regarding the status of ethane as a joint product. Thus even under present conditions it is possible and economically feasible to have sources of supply of natural gas ethane in regions other than the Southwest. This furnishes a second justification for the consideration of an ethane based petrochemical operation either in the Southwest or elsewhere.

Feasible Bases for AWR Petrochemical Expansion: In the following sections of this study we consider in detail the locational factors affecting petrochemicals based on natural gas ethane as well as those based on direct use of natural gas. Natural gas is obviously as transportable as the ethane feedstock. Since, as indicated above, propane and LPG have economically attractive alternative uses and are likely to be more limited in supply for petrochemical development,[30] lesser attention will be paid to petrochemicals based on these feedstocks. Too, since oil refinery capacity is not likely to expand very rapidly in the AWR region,[31] and since refinery gases also have economically attractive alternative uses, we give less consideration to potential petrochemical development in the AWR based on such gases. It is clear that from the standpoint of the AWR region the major opportunity for petrochemical development lies in the use of ethane and natural

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natural gas fields could be inadequate for potential petrochemical expansion envisaged for the AWR. However, it is inconceivable that there will not be significant LPG stripping operations in the natural gas fields areas and hence adequate quantities of ethane for future expansion in petrochemical production.

[30] Carney and Meyer, *op.cit.* p. 124, discuss alternative uses of LPG and its probable increasing cost in the future.

[31] According to figures published in *The Oil and Gas Journal*, during the period from 1942 to 1952 the daily volume of crude oil processed by refineries increased by 760,000 barrels in the Texas Gulf Coast Area; 502,000 barrels in the Illinois-Indiana Area; and 588,000 barrels in the East Coast Area. During the same period the increases in daily volume in the Oklahoma-Kansas-Missouri Area, the Texas Inland Area, and the Northern Louisiana-Arkansas Area were only 190,000 barrels, 71,000 barrels, and 1 barrel, respectively. The latter three areas roughly correspond to the AWR region. Even when relative, rather than absolute increases are considered, the AWR areas show slower growth in crude oil refining. During the period from 1942 to 1952 the increase in the Texas Gulf Coast Area was 59%; in the Illinois-Indiana Area, 69%; and in the East Coast Area, 133%. During the same period the increase in the Oklahoma-Kansas-Missouri Area was 54%, the Texas Inland Area, 36%; and the Northern Louisiana-Arkansas Area, 1.2%. Anon., "Refinery Output Hits New Peak in 1952," *The Oil and Gas Journal*, Vol. 51, Jan. 26, 1953, p. 217.

gas as feedstocks.[32] The crucial questions in what follows are:

1. to what extent ought new petrochemical industry be based upon ethane and natural gas feedstocks on the one hand and refinery gases on the other?

2. where petrochemical industry is assumed to utilize ethane and natural gas feedstocks, should such industry locate in the AWR region or elsewhere?

It should be clearly borne in mind that though it may be established that ethane and natural gas-based petrochemicals should be located in the AWR (which is likely to be the cheapest source of these feedstocks), it may develop that petrochemicals based on refinery gases, despite the economically alternative attractive uses for these gases, are equally profitable. In such a case petrochemical development in the AWR region would be restricted to some extent. This follows since refinery gases are likely to be available in largest quantities outside the AWR region and since the AWR region has inferior transport connections with important market points.

The discussion has already given some indication as to the types of petrochemical raw materials for which refinery gases are likely to constitute the most favorable source of supply. It is pertinent at this point to examine the matter further. The President's Materials Policy Commission estimates that as of 1950, out of 863 million cubic feet of ethane available per day, 446 million cubic feet was available from natural gas. But by 1960, out of an estimated total availability of 1,061 million cubic feet per day, the Commission postulates that 728 million cubic feet will be available from natural gas; and by 1975 the Commission estimates that daily available ethane from natural gas will be 1,150 million cubic feet out of a total daily availability of 1,329 million cubic feet. In each case the remainder of the total amount available represents potential ethane available from refinery cracking gases. The declining proportions of this source of ethane reflect both increasing efficiencies of oil refining operations and more and more attractive alternative uses for refinery gas ethane.

In the case of ethylene it is estimated as of 1950 that, out of a total availability of 808 million cubic feet per day, 379 million cubic feet per day was available from ethane. By 1960 it is estimated that, out of a total daily availability of 996 million cubic feet, 620 million cubic feet will be available from ethane; and by 1975 it is estimated that, out of a total daily availability of 1,260 million cubic feet, 987 million cubic feet will be available from ethane.

When we combine these two sets of availability estimates, it is difficult to escape the conclusion that ethane from natural gas will constitute the chief source of future ethylene production. Even though the figures refer to availability rather than to estimated production, the facts are that the demand for ethylene has already exceeded the supply directly recoverable from refinery gases and that at the present time substantial amounts of ethylene are being produced by cracking ethane (increasingly including natural gas ethane). These facts indicate that future production ratios will be similar to the availability ratios, particularly if there is a continuing high rate of growth in ethylene demand and production.

In the case of propylene, the Materials Policy Commission data suggest that in 1975, out of a total estimated daily availability of 1,135 million cubic feet, 389 million cubic feet will be available from propane cracking. For butylene, out of a total estimated daily availability in 1975 of 1,242 million cubic feet, 223 million cubic feet will be available from butane cracking. Propane and butane in these cases refer to that available both from natural gas and from refinery gas. The relatively large proportions of propylene and butylene available from sources other than the cracking of propane and butane reflect the large amounts of propylene and butylene directly available in refinery gases.

At present there is virtually no production of propylene and butylene from natural gas propane and butane. Furthermore, there is no indication that processes for producing propylene and butylene from natural gas propane and butane will become economically competitive in the future. Thus, although natural gas propane and butane will be available in the future for propylene and butylene production in the ratios given by the Commission, there is no reason to believe that propylene and butylene will actually be produced in these ratios. Since in the case of propylene and butylene one can only speculate about future production ratios, and since there is at present no significant production from natural gas propane and butane, we will not consider in our analysis propylene and butylene from natural gas. In contrast, we have a firm basis for studying thoroughly the production of ethylene from natural gas ethane, not only because of the data and statements of the Materials Policy Commission, but also because of current practices and trends in ethylene production.

6. Some Regional Cost Differentials in Petrochemical Production

As in the location of most industries, some factors are relatively unimportant while others are strategic. Except for instances where the pulls of the strategic factors tend to neutralize each other, analysis can be simplified and still be as significant as ever when the relatively unimportant factors are set aside or treated generally as qualifications to the conclusions reached from consideration of strategic factors only.

How important are various factors in the location of the petrochemical industries? Table 1, which presents information on the production of

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[32] Petrochemical development in the Gulf Coast region can be much more varied. Large amounts of refinery gases and other refinery fractions, together with natural gas and its light hydrocarbon components, will be available. However, our report is restricted—even for the Gulf Coast area—to petrochemical expansion based primarily on ethane, ethylene and natural gas.

Table 1.—PRODUCTION OF ETHYLENE GLYCOL FROM ETHYLENE (ETHYLENE OXIDATION PROCESS)

Plant cost:[1,2]	
Ethylene oxide reaction section	$2,925,000
Oxygen plant	1,250,000
Initial catalyst	345,000
Ethylene oxide purification section	775,000
Ethylene glycol plant	1,100,000
Total	$6,395,000
Utilities consumption:	
600 PSIG, steam, M lb/hr.	139.4
200 PSIG, steam, M lb/hr.	[5] - 130.1
70 PSIG, steam, M lb/hr.	60.
Cooling water, gpm.	6,700.
Condensate, gpm.	115.
Electric power, kw.	540.
Fuel gas, MM BTU/hr.	13.5
Manufacturing costs:	
Materials:	
Ethylene, ¢/lb.	3.82
Chemicals, ¢/lb.	.01
Catalyst[3], ¢/lb.	.29
Manufacturing costs—Con.	
Utilities:[4]	
600 PSIG, steam, ¢/lb.	.83
200 PSIG, steam, ¢/lb.	-.74
70 PSIG, steam, ¢/lb.	.31
Cooling water, ¢/lb.	.09
Condensate, ¢/lb.	neg.
Electric power, ¢/lb.	.05
Fuel gas, ¢/lb.	.03
Direct operating labor[5], ¢/lb.	.32
Maintenance, interest, inventories, taxes, insurance, land rental[7], ¢/lb.	1.72
Total, excluding amortization, ¢/lb.	6.74

[1] Excludes contingency, contractor's overhead and profit, utility generating equipment and offsite facilities.

[2] If acetylene content of feed exceeds 10 PPM the plant cost should be increased for acetylene removal facilities by $125,000.

[3] Catalyst cost is $1.26 per pound.

[4] Unit costs of utilities are: 600 PSIG steam, $0.40/M lb; 200 PSIG steam, 0.38/M lb; 70 PSIG steam, 0.35/M lb; Cooling water, 0.015/M gal; Condensate makeup, 0.01/M gal; Electric Power, 0.0062/kwh; Fuel gas, 0.15/MM BTU.

[5] Minus sign signifies production.

[6] Labor force: 21 Men/Day. Wage: $2.75/hr.

[7] Estimated percentage on plant costs: For maintenance, 8.0; for interest, 4.5; for inventories, 0.8; for taxes, insurance, and land rental, 1.0.

neg. Negligible.

Source: The Lummus Company, *The Shell Process for Manufacturing Ethylene Oxide and Ethylene Glycol*, New York, March 1, 1953.

ethylene glycol,[33] an important yet typical petrochemical, throws considerable light on this question. Consider first plant cost.

Plant Costs and Fixed Charges: Some contend that the more clement weather of the Gulf Coast and parts of the AWR region may render unnecessary certain structural features characteristic of factories in the more northern sections of the United States, and cause less deterioration of plant and equipment. And it has been true in the past that outdoor plants (plants without outside structural enclosures) have been much more characteristic of the Gulf Coast and California than of the more northern regions. (It has been estimated that construction costs of outdoor plants run ten to twelve percent less than those of indoor plants.[34])

It is our impression, however, from conversation with construction engineers and from a careful perusal of the technical literature that the outdoor plant is as feasible for the more northern regions of the United States as for the Gulf Coast, AWR, and California areas.[35] Hence, the difference in plant costs among regions which in the past was primarily due to structural cost (indoor vs. outdoor) will tend to reduce to a difference among regions in insulation costs for outdoor plants.[36] Since this last difference will be slight,[37] we shall assume plant costs for any given new capacity as approximately the same from region to region.

Plant costs form the backbone for calculation of fixed charges. Even where plant costs are alike among regions, major differences in fixed charges may result from the application of differ-

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[33] For a plant capable of producing 40 million pounds of reactor effluent ethylene oxide, and 53.1 million pounds of product ethylene glycol (600 to 200 PSIG steam for all turbine drives).

In addition to Table 1, the reader is referred to W.L. Faith, Donald B. Keyes, and Ronald L. Clark, *Industrial Chemicals*, New York, 1950. This excellent book is the best single source of technical process descriptions, chemical formulae and reaction equations, principal raw material input requirements, past production figures, use patterns, historical data, economic aspects, and other information not only for ethylene glycol but for one hundred and five other important industrial chemicals.

[34] J.H. Minevitch, G.B. Knight, S.E. Root, and H.F. Boraks, "Chemical Plant Construction Cost, Indoors versus Outdoors," *Chemical Engineering Progress*, Vol. 47, Aug. 1951, pp. 385-391.

[35] Minevitch, et.al. *op.cit.*; W.H. Williams, "Chemical Plant Operations and the Weather," *Chemical Engineering Progress*, Vol. 47, June 1951, pp. 277-282; H.S.Kemp, L.T.Mullen, A.P. Guess, "Construction of Acid Recovery Units, Indoors or Outdoors?" *Chemical Engineering Progress*, Vol. 47, July 1951, pp. 339-340; Homer Kieweg, "Safety and Outdoor Construction," *Chemical Engineering Progress*, Vol. 47, July 1951, pp. 341-343.

[36] Obviously, short-run differences among regions in efficiency of construction labor and availability of materials may lead to significant differences in realized plant costs. Such special short-run factors cannot in general be anticipated, and hence lie outside the scope of our study.

[37] In two typical cases cited by Minevitch, et.al., (*op.cit.*, p. 387), insulation costs per $100 of indoor plant cost rose from $6.00 for an indoor plant to $6.40 for an outdoor plant, and from $2.40 for an indoor plant to $5.00 for an outdoor plant, respectively, for cold climate regions. It seems reasonable to assume that insulation costs for an outdoor plant in a warm climate region would be at least as large as insulation costs for an indoor plant in a cold climate region.

ent rates of interest, amortization, insurance, taxes, maintenance and the like. There is no firm basis upon which regional differences in interest, amortization, insurance and tax rates may be anticipated. We expect the price and availability of capital to be effectively regionally equalized, particularly for large national concerns which have easy access to the major financial markets. The regional variable does not seem to have any significant effect upon amortization and insurance rates. And although tax rates and land rents and costs may vary greatly from site to site within any region, there does not appear to be any systematic regional variation in these items.[38] Therefore, identical interest, amortization, insurance, tax rates and land costs are assumed for all regions.

Maintenance Costs: In contrast, there is some basis to expect that maintenance costs will tend to be higher in the more inclement climates. In severe weather equipment maintenance is more difficult. However, the practice of concentrating major maintenance work during periods of favorable weather tends to lessen any resulting regional difference in maintenance costs.[39] Clearly, maintenance cost is not a strategic location factor in the petrochemical industry. For purposes of our study, attention to possible differences in maintenance costs (as well as plant costs) is justifiable only in the special circumstance when the interaction of the several strategic location forces yields an inconclusive result.

Labor Costs: Another location factor is labor. Per pound of ethylene glycol labor cost in Table 1 is 0.32 cents, or approximately 5 percent of total costs. However, to investigate the pull of labor, as well as other factors to be discussed later, on the basis of the figures of Table 1 would be inadequate. These figures relate to the conversion of ethylene into ethylene glycol. But ethylene is only an intermediate and, for our regional analysis, an immobile intermediate, since it is generally considered infeasible to transport ethylene over long distances. Any operation which utilizes ethylene to a large extent must be regionally juxtaposed to the ethylene manufacturing plant. In this context, location analysis of a single stage operation is anemic. An operation of more than one stage must be considered as the ultimate unit for regional disaggregation. Accordingly, an analysis of ethylene glycol must encompass the process whereby ethylene is derived from cracking an ethane or an ethane-propane stream; the analysis must not geographically split the production of ethylene and the production of ethylene glycol. It should be recognized, however, that the production of other types of petrochemicals may require only transportable intermediates, and not immobile ones. In such cases the analysis can and should proceed on a single as well as a multiple stage basis, as will be apparent later.

To permit more complete analysis for ethylene glycol, Table 2 is constructed. It presents total requirements of the more important materials and utilities and some of their associated costs in the manufacture of ethylene glycol from the raw material ethane.[40] In effect, the 3.82 cents worth of ethylene per pound of ethylene glycol recorded in Table 1 is decomposed, and the costs of selected materials and utilities required to produce 3.82 cents worth of ethylene are added to the corresponding cost figures for these materials and utilities in Table 1.

A few remarks about the construction of Table 2 ought first to be made. It is clear from Table 1 and from information on the production of ethylene from ethane that the cost of condensate makeup is negligible; thus, condensate can be ignored as a location factor. Also, both the chemicals and catalyst required can be disregarded as location determinants. Though in Table 1 cents requirements of these items per pound ethylene glycol add to 0.30, a figure which is comparable to that of labor, the actual weight of chemical and catalyst involved is insignificant. This is still more so in the production of ethylene from ethane.[41] Per pound of ethylene glycol (from ethylene) only 0.019 lbs. of chemicals and catalyst are required. Hence, even though the price of chemicals and catalyst may vary significantly from region to region (in the long run the maximum variation is limited by the interregional transport cost on these items), when we multiply any regional difference in price per pound of these items by 0.019, we necessarily obtain an insignificant figure. The cost differentials, among regions, for these items are negligible, in the particular instance where ethylene glycol is produced via the oxidation method. As a consequence, data on the requirements of condensate and chemicals and catalysts are excluded from Table 2.[42] However, it should be noted that in certain processes chemical requirements bulk large, as, for example, in the production of ethylene glycol via the chlorhydrin process. When such is the case in processes cited below, chemical requirements will be listed and their impact upon the location pattern evaluated. Also, in Table 2, the amounts of the various types of steam requirements have been combined into one net figure in order to simplify the analysis;[43] and data on the hourly inputs of ethane, labor and output of ethylene glycol have been added.

With the data of Table 2 as background, we are in a better position to analyze the pull of labor as a location factor. Per pound of ethylene glycol, 0.537 cents of labor is required, a cost which is greater than any of the utilities listed.[44] This figure represents almost 8 percent

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[38] For example, see W. Isard and J.A. Cumberland, "New England as a Possible Location for an Integrated Iron and Steel Works," *Economic Geography*, Vol. 26, October 1950, pp. 252-53.

[39] According to Williams, *op.cit.*, p. 281, Dow Chemical Corporation has experienced very satisfactory results in major maintenance work in its Northern plants during periods of favorable weather.

[40] Plant costs to produce ethylene from ethane should also be added to the plant cost figures of Table 1. However, since plant costs have been excluded as a consideration in the location analysis to follow, we omit in Table 2 any data pertaining to them.

[41] According to one report, less than 0.001 pounds of chemicals were required per 3.82¢ worth of ethylene.

[42] Strictly speaking, as we shall see later, labor and electric power should also be excluded for the same reasons. However, since the total requirements of these two items are easily computed, and since these two items are generally considered significant from a locational standpoint, data on them have been retained in Table 2.

[43] See footnote 52 for justification of this procedure.

[44] This requirement pertains only to a combined operation where the ethylene plant has an annual capacity of 66 million lbs.; and the ethylene glycol plant, an annual capacity of 53.2 million lbs. As will be discussed later the labor requirement varies with the scale of plant; and as a consequence, labor cost differentials vary with scale, too.

Table 2.—PRODUCTION OF ETHYLENE GLYCOL FROM ETHANE[1]
(VIA OXIDATION PROCESS)

Selected inputs:		
Ethane	7,240.9	lbs/hr.
Utilities:		
Steam	83,672	lbs/hr.
Cooling water	672,931	G/hr.
Electric power	670.5	kw/hr.
Fuel gas	25,260,679	BTU/hr.
Labor	13.1	men/hr.
Output:		
Ethylene glycol	6,704.5	lbs/hr.
Selected costs (Gulf Coast location):		
Steam	.474	¢/lb.
Cooling water	.151	¢/lb.
Electric power	.062	¢/lb.
Fuel gas	.057	¢/lb.
Labor	.537	¢/lb.

[1] Assuming an ethylene unit of 66 MM lb/yr capacity and an ethylene glycol unit of 53.2 MM lb/yr capacity.

of the cost figure for ethylene glycol of 6.74¢ per pound, listed in Table 1. In location analysis, however, the absolute cost of labor, and labor cost as a percent of total cost are not the significant measures of the pull of labor. The important consideration is the variation in labor costs from region to region as contrasted with differentials in other costs. We require information on such variation.

A recent Bureau of Labor Statistics study of wage rates for various occupations in industrial chemical plants, for October-November, 1951, casts light on this variation.[45] An occupational classification which exhibits a typical interregional variation is chemical operators, Class A. Average straight-time hourly earnings of such workers were, for two size classifications of plants:

	Establishments with—	
	21-500 workers	501 or more workers
United States	$1.81	$2.05
New England	1.56	1.74
Border States	1.69	2.13
Middle Atlantic	1.80	2.15
Great Lakes	1.83	1.82
Pacific	1.89	1.99
Southwest	2.06	2.24

The New England rate of payment deviates most (by approximately 25 percent) from that prevalent in the Southwest, the region of highest earnings.[46] Among regions, the variation ranges from approximately fifteen percent below and above the average for the United States. If the New England wage rates were applied to the data of Table 2 (which relate to the Gulf Coast), labor costs would fall by approximately 25 percent, or by 0.133¢ per pound ethylene glycol. Hence, under current conditions the maximum labor cost differential among regions for this particular product via the oxidation process is roughly 0.133¢ per pound.[47]

Future Labor Costs: It is pertinent at this point to consider the future situation with regard to labor cost differentials. There are strong indications that the current situation is inapplicable to the future.

First, the data of the above table may be misleading. To some extent at least the Bureau of Labor Statistics data relate to chemical industrial structures which are different from region to region. They presumably include more of the higher paying industries in the Southwest than, for example, in New England. This tends to overstate labor cost differentials.

Second, the degree of unionization within the chemical industry is subject to change. Likewise are regional differences in wage rates. It seems best to assume that in the future there will be an increase in the degree of unionization within the chemical industry and a decrease in any regional labor cost differential that may exist.

Finally, even if there were a firm basis for anticipating the existence of labor cost differentials among regions in the chemical industries, it is not clear whether such labor cost differentials would favor or disfavor the AWR region. On the one hand, the AWR region is a source of cheap labor migrating occupationallywise from a declining agricultural setting. This would suggest a lower labor cost in the chemical industries within the AWR. On the other hand, the AWR region is geographically linked to the Gulf Coast area, where the highest wage rates tend to prevail. This suggests high wages in chemical industries within the AWR region, both because of proximity and because of a possible tendency to establish blanket rates in order to facilitate the administrative process in unions and in government.

Thus, it is rather speculative to suggest any labor cost differential favoring or disfavoring the AWR region. In fact, if the labor cost differential were to prove a major factor in petrochemical location, this indeterminacy with respect to labor cost would tend to detract from the firmness of any locational analysis for the petrochemical industry. However, as will be apparent later, labor cost differentials are relatively minor and of significance in marginal situations only.

The above statements suggest that when we consider the AWR region a calculation of labor cost differentials tends to become meaningless. We nonetheless make this calculation because it is possible in certain other regions to identify the direction of a labor cost differential if such were to exist. (E.g., if wage rates in the Gulf Coast area were to differ from wage rates in other regions they would tend to be higher.) Hence information concerning labor cost differentials is useful for considering location of petrochemicals within such regions. Secondly, we retain the labor cost differential because labor is generally regarded as an important location factor; and it is of interest, especially to location analysts, to have such information available.

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[45] U.S. Bureau of Labor Statistics, *Wage Structure: Industrial Chemicals, October-November 1951*, Series 2, No. 87, Washington, D.C.

[46] *Ibid.*, p. 11.

[47] This of course assumes that the data of the Bureau of Labor Statistics are representative and can be employed as bench marks in this situation.

Cooling Water Costs: We return to the data of Table 2 to consider other cost differentials. In general, it is our opinion that cooling water is likely to be available at similar cost per unit at "non-water-shortage" sites in all regions, although within any given region the variation may be very great from site to site because of local shortages, and although in the long run it appears that, on the average, water costs will be higher in the Southwest and the California regions.[48] In any case, the percentage variation among regions in water cost would need to be much larger than in the case of labor cost to exert an equal location pull in terms of ethylene glycol. We do not anticipate such a large, or even smaller, percentage variation among the more favorable industrial water sites (which large water-consumers will seek) of the several regions. For this study we do not judge water to be a selective factor in location among regions. We do judge it to be very selective in terms of possible industrial sites within any given region.

This is not to gloss over the fact that of the AWR sub-regions the extensive Panhandle-Hugoton area possesses the greatest reserves of natural gas and at the same time is a general area of water shortage. It thus becomes imperative to consider the restrictive influence of water upon any major petrochemical development in this sub-region. However, at this point of our analysis we do not know whether or not the Panhandle-Hugoton area should logically attract petrochemical activity on the basis of other considerations. If in the ensuing analysis it is established that aside from its shortage of water the Panhandle-Hugoton area would be a favorable location for substantial petrochemical expansion, then such a conclusion must be explicitly qualified to recognize the water shortage problem.

Power Costs: In the production of ethylene glycol as well as other petrochemicals, power is a general requirement. Since power rates currently vary from region to region and may be expected to continue to vary regionally in the future, the power cost differential must be investigated.[49] Since the AWR region has cheap fuel sources, it possesses a power cost advantage over at least some regions of the United States. The extent of its advantage depends on two factors, viz., the amounts of power consumed per unit product and the differential among rates (kwh costs) in different regions.

Scrutiny of data available on fuel costs in various regions and on rates charged indicates that a six mill spread between regions is a reasonable maximum for calculation of differential power costs among regions. It is true that when we consider extreme conditions such as exist on the one hand at very cheap hydro-power sites and on the other hand at local areas remote from fuel and energy sources, the spread may be two or even three times greater.[50] However, it is fairly clear that petrochemical plants will not be eligible for extremely low rate power since they will be outbid by intensive power consuming industries such as the electro-process industries. Nether will they locate in remote isolated areas. It is also significant to note that even the high fuel cost areas such as New England and Minnesota do have power rates within six mills of those at the generally cheap power areas in the United States, excluding government hydro-power developments.[51]

It can be calculated from the data in Table 2 that power requirements for the production of ethylene glycol are 0.1 kwh per pound. This figure multiplied by six mills represents the maximum power cost differential an AWR location might have over a high fuel cost region such as New England. To the extent that natural gas prices in the Southwest rise, as they are expected to do, this differential ought to be narrowed. And in fact, with reference to some areas, the AWR might be subject to a disadvantage. We shall proceed, however, on the assumption that the AWR has a maximum power cost advantage of 0.06¢ per pound.

Fuel, Steam and Feedstock Costs: Cost differentials for fuel and steam can be estimated in several ways. Careful consideration could be given to steam which is generated for power production and exhausted to process operations, to the specific temperatures and pressures at which steam is required, to the extent to which high pressure process steam can be reused in low pressure operations, and to the temperature of the condensate which is recycled to the boilers.[52] Also, in regard to fuel, one could pay close attention to such considerations as the different BTU contents of various fuels as compared to their prices, the relative thermal efficiencies at which different fuels can be used in boilers and furnaces, and the demand characteristics for natural gas as they affect pipeline load factors and hence fuel price.

These considerations may be strategic in a cost and profitability computation for an individual

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[48] Of course, regions can be defined in terms of the water shortage problem. In such a case our statement would not be valid. In this study, however, we are thinking of "general purpose" regions, much along the lines of the Bureau of the Census and the Area Development Division, Department of Commerce.

[49] We are assuming that power is purchased or generated by non-natural gas power systems. To the extent that power is plant generated from natural gas, the analysis which follows with respect to fuel gas and steam cost differentials, where such differentials are translated into BTU cost differentials, would be more appropriate than one based solely on a regional comparison of power rates.

[50] For example, as of January 1, 1951, for billing demands of 1,000 kilowatts and monthly consumption of 400,000 kilowatt hours the average rate per kilowatt hour was 4.5 mills in Tacoma, Washington (publicly owned utility), while the average rate in Aberdeen, South Dakota was 22.2 mills. Federal Power Commission, *Typical Electric Bills, Cities of 50,000 Population and More*, Washington, D.C., 1951, pp. 38 and 40.

[51] For supporting materials the reader is referred to: Sam H. Schurr and Jacob Marschak, *Economic Aspects of Atomic Power*, Princeton, N.J., 1950, map 1, p. 46; National Resources Planning Board, *Industrial Location and National Resources*, Washington, 1943, Figure 74, p. 175, and Table 13, p. 176; and Walter Isard and Vincent Whitney, *Atomic Power, An Economic and Social Analysis*, New York, 1952, pp. 37-43.

[52] Actually, most of these factors are resolved into a comparison of the cost of steam at different pressures.

Since we have already concluded that there will be no long run basis for expecting systematic regional differences in plant and equipment cost, we can further conclude that the regional difference in steam cost will result primarily from regional difference in fuel cost. For that reason we consider at this point the effect on fuel requirements of differences in pressure of required steam. The *Mechanical Engineers' Handbook* gives the total heat content of one pound of 50 psig saturated steam as approximately 1,179 BTU. As steam pressure increases, the total heat content per pound rises to an approximate maximum of 1,204 BTU per pound at a pressure of 400 psig. Further increases in pressure result in a *decrease* in total BTU content per pound. Therefore the maximum differential in fuel requirements for steam (assuming a minimum pressure of 50 psig) occurs between pressures of 50 psig and 400 psig.

If we assume boiler feedwater at a temperature of 70°F (containing 38 BTU of heat per pound) and a boiler efficiency of 80%, the amount of heat required to generate one pound of 50 psig satu-

(Continued)

plant at a specific site and moment of time. However, given the uncertainties of the future and the dynamic technology of petrochemicals, such precise calculations seem unwarranted. For the objective of this study, viz., to cast light on the future optimum location pattern for petrochemicals, a very simplified approximative procedure suffices. We assume that all fuel is natural gas, and, further, that the heat required to generate process steam is obtained from burning natural gas. Hence, cost differentials among regions for fuel gas and steam reduce to the differentials among regions in transport cost for the equivalent natural gas. These will be discussed in the next section.

We realize that the current spread between the price of natural gas at a distant site (such as an East Coast location) and at the source (such as a Gulf Coast location) frequently exceeds transmission costs. At the distant site demand outruns supply and permits a monopoly profit in the short run. However, in the long run, when the forces of demand and supply have adjusted themselves, particularly when additional transmission facilities have been constructed, the spread between natural gas prices should equal transmission costs. At least historical experience with petroleum and its products indicates that this is the best basis upon which to proceed.

It should also be kept in mind that if the delivered price of natural gas to a region proves to be higher in terms of BTU cost than a competitive fuel, our procedure overstates fuel gas and steam cost differentials. In such a situation the difference among regions on outlays on the cheapest possible form of fuel for each region should be explicitly calculated.

Like those in fuel gas and steam costs, regional differences in the price of ethane (stripped from natural gas) and natural gas as feedstocks for petrochemicals are in the long run essentially transport cost differentials. Hence, they too will be discussed in the following section.

7. Basic Transport Cost Differentials Among Regions (With Particular Reference to Ethylene Glycol, Oxidation Process)

Hitherto our discussion of empirical material has centered around minor regional cost differentials. We now investigate a major cost differential among regions, viz., that associated with the transport cost of fuel for heat and steam generation, and ethane and natural gas for feedstock use. As already indicated, regional differentials in prices of each of these items will in the long run tend to equal transport cost.

Since it has already been assumed that all fuel is natural gas, and since it seems most reasonable to postulate that ethane and other natural gas feedstock will in general tend to bear the same transport expense as natural gas,[53] we can analyze at one stroke the combined cost differentials of fuel gas, steam, ethane and other natural gas feedstock per pound ethylene glycol.[54] We can accomplish this by considering the total volume of gases which are involved, the data for which are presented in Table 3.[55] Knowing the transport rate per unit volume of natural gas, we can derive transport cost differentials for various regions once we are given relevant points of origin and destination.

Representative Markets and Natural Gas Sites: For this report it is sufficient to consider two locations in the AWR region: one in the eastern sector centering around Monroe, La.; and one in the western sector centering around Amarillo, Tex. Both of these locations lie within natural gas fields, where the prices of fuel gas, steam, and ethane are likely to be lowest.

In the consideration of locations other than those in the AWR region one of the key questions is the delimitation of market areas to be served by these other locations. As will be discussed later, petrochemicals production is subject to significant economies of scale. Thus it is of critical importance to select locations which lie within, or are strategically located with respect to market areas adequate to absorb the output of an efficient size plant. One such market area is the urban-industrial complex extending from Baltimore, Md., to New Haven, Conn. This area could conceivably be extended northward to include most of New England and southward to include Washington, D. C. In any case, a site near New York City would be central and would seem to be the most favorable one within the general area described. We shall henceforth speak of the potential *market* location for petrochemicals production serving

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rated steam is 1,426 BTU; and the heat required to generate one pound of 400 psig saturated steam is 1,458 BTU. If the cost of fuel is 15¢/MM BTU the difference in the cost of the 12.48 pounds of steam required to produce one pound of ethylene glycol if all steam is at 50 psig pressure and if all steam is at 400 psig pressure amounts to 0.006 cents. This is approximately 1.3 percent of the steam cost per pound of ethylene glycol listed in Table 2. Even if fuel cost is assumed to be 40¢/MM BTU the difference in steam cost per pound of ethylene glycol is only 0.016 cents. Furthermore these figures overstate the actual error in steam cost calculation since the production of ethylene glycol requires a combination of different steam pressures.

Consequently, little error is introduced when all steam requirements are combined into one net figure and the corresponding fuel requirements estimated at the same BTU rate per pound of steam. We use the figure of 1,500 BTU as the heat required to generate one pound of steam. This provides some allowance for boiler efficiencies of less than 80% and/or the necessity for some superheating of the steam.

For properties of steam, see Lionel S. Marks, ed., *Mechanical Engineers' Handbook*, New York, 1951, pp. 307-313. For discussion of boiler efficiencies, see John H. Perry, ed., *Chemical Engineers' Handbook*, New York, 1950, pp. 638-639.

[53] Roughly 85% or more of a natural gas stream is methane, and 4% or less is ethane. Since the ethane component constitutes such a small fraction of a normal natural gas stream it would be an unwarranted refinement, in view of the approximate nature of the above data on material balances and utilities, to attempt to assign a higher transport rate to ethane in order to reflect its heavier weight. As far as we know, a normal natural gas stream containing ethane does not encounter technical obstacles which lead to higher transmission costs than in the case of a natural gas stream from which ethane has been stripped.

However, since ethane has a substantially greater BTU value than methane, the reader may wish to assign to ethane a more than proportionate share of the transport cost of an entire natural gas stream on the basis of charging what the traffic can bear. This would necessitate in general only minor revisions of the subsequent analysis.

[54] The combined figures for these items in Table 2 exclude amounts required for the stripping of ethane from natural gas. Such a procedure is justified when ethane is considered a by-product. However, if ethane is stripped as a joint product it would have to bear its share of the costs of fuel and steam required for the stripping operation.

[55] In converting the weight data of Table 2 into the volume data of Table 3 we assumed: 1 lb. of 95% ethane as equivalent to 12.7 cu.ft. of ethane; 1 lb. of steam as equivalent to 1,500 BTU and 1,000 BTU as equivalent to 1 cu.ft. of fuel gas.

this area as a "New York City location." For similar reasons the location of production serving the industrial area centering at Chicago can be conceived as a "Chicago location."

When we consider regions in which industrial and urban development is less intense, such as West Virginia, Ohio, and Western Pennsylvania, our general market areas are significantly larger. Nonetheless, for calculation of transport rates (costs) we must consider specific locations. For the general area of western Pennsylvania, Ohio, Kentucky, West Virginia, western New York State, and parts of Indiana and Virginia, Cincinnati appears to be favorably located as a distribution point. Furthermore, Cincinnati becomes a strategic gateway point if the area must be expanded to include more of the Middle Atlantic census region, western New England, and even Michigan in order to yield a large enough market demand to justify a petrochemical operation of adequate scale.

Table 3.—VOLUME OF RAW MATERIAL AND FUEL GASES PER POUND ETHYLENE GLYCOL (OXIDATION PROCESS)

	Cu. ft.
Ethane......................	13.72
Fuel gas—	
For generating steam......	18.72
For process heat..........	3.77
Total volume...........	36.21

St. Louis is a fourth location which is meaningful both as a gateway point and as a focal point for distribution within a region. A number of other cities could have been chosen, such as Pittsburgh, Buffalo, Kansas City, Los Angeles, San Francisco, and Atlanta; but since the techniques and procedures would not change if more cities were considered, analysis for the above four suffices.

In order to allow for the possibility of competition from locations at other natural gas sources outside the AWR region, we consider the economic feasibility of a Houston operation. A Houston operation may be taken as generally representative of operations along the Texas and Louisiana Gulf Coast.

Initially, we can simplify the ensuing analysis by identifying the situations in which a Houston operation would and would not be competitive. For serving the Eastern seaboard with large-tonnage petrochemicals a Houston location has a significant advantage over an AWR location. Houston can reach the Eastern seaboard by ship. In contrast, AWR would have to resort to the more costly haul by rail, or by rail and ship (Amarillo to a Gulf Coast port to the Eastern seaboard), or by barge and rail (Monroe to Pittsburgh to the Eastern seaboard). Coupled with this are the facts that the estimated natural gas reserves in the Texas Railroad Commission District #3 centering around Houston are nearly one quarter of such reserves in Texas and more than one eighth of those in the United States, and that the reserves in the Gulf Coast section of Louisiana account for at least another one sixteenth.[56] These data strongly suggest that Gulf Coast natural gas-based petrochemical production can be of sufficient magnitude to handle the entire Eastern seaboard demand. Hence in the ensuing transport cost analysis we need not consider the AWR as a location for the production of large-tonnage petrochemicals destined for the Eastern seaboard market.[57]

For supplying the markets of Chicago, St. Louis, and Cincinnati and other market and gateway points such as Pittsburgh and Kansas City, AWR locations are better situated geographically than Gulf Coast locations. Both by rail and barge, these interior markets can in general be reached more easily from AWR locations than from Gulf Coast locations. In addition the raw material costs in an AWR location, if they are different from those at the Gulf Coast, will tend to be lower. Consequently, for serving these interior markets it is not necessary to consider Gulf Coast locations.[58]

At this point it is pertinent to consider the question of adequacy of reserves. In most areas of the AWR and Gulf Coast, reserves seem to be adequate for the envisaged petrochemical expansion. However, in the Monroe field, which is the AWR field most accessible to the Mississippi River, reserves of natural gas seem to be undergoing depletion and production dwindling. This implies declining supplies of petrochemical feedstocks from this field.

Counterbalancing this consideration is the fact that only a limited petrochemical expansion is anticipated in the AWR region. Further, large reserves exist in the Carthage field, a field which is constantly being extended and which is connected by feeder pipelines to the major trunklines intersecting the Monroe field. These trunklines also bring supplies from the Texas Gulf Coast. It therefore seems that supplies of ethane and other petrochemical feedstocks will be adequate for significant petrochemical expansion near Monroe. In fact the quantities of such feedstocks should be sufficient to support the major portion of petrochemical expansion expected for the entire AWR region.

The following analysis is thus framed to consider three types of location:

1. Market or gateway point location—in which case we assume that natural gas will be piped from the AWR fields;

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[56] Federal Power Commission, *Natural Gas Investigation Docket No. G-580* (Smith-Wimberly report), Washington, D. C., 1949; F. A. Buechel, *A Summary of Basic Factors Underlying the Economy of Texas and the Texas Gulf Coast Area*, Houston, 1952; Ralph E. Davis, "Method of Estimating Gas Reserves," *The Oil and Gas Journal*, Vol. 50, September 27, 1951; American Gas Association, *Gas Facts, 1952 Data*, New York, 1953; United States Bureau of Mines, *Minerals Yearbook*, Washington, D. C., annual.

[57] Because of economies of scale it may be necessary to serve from one plant the combined markets of the Eastern seaboard and the East North Central region, and perhaps even the East South Central and other regions of the United States. In such a situation, an AWR location may prove to be more favorable than a Houston location. In this case the AWR location would be serving Eastern seaboard markets. On the other hand it may develop that a location at Houston, or even more likely, one in southern Louisiana, would have better access to the combined markets of these regions via rail as well as water.

[58] Except in the case where the entire nation, coastal markets as well as interior markets, must be served from one location because of economies of scale.

2. AWR location with reference to interior markets—in which case finished products are shipped by rail or by barge and rail; and
3. Gulf Coast location (Houston) with reference to Eastern seaboard markets—in which case finished products are shipped by water.[59]

Natural Gas Transmission Costs: The next step is to determine transport cost differentials. To do so we must establish natural gas transmission rates (costs) between Amarillo and Monroe on the one hand and each of the four selected cities on the other. This requires consideration of future changes in the technology of gas transmission.

One gains the impression from conversations with transmission company officials that at least the very rapid period of development in transmission technology has already taken place; that although many refinements and improvements remain to be realized, the likelihood of further fundamental changes or major innovations in the forseeable future is small. We judge that 34 inch pipeline systems can be expected in the future with some degree of certainty. Therefore, the lowest transmission cost to be considered is based on such a system operating under conditions of the most favorable expected load factor, i.e., 90% to 95%.

Figures 4 and 5, which are based on data gathered from various sources, aid in the estimation of transmission costs corresponding to different combinations of pipeline diameter and load factor. Figure 4 illustrates how the cost of transporting one thousand cubic feet of gas one hundred miles varies with the size of pipeline when optimum conditions of 100% load factor are assumed. Figure 5 depicts for a system of 26-30 inch pipeline how the cost of transmitting one thousand cubic feet of natural gas one hundred miles varies with the load factor of the system. Together these two figures suggest that a minimum of 1.3 cents per thousand cubic feet per hundred miles is to be expected from a 34 inch pipeline system operating at a 90%-95% load factor.[60] This estimated cost provides a lower limit for a range of natural gas transmission costs that might characterize the future.

Considering the forces of competition prevalent among natural gas transmission companies, we judge that the future maximum cost to pipe one thousand cubic feet of gas one hundred miles will not exceed that cost which would be associated with a 26-30 inch pipeline system operating at a 60-65% load factor.[61] Figure 5 suggests that 1.7 cents is a

FIGURE 4

Estimated Cost of Transporting Natural Gas, by Size Pipeline

(100% Load Factor)

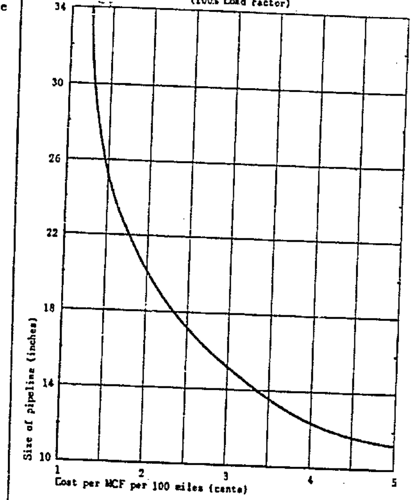
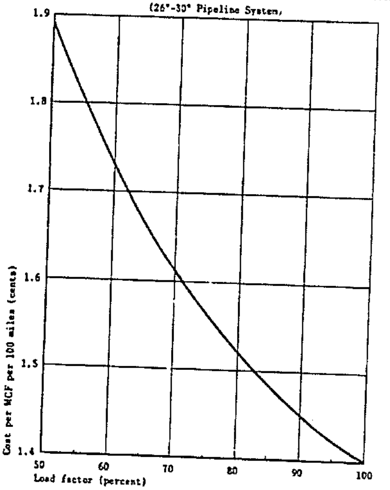


FIGURE 5

Estimated Cost of Transporting Natural Gas, by Percent Load Factor

(26"-30" Pipeline System)



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[59] As already indicated, in a study which embraced every type of petrochemical, both major and minor tonnagewise, a fourth type of location should be considered, viz., an AWR or Gulf Coast location which serves the entire nation and *must* serve the entire nation if demand is to be adequate to absorb the output of an economic size plant. Since we deal only with large tonnage petrochemicals in the production of which at least several economic size plants are required by the nation, this type of location does not arise; nor does its counterpart, viz., a market location which is centrally located with respect to all the markets of the United States and from which all the markets of the United States must be served.

[60] These estimated costs as well as others to follow refer to transmission over distances greater than 500 miles. Costs tend to increase linearly with distance beyond this minimum. See, for example, Federal Power Commission, *op.cit.*, pp. 258-267. Also, see the monograph prepared by E. Holley Poe and Associates, New York, in connection with the data presented in the Federal Power Commission reference just cited.

[61] Federal Power Commission, *ibid.*; E. Holley Poe and Associates, *op.cit.*, John R. Stockton, Richard C. Henshaw, Richard W. Graves, *Economics of Natural Gas in Texas*, Austin, 1952, Chapter 6.

Table 4.—ETHYLENE GLYCOL (OXIDATION PROCESS): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	$1.84	$0.72	$0.95	....	....	$1.12	$0.89
				Monroe source					
	2. Monroe...	Rail...	1.51	0.53	0.69	....	....	0.93	0.82
				Monroe source					
	3. Houston..	Rail...	1.73	0.53	0.69	....	....	1.20	1.04
		Ship...	0.39			0.14	0.30	....	....
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.13	0.46	0.60	....	....	0.67	0.53
				Monroe source					
	2. Monroe...	Rail...	0.89	0.29	0.38	....	....	0.60	0.51
		Barge..	0.16			0.13	0.22	....	....
				Amarillo source					
Chicago......	1. Amarillo	Rail...	1.08	0.42	0.54	....	....	0.66	0.54
				Monroe source					
	2. Monroe...	Rail...	0.94	0.52	0.42	....	....	0.62	0.52
		Barge..	0.16			0.16	0.26	....	....
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	0.83	0.32	0.42	....	....	....	....
				Monroe source					
	2. Monroe...	Rail...	0.62	0.20	0.26	....	....	0.42	0.36
		Barge..	0.11			0.09	0.16	....	....

figure which is likely to characterize this maximum rate (cost). Of course, if widespread operation of 26-30 inch pipeline systems at a higher load factor, or of 34 inch systems at less than 90% but more than 60% load factor prevails, the cost of transmission will likely be *between* 1.3 and 1.7 cents.

Multiplying 1.3 and 1.7 by the distances (in hundred mile units) between Amarillo and Monroe and the four key cities isolated above,[62] and by the volume of gases required in ethylene glycol production (from ethane) as given in Table 3 yields respectively minimum and maximum transport costs differentials on feedstock, fuel gas, and steam between Monroe and Amarillo on the one hand and each of the four key cities on the other. These minimum and maximum differentials are recorded in columns 4 and 5 of Table 4.[63]

Transport Cost on Finished Product: To appraise effectively the significance of the transport factor in location analysis it is also necessary to consider transport costs on the finished product for any given market. If location of a petrochemical plant is at a market point which can absorb the full output of the plant, transport costs on the finished product are avoided. However, when location is at a point other than the market, transport cost on the finished product is incurred and must be considered along with transport costs on the raw materials, fuel and other items.

Hence in Table 4, column 3, are presented the transport costs on finished product to each of our four market points by rail, ship, and barge, whenever each is relevant, from each of the three natural gas sites.[64] As already mentioned, when large tonnage shipments are involved the Houston site is the only one relevant for serving the New York market. This becomes immediately apparent from

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[62] Distances are taken to be straight-line distances.

Not all of the strategic cities mentioned are connected by pipeline to each of our two AWR points. However, each is connected to one of the AWR fields and may be connected to the other in the future.

[63] In Table 4, the unnumbered column at the extreme left lists the four market cities: New York, Cincinnati, Chicago, and St. Louis. Columns 4 and 5 present respectively, the minimum and maximum regional cost differentials resulting from the transport of fuel and feedstock gas. (These differentials are equivalent to the cost of transporting by pipeline from the natural gas source to the market site the total volume of fuel and feedstock gas required to produce 100 pounds of ethylene glycol.) The minimum differential (column 4) is associated with transmission via 34 inch pipeline, 90% to 95% load factor. The maximum differential (column 5) relates to transmission via 26-inch to 30-inch pipeline, 60% to 65% load factor. The source supplying each market point with fuel and feedstock gas is identified by the words "Amarillo Source" or "Monroe Source," which appear in columns 4 and 5 of each relevant market row.

For example, in the production of 100 pounds of ethylene glycol, $0.72 is the figure which appears in the first row of column 4. It indicates that under conditions of 34-inch pipeline, 90%-95% load factor, 72 cents is the cost of transporting by pipeline from Amarillo to New York the total volume of fuel and feedstock gas required to produce 100 pounds of ethylene glycol. It represents the minimum amount by which the cost at a New York location would exceed the cost at an Amarillo location solely on account of the need to transport fuel and feedstock gas from Amarillo to New York for a New York operation.

[64] In Table 4, column 1 lists the different natural gas site locations from which each of the selected market areas could be supplied with finished ethylene glycol. Column 2 identifies the relevant transport media for the shipment of ethylene glycol supplies. Column 3 records the estimated transport costs. For example, 100 pounds of ethylene glycol could be transported to New York from Amarillo by rail for $1.84; from Monroe by rail for $1.51; and from Houston by rail for $1.73 or by ship for $0.39

Table 4, column 3, when we consider the spread between the recorded ship costs and rail costs, and when we bear in mind that Houston can reach New York at considerably lower rates by water than can either Amarillo or Monroe by water or by combined water and rail shipment. Nonetheless, we include in Table 4 rail rates from Amarillo and Monroe to New York in order to present in full the transportation setting of the AWR region. For interior markets we do not consider Houston for reasons already mentioned; we consider only Amarillo and Monroe as locations at natural gas sites.

Table 4 does not include any transport costs associated with distribution of product from a gateway point such as Cincinnati and St. Louis. Whether location is at Cincinnati, or whether location is at a natural gas site and product moved in bulk to Cincinnati for distribution,[65] approximately the same transport costs will be involved in the distribution of the product to the many small markets for which Cincinnati may be a gateway point. Since small, if any, cost differentials arise in this phase of the transport problem, the transport costs associated therewith can be ignored.[66]

Remarks on Transport Cost Computations: A few words ought to be said about the computation of transport costs on finished product by rail, barge, and ship. In deriving rail costs we employed the regular classifications with their exception and commodity rates. Also we estimated by comparison with existing commodity rates those commodity rates which might be put into effect between points were large tonnage shipments to develop.[67] For example, a commodity rate on ethylene glycol between Houston and New York is effective. We therefore judge that commodity rates between Amarillo and New York, and Monroe and New York would be established if large tonnages were to be shipped between these points.[68]

In the calculation of cost of shipment by barge it was necessary to establish some representative tariffs that might characterize the transport of liquid chemicals. It is obvious that different rates will apply to those liquid chemicals requiring pressure tanks than to those requiring ordinary tanks. Furthermore, of those requiring ordinary tanks, a distinction between corrosive and non-corrosive chemicals must be maintained. Materials on barge rates are sparse. Standard rates are not published as far as we can gather. However, it was possible to determine from available materials[69] the following rates, which seem to be fairly representative of what might be expected in *efficient* barge operation over *long distances:*

3 mills per ton-mile for non-corrosive chemicals using nonpressure tanks;
3.5 mills per ton-mile for liquid chemicals which are corrosive, but which do not require pressure tanks; and
8 mills per ton-mile for chemicals requiring pressure tanks.[70]

Given these barge rates and respective inland waterway distances between points,[71] the relevant barge costs were calculated and recorded in column 3, Table 4.

In calculating the tanker rates to apply for shipment between the Gulf Coast and the Eastern seaboard we have assumed that an ordinary liquid chemical tanker of 5,000 ton capacity would cost approximately $3.6 million, and that under efficient conditions it could be operated profitably at a rate of 4.5 mills per ton-mile on long intercoastal shipments of non-pressure, non-corrosive chemicals. When standard cost estimates and procedures[72] are applied to the operation of tankers of capacities of 10,000-12,000 tons we estimate that ton-mile costs would fall by one mill to 3.5 mills. When the chemical products are corrosive or for any other reason require specially lined tanks, it is appropriate to add 0.5 mills to the above two rates. This raises them to 5 mills and 4 mills respectively.

Obviously, the capital cost of pressure tankers is higher than that of non-pressure tankers; but we judge that capital cost does not rise as rapidly with increasing size as in the case of barges. On the basis of the information available on pressure tankers, we estimate that the ton-mile cost for pressure tanker shipment of ordinary chemicals will be 2 mills greater than for non-pressure tanker shipment; or 6.5 mills in the case of a 5,000 ton tanker, and 5.5 mills in the case of a 10,000-12,000 ton tanker.[73]

Finally, in calculating transportation rates we have not included terminal or handling charges, or rental charges on transportation equipment. Such charges are very closely linked with storage services. Though we can visualize differences in storage, handling, rental, and terminal charges associated with raw material as against market locations and associated with different transport media, the magnitude of these differences is not clear. This is especially so when these charges are put on a full cost basis, i.e. when all terminal, storage, handling, and rental costs

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[65] It should be noted that in general, with modern transport rate structures, an intermediate location is not feasible unless special circumstances obtain. See E. M. Hoover, *Location Theory and the Shoe and Leather Industries*, Cambridge, Mass., 1937.

[66] Conceivably, if a petrochemical plant were located in the AWR region, shortcut shipments might be made to markets within the hinterland of Cincinnati. We do not judge that the resulting savings would be of such a magnitude as to require explicit consideration.

[67] We are deeply indebted to Mr. Frank L. Barton, Director, Traffic Management Division, General Services Administration, and his staff for supplying us with extensive information on rates.

[68] Our estimated commodity rates for any pair of points bear the same ratio to existing commodity rates between another pair of points as do the rates derived from application of the uniform classification.

[69] E.g., National Resources Planning Board, *Transportation and National Policy*, Washington, D. C., 1942, pp. 438-439; unpublished quotations of barge transportation companies; and conversations with transportation experts.

[70] The steep increase in ton-mile rates on pressure-tank barges as compared to non-pressure-tank barges results from the much greater capital cost of the former. Obviously, for short distances these barge rates must be scaled upwards.

[71] United States Department of Commerce, Coast and Geodetic Survey, *Distances Between United States Ports*, Washington, D. C., 1929. United States Hydrographic Office, *Tables of Distances Between Ports*, Washington, D. C., 1927.

[72] Described in an unpublished manuscript by Kenneth S.M. Davidson, Director, Stevens Institute of Technology, Hoboken, N.J.; see also H.F. Robinson, J.F. Roeske, and A.S. Thaeler, "Modern Tankers," *Marine Engineering and Shipping Review*, Vol. 53, November 1948, pp. 36-49.

[73] Based upon T.E. Swigart, "Postwar Uses of War Emergency Pipe Lines for Petroleum Transportation," *Petroleum Technology*, September 1944, pp. 17-22; United States Department of Commerce Industry Report, *Domestic Transportation*, Washington, D. C., 1949, pp. 57-59; the Davidson manuscript cited in footnote 72 above, and unpublished confidential materials.

are comprehensively and properly allocated and are not set by arbitrary rule of thumb methods.[74]

Net Transport Cost Differentials: We are now in a position to evaluate the data of Table 4. To reiterate, column 3 presents the transport cost on 100 pounds of finished product from several natural gas sites via different transport media to our several markets. Columns 4 and 5 record best estimates of respectively minimum and maximum pipeline transmission costs on fuel and feedstock gas per 100 pounds of product from the several fields to each market. Hence, the differences between columns 4 and 3 and columns 5 and 3 yield the figures of columns 6 and 8, and 7 and 9, respectively. These last four columns indicate the net transport cost differential of a natural gas site or of a market site under each of the situations we have posed.[75]

We have already indicated that for large-tonnage petrochemicals Houston has a clearcut advantage over Amarillo and Monroe in reaching the Eastern seaboard. Table 4 indicates that when we consider large tonnage ship movement of ethylene glycol from the Gulf Coast area, the Houston location has a transport cost advantage over a New York location. Ship rates are so low that it becomes feasible to locate at a Gulf Coast natural gas site and ship the finished product to the market, an efficient 34 inch pipeline system with high load factor notwithstanding. However, when we consider shipment by rail only, it becomes definitely advantageous, from a transport cost standpoint alone, to locate at the market site, viz., New York City.

Consideration of the markets represented by each interior point, Cincinnati, St. Louis, and Chicago, yields a similar picture.[76] When ethylene glycol must be shipped by rail, if it is to be shipped at all, it is better from a transport cost standpoint alone to avoid such shipment by piping natural gas to a plant at the market point. In contrast, when barge shipment of ethylene glycol can be utilized, the inexpensiveness of such shipment weights the scales in favor of a natural gas field location. However, such a location must, like Monroe, be close to an inland waterway. Thus, from an examination of transportation costs alone, we conclude that for a large tonnage chemical such as ethylene glycol each of the major market points considered can be efficiently served from a plant at a natural gas field site.

8. Economies of Scale (With Particular Reference to Ethylene Glycol, Oxidation Process)

The final, major set of cost differentials to be discussed is associated with economies of scale or plant size. If it were dictated by physical or technological reasons that plants of only one given size had to be constructed, regardless of their geographic position, then it would not be necessary to consider these economies; they would not exist. However, in the petrochemical industry plants of different sizes are currently, and will continue to be, associated with different market and natural gas sites. This entails substantial differences in the costs of production among sites. Past experience has established the fact that both capital costs (costs of plant and equipment) and labor costs associated with different capacities are not directly proportional to these capacities. As we proceed from one size plant to another of increasing size, both capital costs and labor costs tend to rise, within a significant range, less than proportionately.

There are various reasons for this relation. Doubling the capacity of a distillation tower or of a pot does not entail doubling the quantity (and hence the cost) of steel required. Or, to take another example, five men may be required to handle three units of equipment whereas only eight men may be required to tend six units. It is beyond the scope of this report to discuss the various counts on which economies of scale arise. We are concerned only with how the existence of these economies affects the future location pattern of the petrochemical industry.

There are several aspects of this problem which deserve some discussion. Economies of scale do not continue indefinitely with increase of capacity. It is the concensus of chemical engineers that once a certain capacity is reached, a capacity which varies greatly from product to product and which varies with the state of technology, economies of scale are no longer obtainable with further increases in capacity. At this point best practice involves the duplication of an existing unit, or the construction of an additional plant. Thus it becomes imperative for our analysis to

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[74] The reader who has a firm basis for judging the magnitude of any of these costs may easily make the appropriate adjustment in our figures. For example, in the case of a plant located at a raw material site and shipping to a gateway point where liquid chemicals need to be stored in terminal facilities, he may want to add a few cents to cover charges for additional chemical storage and terminal facilities. This would be in contrast to a plant at a market site, which would require only plant storage facilities and not terminal facilities *plus* some plant storage facilities.

[75] For example, compare the alternatives of supplying the New York market with ethylene glycol from an Amarillo plant which ships the glycol to New York by rail, or from a New York plant using fuel and raw material gas piped from Amarillo. The relevant data appear in the first row of the New York section of table 4. The rail cost of shipping 100 pounds of ethylene glycol from Amarillo to New York is $1.84 (column 3). Under conditions of 34 inch pipe, 90%-95% load factor, the cost of transmitting by pipeline the equivalent required volume of raw material and feedstock gas from Amarillo to New York is $0.72 (column 4). Subtracting $0.72 from $1.84 yields $1.12 (column 8) as the net transport cost differential, which in this case favors the New York location. Under pipeline transport conditions of 26 inch-30 inch pipe, 60%-65% load factor, the cost of transmitting the required volume of raw material and feedstock gas from Amarillo to New York is $0.95 (column 5). This amount subtracted from $1.84 (column 3) yields $0.89 (column 9) as the net transport differential, again in favor of the New York location.

Also, consider the alternatives of supplying the New York market with glycol from a Houston plant, or from a New York plant using fuel and feedstock gas piped from the Monroe area. The relevant data for this comparison appear in the third row of the New York section of table 4. If gas can be piped from Monroe to New York via a 34 inch pipeline operating at 90%-95% load factor, and if ethylene glycol must be shipped from Houston to New York by rail, the transport cost of 100 pounds of ethylene glycol, $1.73 (column 3), exceeds the transport cost of the equivalent required volume of feedstock and fuel gas, $0.53 (column 4), by $1.20 (column 8). Thus $1.20 is the net transport cost differential in favor of the New York location. However, if ethylene glycol can be shipped by tanker (and the same pipeline transport conditions hold), the transport cost of ethylene by ship, $0.39 (column 3), should be subtracted from $0.53 (column 4). This yields $0.14 (column 6), the net transport cost differential which in this case favors the Houston location.

[76] It is also possible to compare from the data presented in table 4 the transport advantage or disadvantage of a market site using natural gas from the Panhandle-Hugoton field (Amarillo) as against a natural gas location at Monroe, or of a market site using Monroe gas as against a location in the Panhandle-Hugoton field.

identify for each product that capacity beyond which economies of scale are no longer realizable.

At the other extreme, because of the steep rise in unit production costs that would arise, it is not feasible to operate a plant smaller than a certain minimum size. This size corresponds to a point on the economist's U-shaped envelope curve in the general area where the curve begins to flatten out. It is not to be denied that plants smaller than this "minimum feasible" capacity can be operated. However, it is generally agreed among engineers that such operation would not be profitable. Thus, for each product we must determine a minimum capacity—a capacity again which varies from product to product, and which varies with the state of technology, and with the age and maturity of a particular process.

For each product upon which we report, we have established minimum and maximum limits of capacity. Our estimates are based upon available literature, correspondence with producing companies, and consultation with chemical engineers who have had experience in the construction of plants for the production of these chemicals. For such a young and dynamic industry as the petrochemicals, these limits cannot be established with the firmness that they can for old and mature industries. At best the limits can represent only informed judgment.

Plant, Labor, and Other Factors: In attacking the problem of economies of scale, we must also establish the rate at which various costs rise with increase in scale of operations. There is general agreement that such inputs as feedstock, utilities, water, catalyst, and chemicals tend to increase linearly with scale.[77] As already mentioned, the two major inputs or costs which do not rise linearly are the services of capital and equipment, and labor. Therefore, it was necessary to establish factors which relate increases of each of these last two items to increases in capacity. Again, recourse was had to published literature, especially that based on active experience, to correspondence with petrochemical producing companies, and to the judgments of chemical engineers. Also when data on factors relevant for a particular product were lacking, existing data on other products manufactured by similar processes were employed as benchmarks. Thus, for every product we derive a plant and equipment factor (henceforth called plant factor) and a labor factor.[78] We assume a factor of unity for all other cost items.

Table 5.—ETHYLENE PRODUCTION: ECONOMICS OF SCALE CALCULATION

[Plant factor 0.67, labor factor 0.2]

Plant capacity (MM lbs/yr).......	25	66	132	198
Plant investment (in $000).......	$2,300	$4,500	$7,200	$9,400
Labor manhours per year..........	51,900	63,300	72,600	78,600
Selected costs per year (in $000):				
Operating labor................	$143	$174	$200	$216
Supervision....................	14	17	20	22
Plant maintenance..............	92	160	288	376
Equipment and operating supplies..........................	14	27	43	56
Payroll overhead...............	30	42	55	64
Indirect production cost......	131	199	275	335
General office overhead.......	26	40	55	67
Depreciation...................	230	450	720	940
Taxes..........................	23	45	72	94
Insurance......................	23	45	72	94
Interest.......................	92	180	288	376
Total......................	$819	$1,400	$2,088	$2,640
Selected costs per 100 lbs.......	$3.28	$2.12	$1.58	$1.33
Difference between consecutive columns in selected costs per 100 lbs.................		$1.16	$0.54	$0.25

Note: Minor discrepancies exist owing to the rounding of figures.

With the use of these factors it is possible to estimate the economies of scale in the production of each petrochemical product considered within the feasible range of capacities. Table 5 illustrates this calculation with respect to ethylene produced from plants of four different capacities. In this table we do not record those items of cost which vary linearly with capacity. They give rise to no differentials. We record only those cost items directly or indirectly based upon plant investment and labor requirements and costs. As listed in the left hand column of Table 5 these include operating labor, supervision, plant maintenance, equipment and operating supplies, payroll

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[77] See for example R. S. Aries and Associates, *Chemical Engineering Cost Estimation*, New York, 1951; U. S. Bureau of Mines, *Report of Investigations 4534, Guide for Making Cost Estimates for Chemical-Type Operations*, Washington, 1949; and R. Norris Shreve, *The Chemical Process Industries*, New York, 1945.

[78] These "factors" are actually exponents. For a given process or product the ratio of two plant capacities (larger over smaller) raised to the power indicated by the plant factor yields the ratio of plant investment costs of the two capacities. Similarly the former ratio raised to the power indicated by the labor factor yields the ratio of annual labor manhours (or cost) of the two capacities. For example, if a process had a plant factor of 0.65 and a labor factor of 0.25, the ratio of the plant investment cost of a 200 million lb/yr plant to that of a 100 million lb/yr plant would be $(\frac{2}{1})^{0.65}$ and the ratio of annual labor manhours required by the two plants would be $(\frac{2}{1})^{0.25}$. It is evident that if one knows the plant factor and the investment cost of one size plant, he can calculate the investment cost of any size plant within the range over which the plant factor is relevant. Labor requirements can be calculated in a similar manner. Graphically, if plant investment costs (or labor requirements) are plotted against plant capacity on a double logarithmic scale, the result will be a straight line with a numerical slope equal to the plant factor (or labor factor).

In our analysis we assume that one plant factor and one labor factor apply over the range between the estimated minimum and maximum plant capacities.

It is generally agreed that the costs of several sizes of a particular unit of plant equipment can be estimated in a manner such as the above; and there is considerable empirical evidence to justify the assumption that complete plant costs vary in a similar way. For an excellent discussion of the so-called "six-tenths rule" and its application to complete plant costs together with a good bibliography of published literature regarding equipment cost variation, see Cecil H. Chilton, "Six-Tenths Factor Applies to Complete Plant Costs," *Chemical Engineering*, Vol. 57, April 1950, pp. 112-114.

For an interesting chart and discussion of labor requirement variations relative to plant capacity, see Henry E. Wessel, "New Graph Correlates Operating Labor Data for Chemical Processes," *Chemical Engineering*, Vol. 59, July 1952, pp. 209-10.

It is necessary to obtain the actual investment cost of at least one size plant and the actual labor requirement of one size plant in order to have a starting point from which to apply the plant and labor factors. For many products, scattered estimates of at least one size plant costs and labor requirements are to be found in published articles. We supplemented these sources with estimates obtained from correspondence and conversations with chemical engineers and construction engineering firms. Useful, too, as a general check were the plant cost estimates in W. L. Faith, Donald B. Keyes, and Ronald L. Clark, *op.cit.*, and Anon., "What Price Process Plants," *Chemical Engineering*, Vol. 58, May 1951, pp. 164-165. Also, the Wessel nomograph and article cited above furnished a general check on labor requirements.

overhead, indirect production cost, general office overhead, depreciation, taxes, insurance and interest.[79] Taking into consideration all these cost items we are therefore able to derive per hundred pounds of ethylene the total of these selected costs for different size plants, and the differentials or economies of scale associated with any two consecutive sizes. These differentials are recorded in the last row of Table 5.[80]

Similarly, we have calculated the differentials associated with consecutive sizes of ethylene glycol plants within the feasible range of capacities, as well as for plants producing other petrochemical products. The resulting cost differentials associated with plants of consecutive capacity in the production of ethylene glycol are recorded in the last row of Table 6.

Table 6.—ETHYLENE GLYCOL (OXIDATION PROCESS): ECONOMICS OF SCALE CALCULATION

[Plant factor 0.625, labor factor 0.22]

Plant capacity (MM lbs/yr)................	10	20	40	60	70
Plant investment (in $000).................	$2,250	$3,470	$5,351	$6,895	$7,592
Labor manhours per year	42,724	49,762	57,960	63,367	65,553
Selected costs per year (in $000):					
Operating labor.....	$118	$137	$159	$174	$180
Supervision.........	12	14	16	17	18
Plant maintenance...	90	139	214	276	304
Equipment and operating supplies.....	14	21	32	41	46
Payroll overhead....	26	33	42	49	53
Indirect production cost...............	116	155	211	254	274
General office overhead...............	23	31	42	51	55
Depreciation........	225	347	535	690	759
Taxes...............	23	35	54	69	76
Insurance...........	23	35	54	69	76
Interest............	90	139	214	276	304
Total............	$759	$1,084	$1,573	$1,967	$2,143
Selected costs per 100 lbs...................	$7.59	$5.42	$3.93	$3.28	$3.06
Difference between consecutive columns in selected costs per 100 lbs........	$2.16	$1.49	$0.65	$0.22	

Note: Minor discrepancies exist owing to the rounding of figures.

9. The Net Effect of the Several Cost Differentials (With Particular Reference to Ethylene Glycol, Oxidation Process)

We are now in a position to weigh transport cost differentials, labor cost differentials, power cost differentials, and economies of scale, as they affect the location of ethylene glycol production.

It has already been mentioned that for practical purposes ethylene is non-transportable. An ethylene glycol plant must be located within the same general region of an ethylene unit, although the size of the ethylene and ethylene glycol units need not correspond. A small ethylene glycol plant can be associated with a large ethylene unit, where the glycol unit absorbs only a fraction of the output of the ethylene unit, and where the remainder of the ethylene is consumed by other petrochemical units. Or a small ethylene glycol plant can be associated with a small ethylene unit, consuming 100% of its output. In this latter case, however, economies of scale would be foregone since both units would be operating on a

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[79] In the calculation of capital and indirect cost items, principal reliance was placed on percentages estimated in U. S. Bureau of Mines, *op.cit.*, Aries, *op.cit.*, and on percentages employed in various articles and monographs on individual petrochemical products. All the percentages which will be quoted are used to estimate *annual* costs.

For the item of supervision, both Aries and the Bureau of Mines, whose recommendations are obviously not independent of one another, estimate 10% of operating labor cost. We also use this figure. For payroll overhead (which includes all "fringe" benefits) both sources estimate 15% of direct labor and supervision plus 7.5% of plant maintenance. We use the same figure. For plant maintenance, Aries estimates 2-10% of plant cost (an average of 4%) plus 5% of building cost. The Bureau of Mines estimates 3-8% of total plant investment (4% average). It is true that a careful consideration of each specific chemical process would justify differing percentages of plant investment cost to be charged to maintenance, since some processes require more maintenance work than others. Because we lack the detailed technical data necessary to make such judgements, we have used for all processes 4% of investment cost as an estimate of plant maintenance cost, a procedure which seems to be generally consistent with actual and recommended practice.

For the cost of equipment and operating supplies, Aries suggests a figure of 1/2-1% of plant cost or 13-20% of plant maintenance, while the Bureau of Mines suggests 13-20% of plant maintenance. We use 15% of plant maintenance as an approximate average for all processes.

Indirect production cost includes such items as first aid facilities, transportation within the plant, safety equipment, sanitation facilities, analytical or technical services of non-operating employees, maintenance of roads and yards, operation of the general stockroom, utilities of non-operating areas, and non-specific maintenance expense. Aries uses a figure of 40-60% of operating labor, supervision, and plant maintenance, *or* 15-30% of direct production cost as an estimate of indirect production cost. Bureau of Mines estimates 40-60% of operating labor, supervision, plant maintenance, and operating supplies. We use 50%.

General office overhead is essentially a part of the indirect production cost, but should be considered separately in estimating costs of a branch plant or of one unit of an integrated operation. It consists of a share in general office salaries and overhead items such as accounting, purchasing, office and payroll service, and managerial staff. Aries suggests a figure of 10% of operating labor, supervision, and plant maintenance as an estimate of general office overhead. Bureau of Mines estimates 10% of operating labor, supervision, maintenance, and equipment and operating supplies. We follow the Bureau of Mines.

For the item of depreciation, Aries suggests 10% of plant investment; the Bureau of Mines suggests 10% of plant cost plus 5% of building cost. We estimate annual depreciation at 10% of total plant investment, though we are fully aware that for different petrochemical products where different risks of obsolescence are involved, different rates ought to be applied.

Aries estimates taxes at 1-2% of capital investment; the Bureau of Mines estimates taxes at 1% of capital investment, as we do also. For insurance, Aries estimates 1% of plant and buildings cost; the Bureau of Mines estimates 1% of capital investment. We utilize the figure of 1% of plant investment.

There appears to be some disagreement among engineers as to whether or not interest should be considered as a production cost. Aries does not make any suggestion as to how interest could be estimated; however, the Bureau of Mines reference suggests a figure of 3-5% of plant investment. Since interest can in some cases be an actual money cost and in any case can be considered as an implicit cost, we have included it and have used 4% of plant investment as an estimate of interest cost.

[80] For example, in Table 5 the total of these selected costs per hundred pounds of ethylene amounts to $3.28 for an ethylene plant of 25 million pounds per year capacity, and $2.12 for an ethylene plant of 66 million pounds annual capacity. The difference, $1.16, represents the savings due to larger size, i.e., economies of scale. Similarly, per hundred pounds of ethylene the economies of scale which a 132 million pound per year plant obtains when compared with a 66 million pound per year plant amount to $0.54.

small scale. Another combination would be a large ethylene glycol unit and a medium ethylene unit wherein all the output of the ethylene unit would be consumed by the ethylene glycol unit. And still another combination would be a maximum size ethylene glycol plant and a maximum size ethylene unit wherein only a fraction of the output of the ethylene unit would enter into the ethylene glycol operation. In this last combination economies of scale would be at a maximum, *ceteris paribus*.

To simplify the weighing of the various cost differentials in the production of ethylene glycol we have constructed Table 7. In column 1 we consider three types of ethylene glycol units: (1) large, representing an annual production of 70 million pounds; (2) medium, representing an annual production of 40 million pounds; and (3) small, representing an annual production of 10 million pounds. Associated with these glycol units are three types of ethylene units which are listed in column 2: (1) large, representing 198 million pounds annual production; (2) medium, representing 66 million pounds annual production; and (3) small, representing 26 million pounds annual production. We consider various combinations of these ethylene glycol and ethylene units.[81]

Table 7.—ETHYLENE GLYCOL (OXIDATION PROCESS): ECONOMIES OF SCALE FOR DIFFERENT UNIT COMBINATIONS

[Per 100 lbs of product]

Ethylene glycol unit	Ethylene unit	Economies of scale vis-a-vis	
		Small-small combination	Large-large combination
(1)	(2)	(3)	(4)
Small..........	Small..........	$0.00	$-6.13
Small..........	Medium........	+0.96	-5.17
Small..........	Large..........	+1.61	-4.52
Medium........	Small..........	+3.65	-2.48
Medium........	Medium........	+4.61	-1.52
Medium........	Large..........	+5.26	-0.87
Large..........	Medium........	+5.48	-0.65
Large..........	Large..........	+6.13	0.00

In column 3 of Table 7 we have listed for each combination of units the combined economies of scale which would be realized from production when contrasted with production from a small-small combination (small ethylene glycol unit and small ethylene unit). For example, a large-large combination achieves scale economies of $6.13 per hundred pounds of ethylene glycol over a small-small combination. In column 4 is presented the disadvantage of each combination with respect to the most efficient combination of all, the large-large. For example, column 4 shows that relative to the large-large combination a large-medium combination has a scale disadvantage of $0.65 and a medium-medium combination a scale disadvantage of $1.52, per 100 pounds of ethylene glycol.

From the data of Table 4 above we have concluded that where large shipments of ethylene glycol by barge or tanker are feasible and achievable, transport considerations tend to favor plant location at a natural gas site. Since AWR locations have access to not just one, but several market areas, it is logical to expect that AWR plants will be at least as large and probably larger than any feasible market site plant. Thus economies of scale considerations do not diminish any advantage of an AWR location and may augment the pull of such a location on transport account when barge shipment of product is feasible.

It is pertinent, however, to consider a situation where tanker or barge shipments will not be feasible. Such would always be the case with respect to an Amarillo location. When rail shipment of product must be utilized the balance of cost advantage on transport account shifts to a market location. In Table 8 we have listed the transport advantage of a market location vis-a-vis an AWR location for each of the four markets considered. For the New York City market area the minimum transport advantage of a market location is $0.82. This is the difference between the freight cost of shipping one hundred pounds of ethylene glycol by rail from Monroe to New York and the cost of transporting the required amount of natural gas feedstock and fuel from Monroe to New York via 26-30 inch pipeline at 60-65% load factor. The maximum transport advantage of a New York location is $1.12. This is the difference between the freight cost of shipping one hundred pounds of ethylene glycol by rail from Amarillo to New York and the cost of transporting the required amount of natural gas feedstock and fuel from Amarillo to New York via 34 inch pipeline at 90-95% load factor. Likewise, in Table 8 are recorded minimum and maximum transport advantages for each of the other three market sites when rail shipment of finished product is postulated.

Table 8.—ETHYLENE GLYCOL (OXIDATION PROCESS): TRANSPORT ADVANTAGE OF A MARKET LOCATION VIS-A-VIS—AN AWR LOCATION*

[Per 100 lbs of product]

	Minimum	Maximum
1. New York.................	$0.82	$1.12
2. Cincinnati...............	0.51	0.67
3. Chicago..................	0.52	0.66
4. St. Louis................	0.36	0.51

*When water shipment infeasible.

Maximum direct labor cost differential = 12¢
Maximum indirect labor cost differential = 11¢
Maximum power cost differential = 6¢

These transport cost advantages can now be contrasted with economies and diseconomies of scale listed in Table 7 and with the direct labor, indirect labor, and power cost differentials listed at

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[81] However, we do not consider a large ethylene glycol unit together with a small ethylene unit; the latter would produce an insufficient amount of ethylene to insure an adequate supply of ethylene to the glycol unit.

the bottom of Table 8.[82] It is immediately apparent that the relatively small transport advantage enjoyed by a market site would be swallowed up by the relatively large economies of scale of an AWR site if the former could support only a small-small combination and if the latter could support any combination including a medium or large ethylene glycol unit or a combination of a small glycol unit and a large ethylene unit.[83]

Since power cost differentials and labor cost differentials are relatively minor and since on balance they will probably tend to favor an AWR location, the data indicate that in general a market site can compete with a large-large combination in the AWR only if the market site together with its tributary areas can support a large-large combination of its own (or possibly a large-medium or medium-large combination in the case of a New York market) and *if the product must be shipped by rail*. However, conditions of demand which will support the large combinations are just the conditions under which water shipment of product is feasible. It therefore becomes relevant to consider a Houston or a Monroe location, at least one of which under these conditions will possess via water a transport cost advantage over any market site. Hence, we conclude that market sites will probably not be able to compete with natural gas sites under conditions justifying large scale productive units and combinations.

There remains the question of whether or not market locations can effectively compete with natural gas locations in a situation where the market demand could support only medium and small units and combinations. The data suggest that market locations could so compete *provided* the AWR plants were of the same size as the market site plants. However, as already indicated, the AWR plants are likely to be larger rather than of the same size since they will have access to more markets. Thus, on this second important count, market sites are likely to be in an unfavorable competitive position.

Our general conclusion is that natural gas sites are likely to receive the lion's share of new capacity when ethylene-ethylene glycol units are considered. This is not to deny, of course, that major developments may take place at market sites because of special conditions and circumstances.

10. The Effects of Regional Differentials in Process Chemical Costs (With Particular Reference to Ethylene Glycol, Chlorhydrin Process)[84]

The above analysis relates to ethylene glycol via the oxidation process. We must also consider the production of ethylene glycol via the chlorhydrin process. Since this latter process requires large amounts of chemicals, its analysis requires us to test the locational pull of chemicals.

Table 9 presents input requirements per hundred pounds of ethylene glycol (strictly speaking, per hundred pounds of the joint products ethylene glycol, polyglycols, ethylene dichloride, and chloroethers; of which ethylene glycol constitutes 77% by weight and ethylene dichloride 16% by weight). Ethylene requirements are not stated in this table. Rather, the inputs required to produce the ethylene are added to the inputs required to manufacture the ethylene glycol from ethylene. As before, this procedure is necessary since ethylene is for practical purposes an immobile commodity; the ethylene glycol unit must necessarily be regionally adjacent to the ethylene unit. Thus we have listed the requirements of ethane, steam, fuel gas, electricity, cooling water, and labor.[85] So far as these inputs are concerned the location analysis proceeds as it did for ethylene glycol via the oxidation process.

In addition to the inputs already mentioned are the inputs of chemicals. Caustic soda and sulfuric acid requirements are minor; hence the locational pull of these chemicals is negligible and can be ignored. On the other hand, large quantities of quicklime are required. Since quicklime is a re-

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[82] Strictly speaking the labor cost differentials, both direct and indirect, which are recorded in Table 8, apply only to a combination of a 66 million lb/yr ethylene unit and a 53.2 million lb/yr ethylene glycol unit. The direct labor cost differential was derived by multiplying the total number of manhours required in both process units per hundred pounds of ethylene glycol by the wage rate and the 25% wage rate differential. The term indirect labor cost includes all cost items computed as a percentage of direct labor cost; thus the indirect labor cost differential is directly dependent on the number of direct labor manhours required.

We have already seen that total labor requirements do not vary linearly with capacity. Hence, labor requirements per hundred pounds and labor cost differentials, both direct and indirect, will be different for each specific combination of units considered. The following table illustrates such differences:

Size of ethylene glycol unit	Size of ethylene unit	Total manhour requirements per 100 lbs.	Wage rate times 25%	Direct labor cost differential (per 100 lbs.)	Indirect labor cost differential (per 100 lbs.)
Small (10 MM lb/yr)	Small (25 MM lb/yr)	0.60	$0.69	$0.41	0.38
Small (10 MM lb/yr)	Medium (66 MM lb/yr)	.51	.69	.35	.32
Small (10 MM lb/yr)	Large (193 MM lb/yr)	.46	.69	.32	.30
Medium (40 MM lb/yr)	Small (25 MM lb/yr)	.32	.69	.22	.20
Medium (40 MM lb/yr)	Medium (66 MM lb/yr)	.22	.69	.15	.14
Medium (40 MM lb/yr)	Large (193 MM lb/yr)	.18	.69	.12	.11
Large (70 MM lb/yr)	Medium (66 MM lb/yr)	.17	.69	.12	.11
Large (70 MM lb/yr)	Large (193 MM lb/yr)	.13	.69	.09	.08

As a result, a rigorous analysis would require computation of labor cost differentials for each combination considered. However, the above table indicates that the variation in labor cost differentials is not very great when combinations having small units are excluded. Since small units suffer a decided scale disadvantage compared to medium and large units it is unlikely that in the future many small units will be justified. Thus, for practical purposes, labor cost differentials for medium-medium, medium-large, or large-medium combinations can be taken as generally indicative of differentials that will exist for economically feasible combinations.

Even calculating labor cost differentials as in the above table is not strictly correct procedure if one is comparing a given combination in one region with a different combination in another region; e.g., large-large in the AWR with medium-large in New York. Upon which labor requirement should the labor cost differential be dependent? This question can be answered only if one knows which is the high and which the low cost labor region, and by how much the rates in each region deviate from the standard national rate used.

[83] Even a small-medium combination in the AWR would have a scale advantage over a small-small market site combination sufficient to outweigh in most instances the market site advantage on transport account. The only exception would be the case of a New York City market receiving fuel and feedstock via a 34-inch pipeline with 90-95% load factor.

[84] For related technical materials see Faith, Keyes and Clark, *op.cit.*, pp. 327-333; and British Intelligence Objectives Sub-Committee (hereafter referred to as B.I.O.S.) *Final Report*, No. 1059, item No. 22-30.

[85] The labor requirement is for a combined ethylene unit of 66 million lbs/yr capacity and ethylene glycol unit of 70 million lbs/yr capacity.

gional ubiquity,[86] i.e., generally available in all regions and at approximately the same cost, it too exerts no major locational pull. For the ensuing analysis its pull needs to be considered, if at all, only as a qualification to our major conclusions.

Table 9.—PRODUCTION OF ETHYLENE GLYCOL FROM ETHANE[1] (VIA CHLORHYDRIN PROCESS)

	Requirements per hundred pounds of output	
Selected Inputs:		
Ethane	77	lbs.
Utilities:		
Steam	1,031	lbs.
Cooling Water	7,004	gals.
Electric Power	9	kwh.
Fuel Gas	125	cu.ft.
Chemicals:		
Chlorine	132	lbs.
Quick Lime	105	lbs.
Caustic Soda	1.3	lbs.
Sulfuric Acid	1.4	lbs.
Labor	0.14	manhours.[2]

[1] Of total product, 77% by weight is ethylene glycol, 16% by weight is ethylene dichloride, and 7% by weight is polyglycols and chloroethers.

[2] For ethylene glycol plant with annual capacity of 40 MM lbs; for ethylene plant with annual capacity of 66 MM lbs.

Chlorine Cost Differentials: One hundred thirty-two pounds of chlorine are required per hundred pounds of product. Since chlorine costs do differ significantly among regions this item is of locational importance. To analyze the locational pull of chlorine we present Table 10, which indicates major inputs per hundred pounds of chlorine.[87] The requirements of mercury, graphite, hydrogen chloride, sulphuric acid, and sodium carbonate are negligible from a location standpoint. Water and lime have already been excluded from the category of location factors which have a major pull among regions. The remaining items are salt, electricity, steam, and labor.

Table 10.—PRODUCTION OF CHLORINE (ELECTROLYTIC PROCESS)

	Requirements per hundred pounds liquid chlorine	
Inputs:		
Salt	170	lbs.
Hydrogen chloride	2	lbs.
Sulfuric acid	2.5	lbs.
Lime	2.5	lbs.
Caustic soda	1	lb.
Sodium carbonate	0.05	lb.
Graphite	0.30	lb.
Mercury	0.03	lb.
Utilities:		
Steam	55	lbs.
Cooling water	730	gals.
Electric power	171	kwh.
Direct labor	0.18	manhours.[1]
Cost differentials (maximum) per 100 lbs. chlorine:		
Power	103	cents
Steam	2.2	cents
Direct labor	12	cents
Indirect labor	11	cents
Total	128.2	cents

[1] For chlorine plant with annual capacity of 66 MM lbs chlorine.

Salt is generally available among regions of the United States.[88] Though differences in costs of production are undoubtedly associated with the utilization of different deposits, it is beyond the resources of this study to investigate such differences. It is clear that they will be relatively small compared to the major differences in power costs which result in this high-power consuming chlorine process from differences in power rates among regions.

Hence, we conclude that the long run difference in the cost of chlorine among regions will roughly correspond to the difference in the cost of the power, steam, and labor required to produce the chlorine. For the location analysis of a petrochemical requiring chlorine in its production, a logical procedure would be to substitute for chlorine inputs the inputs of power, steam, and labor required in the production of the chlorine. These power, steam, and labor requirements could be added to the power, steam and labor inputs required both directly and indirectly in the production of other raw materials for the given petrochemical. As a consequence, the final aggregate power cost differential, the final aggregate labor cost differential, and the final aggregate differential resulting from total steam requirements, would reflect cost differences in both petrochemical processes and the non-petrochemical process, viz., chlorine production. Since our primary concern is with regional cost and other differentials in *petrochemical processes*, we have instead computed

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[86] Oliver Bowles, *The Lime Industry*, United States Bureau of Mines Information Circular 7651, November 1952.

[87] In the manufacture of 100 pounds of chlorine by the electrolytic process, 112.5 pounds of caustic soda and 500 cubic feet of hydrogen are produced as by-products. For the purposes of our analysis the cost differentials among locations in producing the combined product are attributed solely to chlorine production for two reasons. One, hydrogen is a minor by-product. Two, caustic soda is generally of a by-product rather than a joint-product nature; i.e., it is a product which the producer has to accept, and whose production he attemps to minimize. Chlorine is the primary product. It is the increase in the demand for chlorine rather than the increase in the demand for caustic soda that elicits increases in capacity for the production of chlorine and caustic soda. See in this connection W. L. Faith, Donald B. Keyes, and Ronald L. Clark, *op.cit.*, pp. 221-223.

We realize, of course, the crudeness of this argument. It is invalid to the extent that low caustic soda prices prevail where costs of the electrolytic process are low and high caustic soda prices prevail where costs of the process are high. However, to pursue the analysis on a more refined basis is beyond the scope and resources of this project.

[88] W. C. Phalen, *Salt Resources of the United States*, United States Geodetic Survey, Bulletin 669; C. D. Looker, "Salt as a Chemical Raw Material," *Chemical Industries*, Vol. 49, November 1941, pp. 594-601; United States Bureau of Mines, *Minerals Yearbook*, annual.

a specific chlorine differential, based on power, steam, and direct and indirect labor necessary to produce the required chlorine input. The total chlorine differential, and its component differentials, per 100 lbs of ethylene glycol product (chlorhydrin process) are listed at the bottom of Table 14[89]

The reader is reminded that the analysis we are pursuing is a long run analysis. Pricing systems for chlorine establishing prices for various localities of the United States undoubtedly deviate considerably from a cost of production basis. Nonetheless, in the long run, it seems that chlorine prices will more likely conform to a production cost pattern than to any other pattern. This will be true, at least implicitly, insofar as petrochemical companies produce chlorine where they require it. However, if he cares to the reader may qualify our conclusions by introducing a pattern of chlorine prices which he considers more appropriate for years 1960 and 1975.

Thus we have handled the problem of the locational influence of a chemical such as chlorine. In a similar fashion the influence of any other significant process chemicals can be analyzed.

Interaction of Chlorine and Other Cost Differentials: Having derived the maximum chlorine differential, subdivided into the components due to power, labor, and steam, we can return to the problem of the location of ethylene glycol production via the chlorhydrin process. Henceforth, we proceed as in the analysis of ethylene glycol via the oxidation process. The maximum power cost differential is obtained by multiplying the power requirements (9 kwh) by 6 mills. This yields a figure of 5.4 cents. The maximum direct labor cost differential is calculated by multiplying labor requirements (0.14 manhours) by 25% of the wage rate (0.25 x $2.75). This results in a figure of 9.7 cents. Indirect labor costs are estimated at 92.5% of direct labor costs.[90] Therefore, the maximum indirect labor cost differential is 9.0 cents. Cooling water is set aside as a regional locational factor.

Two cost differentials remain to be considered: (1) the net transport cost differential resulting from moving the required feedstock and fuel gas on the one hand and the finished product on the other; and (2) the production cost differential associated with economies of scale.

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[89] The power cost component is derived by multiplying the amount of power required in the production of the 132 pound chlorine input by 6 mills. The steam cost component is calculated by first computing the amount of fuel gas necessary to produce the steam required in the production of the 132 pound chlorine input and then multiplying that quantity of fuel gas (in thousand cubic feet units) by 26.13 cents, which is the cost of transporting one thousand cubic feet of gas from Amarillo to New York City via a 26-30 inch pipeline with a 60-65% load factor. Obviously, if power costs at two locations differ by less than 6 mills, or if the two locations are closer together than Amarillo and New York City, the actual chlorine differential will be less than the maximum figure we present.

[90] This follows from procedures indicated in footnotes 79 and 82.

Table 11.—ETHYLENE GLYCOL (CHLORHYDRIN PROCESS): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2) Via	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York.....	1. Amarillo	Rail...	$1.84	Amarillo source $0.53	$0.69	....	....	$1.31	$1.15
	2. Monroe...	Rail...	1.51	Monroe source 0.39	0.51	....	....	1.12	1.00
	3. Houston..	Rail... Ship...	1.73 0.39	Monroe source 0.39	0.51	.... 0.00	.... 0.12	1.34 0.00	1.22 ....
Cincinnati....	1. Amarillo	Rail...	1.13	Amarillo source 0.34	0.44	....	....	0.79	0.69
	2. Monroe...	Rail... Barge..	0.89 0.16	Monroe source 0.21	0.28	.... 0.05	.... 0.12	0.68	0.61 ....
Chicago.......	1. Amarillo	Rail...	1.08	Amarillo source 0.30	0.40	....	....	0.78	0.68
	2. Monroe...	Rail... Barge..	0.94 0.16	Monroe source 0.24	0.31	.... 0.08	.... 0.15	0.70	0.63 ....
St. Louis.....	1. Amarillo	Rail...	0.83	Amarillo source 0.23	0.30	....	....	0.60	0.53
	2. Monroe...	Rail... Barge..	0.62 0.11	Monroe source 0.15	0.19	.... 0.04	.... 0.08	0.47	0.43 ....

Table 11 presents the relevant data on the first of these two differentials. The pattern of transport cost differentials in the case of ethylene glycol via the chlorhydrin process is similar to that in the case of ethylene glycol via the oxidation process (Table 4, above). Even though the smaller amounts of feedstock and fuel gas required per hundred pounds of product in the chlorhydrin process tend to decrease the transport cost differentials favoring natural gas sites under conditions of water shipment of product, these differentials are not eliminated except in the case of a New York market served by a 34 inch pipeline operating at 90-95% load factor. Even in this last case there is no net transport cost differential *disfavoring* a natural gas site location.

Thus, we conclude that where market demand[91] is large enough to make feasible barge or tanker shipment of ethylene glycol, transport cost differentials in general favor a natural gas site location for the production of ethylene glycol via the chlorhydrin process. This conclusion is reinforced by the fact that if differentials were to arise from economies of scale, they would favor a natural gas site location.

Consider the situation where the product must be shipped by rail. This would imply a market demand too small to justify barge or tanker shipment of product and hence too small to justify the construction *at any one market site* of a combination ethylene—ethylene glycol plant large enough to take advantage of all possible scale economies. Thus, even though Table 11 shows substantial transport cost differentials favoring a market location, we need to contrast these differentials with other factors, including the scale advantages of a natural gas site location.

Table 12 presents data on economies of scale in the production of ethylene glycol via the chlorhydrin process. The method of estimating the basic plant factor and labor factor and of computing the costs which are based directly or indirectly on investment cost and direct labor requirements has been fully explained above and applies to Table 12 and all similar tables.

As in the case of ethylene glycol via the oxidation process, ethylene is non-transportable, interregionally. Consequently a regional comparison of scale economies must pertain to combined scale economies of various possible combinations of ethylene and ethylene glycol plants. Table 13 presents the total scale advantage of various combinations compared to a small-small combination, and the total scale disadvantage of various combinations compared to a large-large combination. Table 14 presents maximum and minimum transport cost advantages of market site locations compared to AWR locations when finished products must be shipped by rail. Examination of Tables 13 and 14 shows that any combination in the AWR which includes at least a medium sized ethylene glycol unit will secure scale advantages much more than sufficient to counterbalance the transport cost advantage held by a small-small market site combination. Conversely, the demand of any market site must be large enough to justify a medium-large or a large-medium combination in order for a market site location to compete effectively with an AWR location which has a large-large combination. But, as in the previous analysis, such a large market demand would tend to make feasible barge or tanker shipment of product which would in turn eliminate the transport cost advantage of a market location.

Thus, if we consider only transport cost differentials and economies of scale, a natural gas site location appears more favorable than a market location both under conditions of demand which warrant water transportation of ethylene glycol and under conditions which warrant only rail transportation. However, there are other differentials to be considered. The labor cost and power cost differentials even at their maximum, as shown in Table 14, are relatively minor. Furthermore, they will probably on balance tend to favor the natural gas sites and strengthen the influence of the transport and scale factors.

Table 12.—ETHYLENE GLYCOL (CHLORHYDRIN PROCESS): ECONOMIES OF SCALE CALCULATION

[Plant factor 0.625, labor factor 0.22]

Plant capacity (MM lbs/yr).......	10	20	40	70
Plant investment (in $ 000)......	$2,057	$3,173	$4,893	$6,942
Labor manhours per year..........	41,181	47,965	55,867	63,186
Selected costs per year (in $000):				
Operating labor...............	$113	$132	$154	$174
Supervision...................	11	13	15	17
Plant maintenance.............	82	127	196	278
Equipment and operating supplies......................	12	19	29	42
Payroll overhead..............	25	31	40	49
Indirect production cost......	110	146	197	255
General office overhead.......	22	29	39	51
Depreciation..................	206	317	489	694
Taxes.........................	21	32	49	69
Insurance.....................	21	32	49	69
Interest......................	82	127	196	278
Total......................	$705	$1,005	$1.453	$1.577
Selected costs per 100 lbs.......	$7.05	$5.02	$3.63	$2.82
Difference between consecutive columns in selected costs per 100 lbs..................		$2.03	$1.39	$0.81

Note: Minor discrepancies exist owing to the rounding of figures.

Table 13.—ETHYLENE GLYCOL (CHLORHYDRIN PROCESS): ECONOMIES OF SCALE FOR DIFFERENT UNIT COMBINATIONS

[Per 100 lbs of product]

Ethylene Glycol Unit	Ethylene Unit	Economies of scale vis-a-vis	
		Small-small combination	Large-large combination
(1)	(2)	(3)	(4)
Small...........	Small.........	$0.00	$-5.37
Small...........	Medium........	+0.68	-4.39
Small...........	Large.........	+1.14	-4.23
Medium..........	Small.........	+3.42	-1.95
Medium..........	Medium........	+4.10	-1.27
Medium..........	Large.........	+4.56	-0.81
Large...........	Medium........	+4.91	-0.46
Large...........	Large.........	+5.37	0.00

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[91] Again, the reader is reminded that market demand includes demand of hinterland areas and cities served by any given gateway metropolis.

Table 14.—ETHYLENE GLYCOL (CHLORHYDRIN PROCESS): TRANSPORT ADVANTAGE OF A MARKET LOCATION VIS-A-VIS—AN AWR LOCATION*

[Per 100 lbs of product]

	Minimum	Maximum
1. New York	$1.00	$1.31
2. Cincinnati	0.61	0.79
3. Chicago	0.63	0.78
4. St. Louis	0.43	0.60

*When water shipment infeasible.

Maximum direct labor cost differential = 10¢
Maximum indirect labor cost differential = 9¢
Maximum power cost differential = 5¢
Maximum chlorine cost differential = 170¢
  a. due to power..........136¢
  b. due to steam.......... 3¢
  c. due to direct labor....16¢
  d. due to indirect labor..15¢

When we consider chlorine, the situation becomes more complex. The chlorine cost differential noted at the bottom of Table 14 is $1.70, of which $1.36 is on power account. To the extent that the power costs in the AWR region are lower than in various market areas, to that extent the attractive power of the AWR region vis-a-vis these market areas will be enhanced. However, if in the long run higher power costs prevail in the AWR than at certain market points such as the Pacific Northwest or Ohio Valley, the attractive power of the AWR vis-a-vis these latter market points is diminished. For rough purposes, we may set 2 mills as the maximum amount by which power costs in the AWR are likely to exceed power costs in the Pacific Northwest or the Ohio Valley. This yields to the Pacific Northwest and Ohio Valley a maximum possible advantage of approximately 45¢ on power account to produce the chlorine required for one hundred pounds of ethylene glycol. Even in this extreme case, the economies of scale realizable by an AWR location vis-a-vis a small market location such as the Pacific Northwest would tend to wipe out the disadvantage on power account in producing the required chlorine. In contrast, this would not be so in the case of a market such as at Cincinnati which might be able to realize the full economies of scale of a large-large combination. Thus, we must recognize the possibility that a considerable part of the Ohio Valley's new demand for ethylene glycol, together with that of adjacent areas, may be served by chlorhydrin plants in the Ohio Valley.[92]

Nevertheless, we conclude as before that the lion's share of future expansion in ethylene glycol production, especially since the oxidation process seems to be increasingly preferred to the chlorhydrin process, will tend to be located at or near natural gas sites rather than at the market. This is to be qualified somewhat if expansion relates to the chlorhydrin process and if in the long run lower power rates are obtainable in the Ohio Valley than at AWR sites.

11. Distribution of Ethylene Glycol Expansion Among Natural Gas Areas

Having reached the conclusion that the major expansion of ethylene glycol capacity will probably take place at natural gas sites, we proceed to apportion that expansion between the Houston and AWR regions.

It is anticipated that from 1952 to 1975 ethylene glycol production will expand by 550 million pounds.[93] Of this total it may be assumed that antifreeze production will absorb 150 million pounds; dacron production, 350 million pounds; and other items, 50 million pounds. In the case of expansion for antifreeze purposes we judge that the markets in New England, New York, New Jersey, Delaware, Pennsylvania, and other states along the Eastern seaboard plus Washington and Oregon should be served by Houston.[94]

These states contain 48.6% of the population of the cold weather states.[95] The remaining 51.4% of cold weather population is postulated to be served by AWR sites.[96] Multiplying 150 millions by these percentages would give the expected shares of new expansion in ethylene glycol production for each of these regions, *provided* no expansion of ethylene glycol were to develop elsewhere. However, in line with our policy of establishing firm minimum estimates for the AWR region, we assume that 25% of the total expansion will take place in areas outside the Gulf Coast and AWR regions. Of this 25%, more is likely to be associated with the Ohio Valley than with Eastern Seaboard metropolitan areas. The Ohio Valley possesses a chlorine advantage, a power advantage, and a generally superior position vis-a-vis national markets. We therefore assume that 17 1/2% of the total expansion in antifreeze ethylene glycol will occur in the Ohio Valley, and that this 17 1/2% expansion will be at the expense of the AWR's share of national expansion; and that 7 1/2% of the total expansion will occur along the Eastern Seaboard, and that this 7 1/2% will be at the expense of the Gulf Coast's share of national expansion. Hence, 33.9% and 41.1% of the expansion in the national market for antifreeze ethylene glycol will fall to the AWR and Gulf Coast regions, respectively. These percentages, multiplied by 150 million pounds, yield figures of 50.9 million pounds for the AWR and 61.7 million pounds for Houston. For

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[92] This statement is consistent with the recent installation on the Ohio River, near Louisville, Ky., of ethylene glycol capacity based on the chlorhydrin process. The ethylene required for this plant is produced from the ethane component of a mixed hydrocarbon stream supplied from the nearby stripping plant of the Tennessee Gas Transmission Company. The chlorine requirements are shipped in from the western part of Virginia.

[93] See Kuhn and Hutcheson, *op.cit.*, who estimate ethylene glycol production at 740 million pounds for 1952; and the President's Materials Policy Commission, *op.cit.*, which anticipates a total production of 1.29 billion pounds by 1975.

[94] Strictly speaking, western Pennsylvania and western New York State should not be included in Houston's market. However, because of the crudeness of our other data, a breakdown of markets by areas smaller than states is not warranted. As a consequence, western Pennsylvania and western New York State fall in Houston's market. It should be noted that this bias is in line with our policy of underestimating possible petrochemical expansion in the AWR region.

[95] The cold-weather states are taken to include the New England states, New York, Pennsylvania, New Jersey, Delaware, Maryland, Virginia, West Virginia, Ohio, Kentucky, Indiana, Michigan, Wisconsin, Illinois, Missouri, Iowa, Minnesota, North Dakota, South Dakota, Nebraska, Kansas, Colorado, Wyoming, Montana, Idaho, Utah, Nevada, Oregon, Washington, and the District of Columbia.

[96] For reasons already mentioned in connection with other possible refinements, adjustment for differences among cold weather states in antifreeze consumption per capita is not warranted.

these areas they represent the estimated expansions in the production of ethylene glycol for antifreeze use.

Next we consider the apportionment of the 50 million pound expansion in ethylene glycol production to be associated with uses other than in antifreeze and dacron production. We proceed initially as if the total amount were to develop in the Gulf Coast and AWR regions alone. Under such conditions we judge that Houston would supply the new requirements of New England and the states along the Atlantic Seaboard, Gulf Coast, and Pacific Coast; and that an AWR location would serve the remaining states.[97] Lacking a better alternative, we assume that the increased consumption of ethylene glycol in "other uses" will be distributed geographically in the same pattern as current national population. Accordingly, Houston would serve 58.9% and the AWR 41.1% of the new national market. However, we again assume that of this portion of the expansion required in ethylene glycol production, 25% will take place in areas outside the Gulf Coast and AWR. More specifically, 17 1/2% will take place in the Ohio Valley because of its aforementioned advantages (all at the expense of the AWR); and 7 1/2% in the rest of the United States (all at the expense of the Houston region). This identifies 51.4% of the expansion in the national market to be served by Houston and 23.6% to be served by the AWR. Multiplying these percentages by 50 million pounds yields figures of 25.7 million pounds for Houston and 11.8 million pounds for the AWR. These represent for these areas the expansions in the production of ethylene glycol for all uses other than in antifreeze and dacron production.

Finally, in estimating regional expansions of ethylene glycol production to meet requirements for dacron production we judge that future dacron production will be confined primarily to the South. The South contains almost 100% of current synthetic fiber capacity based on synthetic polymers. Moreover, preliminary studies indicate that the South together with Puerto Rico is likely to maintain overwhelming dominance in this type of synthetic fiber production. Therefore, the essential problem is to determine that part of future Southern expansion in dacron production which is tributary to the AWR region, and that part which is tributary to the Gulf Coast region.

At present it is not possible to anticipate the future distribution of new dacron capacity between Puerto Rico and each of the several sub-regions of the South. If the new concentrations develop along the South Atlantic seaboard, the Gulf Coast, and Puerto Rico, ethylene glycol would in all likelihood be shipped from the Gulf Coast area. On the other hand, if the heart of synthetic fiber and synthetic textile production were to shift toward the western interior part of the South, the AWR region would provide a larger share of the ethylene glycol requirements for dacron production. Since there is no basis on which to project the spatial spread of future dacron production in the South and Puerto Rico, it seems most reasonable to assume, somewhat along the lines of our market analysis of "ethylene glycol for other uses," that the Houston and the AWR regions respectively will serve 58.9% and 41.1% of the needs of Southern and Puerto Rican dacron production.[98] Once again we assume that 25% of the expansion in ethylene glycol production for dacron will occur in areas outside the Gulf Coast, and AWR. As before 17 1/2% is apportioned to the Ohio Valley (all at the expense of the AWR), and 7 1/2% to the rest of the United States, primarily to the coastal South (all at the expense of the Houston region). Hence 51.4% and 23.6% of the ethylene glycol required for future dacron expansion will be produced in the Houston and AWR regions respectively. On this account, we apportion 179.9 million annual pounds to the Houston region and 82.6 million annual pounds to the AWR.

Thus, by 1975 it is anticipated that total expansion in ethylene glycol production in the Houston area will amount to 267.3 million annual pounds; and in the AWR region, 145.3 million annual pounds. On the assumption that two new plants each of approximately 70-75 MM annual pounds of capacity are constructed in the AWR region, this would entail the employment of approximately 33 workers in operations and maintenance work.

It should be strongly emphasized that these estimates are very rough. Further, in making the AWR estimate (but not the Houston estimate) we have tried to establish a firm minimum expansion by omitting any increase in production where the basis for such is doubtful.

12. Explanation of the General Summary Tables 15 and 16

Having treated in detail the location factors in the production of ethylene glycol, a typical petrochemical, when a process chemical, such as chlorine, is and is not an important location factor, we pass on to consider briefly each of the various other petrochemicals. We have constructed Tables 15 and 16 wherein are included the basic pertinent locational data relating to each major petrochemical product by type of process. Table 15 treats petrochemical production in whose location chlorine and hydrogen chloride are not important factors. Table 16 relates to petrochemical production in whose location chlorine and HCl are important factors. The supporting materials, from which data for Tables 15 and 16 are derived, are presented in the tables for each petrochemical product in Appendices A, B, and C. These treat respectively input requirements, economies of scale, and transport cost differentials.

It is pertinent at this point to explain the construction of Tables 15 and 16. On the extreme left are listed the products and the processes as-

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[97] Parts of some states listed for Houston such as the Texas Panhandle and northern Louisiana logically belong to the AWR, but as before the crudeness of our other data does not warrant the splitting of states in this connection. We chose states so as to assign to Houston more than its logical share of the national market and to the AWR less, in order to be consistent with our policy of establishing firm minimum estimates for the AWR region.

[98] In view of the arbitrariness of our market division, it would be less misleading to use the figures 60% and 40% rather than 58.9% and 41.1%. The latter imply an accuracy to the first decimal point. However, we have chosen to employ the somewhat misleading figures of 58.9% and 41.1% since this will avoid the use in the ensuing analysis of a second standard market division procedure. The reader will thereby be able to follow more readily our computations.

Table 15.—SELECT COST DIFFERENTIALS BY PRODUCT AND PROCESS

Product and process (excludes processes in which process chemicals are locationally important)	Water shipment				Rail shipment				Economies of scale vis-a-vis		Maximum direct labor cost differential	Maximum indirect labor cost differential	Maximum power cost differential
	Natural gas site transport advantage ¢/100 lbs.		Market site transport advantage ¢/100 lbs		Maximum market site advantage Dollars per 100 lbs.				Small-small combination	Large-large combination			
	Min.	Max.	Min.	Max.	N.Y.	Cin.	Chi.	St.L.	Dollars per 100 lbs		Cents/100 lbs		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Ethylene glycol from ethane (oxidation process).	9	30	.....	.....	1.12	0.67	0.66	0.51	0.96 5.26	-5.17 (SM) -0.87 (ML)	12	11	6
Acrylonitrile from ethane (acetylene) and natural gas (HCN).	23	78	.....	.....	0.84	0.72	0.67	0.70	3.15 7.90	-6.24 (SMSS) -1.49 (MLMM)	25	23	49
Acrylonitrile from natural gas (via acetylene and HCN).	57	195	.....	.....	-0.10	0.19	0.10	0.25	3.54 8.41	-5.35 (SMSS) -1.49 (MLMM)	25	23	52
Acrylonitrile from ethane (ethylene oxide, oxidation process) and natural gas (HCN).	35	119	.....	.....	0.48	0.50	0.45	0.50	1.39 12.89	-11.87 (SSSSM) -0.36 (LLMML)	31	29	50
Acrylonitrile from ethylene oxide, and natural gas (HCN).	42	76	.....	.....	-0.62	-0.35	-0.38	-0.25	3.36 5.23	-2.24 (MSS) -0.36 (LMM)	21	19	45
Ethanolamines from ethane (ethylene oxide, oxidation process) and natural gas (ammonia).	24	82	.....	.....	0.80	0.70	0.65	0.68	1.14 11.00	-11.81 (SSSM) -1.95 (MLLL)	18	17	19
Ethanolamines from ethylene oxide and natural gas (ammonia).	29	55	.....	.....	-0.13	-0.03	-0.06	0.00	5.27 5.40 7.35	-2.16 (MS) -2.02 (MM) -0.07 (LM)	10	9	14
Ethylene oxide from ethane (oxidation process).	* (#)	4	.....	8	1.24	0.97	0.90	0.87	1.37 6.35	-6.15 (SM) -1.17 (ML)	18	17	5
Ammonia from natural gas............	......	.....	13	28	1.61	1.21	1.11	1.03	0.70 0.00	-0.38 (M) -1.08 (S)	3	3	29
Acetic anhydride from natural gas (via acetylene-acetic acid).	21	73	.....	.....	0.57	0.55	0.51	0.65	3.38 8.83	-7.11 (SSSM) -1.74 (MMML)	25	23	17
Acetic anhydride from ethane (via acetylene-acetic acid).	7	24	.....	.....	1.07	0.67	0.60	0.87	3.01 8.35	-7.01 (SSSM) -1.66 (MMML)	25	23	14
Acetic anhydride from ethane (via ethylene-ethanol).	14	57	.....	.....	0.73	0.66	0.61	0.72	0.78 7.17	-7.81 (SSSSM) -1.44 (MMMLL)	25	23	13
Acetic anhydride from acetic acid...	7	23	.....	.....	-0.49	-0.33	-0.35	-0.28	1.78	-0.58 (M)	7	6	......
Acetic acid from natural gas (via acetylene-acetaldehyde).	11	39	.....	.....	0.91	0.77	0.71	0.80	2.63 5.01	-3.71 (SSM) -1.33 (MMM)	14	13	11
Acetic acid from ethane (via acetylene-acetaldehyde).	# # (*)(#)	9	.....	10	1.31	1.02	0.94	0.98	2.34 4.72	-3.62 (SSM) -1.24 (MMM)	14	13	9
Acetic acid from ethane (via ethylene-ethanol).	8	27	.....	.....	1.04	0.85	0.79	0.86	0.60 3.66	-4.25 (SSSM) -1.19 (MMML)	14	13	7
Acetic acid from acetaldehyde.......	9	20	.....	.....	0.11	0.11	0.12	0.20	1.10	-0.45 (M)	3	3	4
Acetic acid from ethanol............	8	29	.....	.....	-0.13	0.11	0.07	0.29	1.07 2.17 2.39	-1.77 (SM) -0.67 (MM) -0.45 (ML)	8	8	7
Acetaldehyde from natural gas (via acetylene).	3	50	.....	.....	0.91	0.76	0.71	0.72	3.38 5.04 5.67	-2.79 (SM) -1.13 (MM) -0.51 (ML)	14	13	10
Acetaldehyde from ethane (via acetylene).	......	.....	10	23	1.55	1.17	1.08	1.00	3.01 4.67 5.18	-2.69 (SM) -1.03 (MM) -0.51 (ML)	14	13	7

Table 15.—SELECT COST DIFFERENTIALS BY PRODUCT AND PROCESS—Con.

Product and process (excludes processes in which process chemicals are locationally important)	Water shipment				Rail shipment				Economies of scale vis-a-vis		Maximum direct labor cost differential	Maximum indirect labor cost differential	Maximum power cost differential
	Natural gas site transport advantage ¢/100 lbs		Market site transport advantage ¢/100 lbs		Maximum market site advantage Dollars per 100 lbs				Small-small combination	Large-large combination			
	Min.	Max.	Min.	Max.	N.Y.	Cin.	Chi.	St.L.	Dollars per 100 lbs		Cents/100 lbs		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Acetaldehyde from ethane (via ethylene-ethanol).	# * (#)	21	.....	7	1.21	0.96	0.88	0.86	0.78 3.03	-3.50 (SSH) - 1.20 (LMM)	14	13	5
Acetaldehyde from ethanol...........	(*)	24	.....	6	-0.29	0.01	-0.05	0.13	1.39	-0.28 (M)	7	6	4
Ethyl alcohol (ethanol from ethane)	* * (*)(#)	6	.....	12	1.47	0.89	0.67	0.67	0.71 1.28 1.76	- 1.68 (SM) -1.09 (MM) -0.61 (ML)	8	7	1
Formaldehyde (37%) from natural gas (via methanol).	*	.....	5	29	1.84	1.36	1.24	1.13	0.35 0.85 1.00	-0.77 (SM) -0.27 (MM) -0.12 (ML)	4	4	15
Formaldehyde (37%) from methanol....	* (*)(*)		8	37	1.24	0.99	0.92	0.85	0.00 0.50 0.62	-0.62 (S) -0.12 (M) 0.00 (L)	3	3	5
Methanol from natural gas...........	* # (#)(#)	12	.....	4	1.35	0.82	0.73	0.62	0.79 0.00	-0.35 (M) -1.14 (S)	3	3	22
Phthalic anhydride from O-Xylene....	# # (#)(*)	5	.....	2	0.37	0.21	0.20	0.40	3.33	-1.32 (M)	8	8	34
Polyvinyl acetate from natural gas (via acetylene and acetylene-acetic acid).	23	79	.....	.....	0.97	0.81	0.76	0.77	3.67 15.81	- 13.69 (SSSSM) -1.55 (MLLLL)	35	32	16
Polyvinyl acetate from ethane (via acetylene and acetylene-acetic acid).	6	20	.....	.....	1.58	1.21	1.12	1.04	3.25 15.29	- 13.58 (SSSSM) -1.55 (MLLLL)	35	32	13
Polyvinyl acetate from ethane (ethylene-acetic acid) and natural gas (acetylene).	11	38	.....	.....	1.40	1.09	1.01	0.96	2.00 14.48	- 14.03(SSSSSMM) -1.55(MLLLLLL)	36	33	11
Polyvinyl acetate from ethane (via ethylene-acetic acid, and acetylene).	20	70	.....	.....	1.07	0.88	0.82	0.81	2.19 14.73	- 14.09(SSSSSMM) -1.55(MLLLLLL)	36	33	13
Polyvinyl acetate from vinyl acetate	1	3	.....	.....	0.30	0.44	0.36	0.45	3.32	-1.55 (M)	14	13	2
Vinyl acetate from natural gas (via acetylene and acetylene-acetic acid).	22	75	.....	.....	0.65	0.41	0.41	0.31	3.60 10.37	-8.65 (SSSM) -1.88 (MLLL)	20	19	13
Vinyl acetate from ethane (via acetylene and acetylene-acetic acid).	5	17	.....	.....	1.25	0.85	0.75	0.57	3.20 9.86	-8.54 (SSSM) -1.88 (MLLL)	20	19	10
Vinyl acetate from ethane (ethylene-acetic acid) and natural gas (acetylene).	19	66	.....	.....	0.75	0.45	0.46	0.35	2.15 9.31	-9.04 (SSSSMM) -1.88 (MLLLLL)	21	19	11
Vinyl acetate from ethane (via ethylene-acetic acid; and acetylene)	10	35	.....	.....	1.07	0.64	0.64	0.49	1.96 9.05	-8.98 (SSSSMM) -1.88 (MLLLLL)	21	20	9
Vinyl acetate from acetic acid and natural gas (acetylene).	14	47	.....	.....	0.06	-0.08	-0.06	-0.18	1.72 7.42	-6.02 (SM) -0.32 (LM)	11	10	6
Vinyl acetate from acetic acid and ethane (acetylene).	5	16	.....	.....	0.33	0.05	0.08	-0.09	1.53 7.23	-5.96 (SM) -0.26 (LM)	11	10	4

Table 15.—SELECT COST DIFFERENTIALS BY PRODUCT AND PROCESS—Con.

Product and process (excludes processes in which process chemicals are locationally important)	Water shipment				Rail shipment				Economies of scale vis-a-vis		Maximum direct labor cost differential	Maximum indirect labor cost differential	Maximum power cost differential
	Natural gas site transport advantage ¢/100 lbs		Market site transport advantage ¢/100 lbs		Maximum market site advantage Dollars per 100 lbs				Small-small combination	Large-large combination			
	Min.	Max.	Min.	Max.	N.Y.	Cin.	Chi.	St.L.	Dollars per 100 lbs		Cents/100 lbs		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Urea from natural gas (via ammonia)	* * (*)(#)	7	.....	11	1.52	1.13	1.06	0.97	0.41 1.15 1.53	-1.31 (SM) -0.38 (ML) 0.00 (LL)	7	6	19
Polyethylene from ethane...........	4	12	.....	.....	1.66	1.26	1.16	1.07	1.22 5.04	-5.33 (SM) -1.50 (ML)	14	13	25
Polystyrene from styrene...........	18	61	.....	.....	-0.62	-0.37	-0.40	-0.27	1.66	-0.77 (H)	10	9	11
GR-S Rubber from butadiene and styrene.	31	75	.....	.....	-0.15	-0.14	0.07	0.06	1.33	-0.63 (H)	7	6	12
Styrene from benzene and ethane (via ethylbenzene).	29	102	.....	.....	-0.07	0.03	0.25	0.35	0.68 8.22	-8.41 (SSL) -0.28 (LLH)	13	12	8
Styrene from ethylbenzene..........	23	79	.....	.....	-0.12	-0.05	-0.07	0.15	2.62	-2.60 (H)	8	8	4
Ethylbenzene from benzene and ethane.	6	19	.....	.....	0.15	0.15	0.31	0.18	0.32 1.82	-2.86 (SM) -1.37 (ML)	4	4	4

sociated with a given product. Columns 1 and 2 list the minimum and maximum transport cost advantage of a natural gas sitelocation when water is the medium of transport for the finished product and for any petrochemical raw material whose shipment by water would be feasible. In the case of ethylene glycol from ethane via the oxidation process (row 1, Table 15) we have listed in columns 1 and 2 the figures 9¢ and 30¢. These were obtained from columns 6 and 7 in Table 4, which presents the total transport cost differential situation for ethylene glycol via the oxidation process. Columns 3 and 4 of Table 15, first row, refer to the minimum and maximum market transport advantage in ethylene glycol production (oxidation process) when water is the medium of transport. Columns 8 and 9 of Table 4 record no such differentials; hence no figures are listed in the relevant boxes of Table 15. However, in the case of other products, e.g. formaldehyde from methanol, an examination of the relevant table in Appendix C shows that transport cost advantages (re: water transport) in favor of a market site location do exist. Such differentials are recorded in columns 3 and 4 of Table 15.

For a relatively few products a computation of net transport cost differentials with reference to water transport reveals that between some pairs of points the transport situation favors a market site location, and between other pairs of points, a natural gas site location. Furthermore, in the production of a given product the transport situation between a given pair of points may favor one type of location if calculated under the assumption of the low set of gas transmission rates and the opposite type of location if calculated under the assumption of the high set of gas transmission rates. An illustration of both these situations is to be found in the production of ethyl alcohol from ethane (Table 15). An examination of the ethyl alcohol table in Appendix C shows that with reference to water transport New York has a transport advantage over Houston, but for the same product Monroe has a transport advantage over Chicago. This holds true when either the low or the high set of gas transmission rates is assumed. However, when we consider the other two pairs of points (Monroe vs. St. Louis, and Monroe vs. Cincinnati) we note that under the assumption of low gas transmission rates a market site location is favored in each case, whereas under the assumption of high gas transmission rates a natural gas site location is favored in each case.

In cases of this kind, figures will be found in columns 2 and 4 of Table 15. They refer, respectively, to the maximum transport cost differential favoring a natural gas site location and to the maximum transport cost differential favoring a market site location. The corresponding spaces in column 1 (except for symbols to be explained below) and in column 3 are left blank, since the minimum transport cost differential in favor of a market site location is the maximum transport cost differential in favor of a natural gas site location with a minus sign prefixed. Similarly, the minimum transport cost differential in favor of a natural gas site location is the maximum transport cost differential in favor of a market site location with a minus sign prefixed. Thus, in the production of ethyl alcohol 6¢ is the maximum transport cost advantage favoring a natural gas site location and -6¢ is the minimum transport cost advantage favoring a market site location; whereas 12¢ is the maximum transport cost differential in favor of a market site location and -12¢ the minimum transport cost differential favoring a natural gas site location.

Table 16.—SELECT COST DIFFERENTIALS BY PRODUCT AND PROCESS

Product and process (includes only processes in which process chemicals are locationally important)	Water shipment				Rail shipment				Economies of scale vis-a-vis		Maximum direct labor cost differential	Maximum indirect labor cost differential	Maximum power cost differential	Maximum chlorine or HCl differential due to power
	Natural gas site transport advantage ¢/100 lbs		Market site transport advantage ¢/100 lbs		Maximum market site advantage Dollars per 100 lbs				Small-small combination	Large-large combination				
	Min.	Max.	Min.	Max.	N.Y.	Cin.	Chi.	St. L.	Dollars per 100 lbs		Cents per 100 lbs			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Ethylene glycol from ethane (chlorhydrin process).	0	15	.....	.....	1.31	0.79	0.78	0.60	0.68 4.10 4.91	-4.69 (SH) -1.27 (MM) -0.46 (LM)	10	9	5	136
Acrylonitrile from ethane (ethylene oxide-chlorhydrin) and natural gas (HCN).	27	91	.....	.....	0.71	0.64	0.59	0.64	0.90 8.59 11.17	-10.65(SSSSH) -2.85(MMMMM) -0.36(LLMML)	27	25	49	176
Ethanolamines from ethane (ethylene oxide-chlorhydrin) and natural gas (Ammonia).	17	58	.....	.....	1.04	0.85	0.79	0.78	0.72 10.30	-11.53 (SSSH) -1.95 (HLLL)	23	22	18	143
Ethylene oxide from ethane (chlorhydrin process).	......	.....	10	20	1.53	1.16	1.31	1.00	0.87 4.26	-4.94 (SM) -1.45 (MM)	14	13	5	173
Polyvinyl chloride from ethane (via ethylene dichloride).	* # (*)(#)	8	.....	9	1.79	1.34	1.23	1.13	0.40 4.45 7.36	-8.25 (SSSH) -4.20 (MMMM) -0.26 (LLLM)	22	20	10	87
Polyvinyl chloride from natural gas acetylene.	20	68	.....	.....	1.09	0.83	0.83	0.82	2.54 6.65	-5.03 (SSM) -1.01 (MLL)	17	15	22	76
Polyvinyl chloride from ethane acetylene.	7	22	.....	.....	1.56	1.19	1.10	1.03	2.14 6.19	-4.94 (SSM) -1.01 (MLL)	17	15	19	76
Vinyl chloride from ethane (via ethylene dichloride).	......	.....	21	46	2.35	1.68	1.54	1.41	3.12	-2.90 (MMM)	11	10	1	78
Vinyl chloride from natural gas acetylene.	# * (#)(#)	20	.....	7	1.71	1.27	1.17	1.13	2.31 3.89	-2.73 (SH) -1.14 (ML)	6	6	11	69
Vinyl chloride from ethane acetylene.	......	.....	14	31	2.15	1.65	1.42	1.32	1.95 3.56	-2.65 (SH) -1.14 (ML)	6	6	9	69
Phenol from benzene.................	15	51	.....	.....	0.38	0.31	0.51	0.55	4.50	-1.11 (M)	15	14	10	8
Ethylene dichloride from ethane.....	......	.....	6	29	1.92	1.41	1.29	1.17	0.35 1.57 2.77	-2.66 (SM) -1.44 (MM) -0.24 (LM)	5	4	1	74
Ethyl chloride from ethane (via ethylene and HCl).	......	......	19	41	2.08	1.52	1.40	1.28	0.53 3.08	-3.44 (SM) -0.90 (ML)	6	5	2	60
Ethyl chloride from ethane (chlorination process).	......	.....	21	45	2.13	1.56	1.43	1.30	1.36	-1.62 (M)	4	4	1	59
Methyl chloride from methane (chlorination process).	......	.....	21	44	2.12	1.56	1.43	1.30	14.03	-1.79 (M)	19	18	2	90
Methyl chloride from methanol.......	* (*)(*)	.....	18	29	0.97	0.85	0.60	0.78	8.20	-0.70 (M)	18	17	2	50
Methyl chloride from natural gas (via methanol).	*	.....	14	30	1.93	1.43	1.32	1.21	0.55 8.20	-9.15 (SM) -1.50 (MS)	20	19	17	80

A further examination of the ethyl alcohol table in Appendix C shows that under conditions of water transportation of finished product and of low gas transmission rates the best location for serving the Eastern Seaboard market is at New York. (New York enjoys a 12¢ transport cost advantage over Houston.) This fact is indicated in Table 15 by the left hand symbol * in the ethyl alcohol row of column 1. Under the same conditions the most favorable locations for serving the majority of inland markets are also market locations (Cincinnati and St. Louis rather than Monroe). This is indicated by the right hand symbol * in column 1. Under conditions of high gas transmission rates the best location for serving the Eastern Seaboard market is again New York (rather than Houston). This is shown by the left hand symbol (*) in column 1 of Table 15. However, the best location for serving interior markets is Monroe (rather than Cincinnati, Chicago, or St. Louis). This is indicated in Table 15 by the right hand symbol (#) in column 1. The same scheme is used throughout Tables 15 and 16 wherever there exist for the same product water transport cost differentials favoring both market site and natural gas site locations. In every case the symbol * indicates a differential favoring a market location; the symbol # indicates a differential favoring a natural gas site location; symbols without parentheses indicate conditions of low gas transmission rates; symbols within parentheses indicate conditions of high gas transmission rates; the two left hand symbols refer to locations serving the Eastern Seaboard; the two right hand symbols refer to locations serving interior markets.[99]

In Table 15, columns 5, 6, 7 and 8 indicate the maximum market site advantage over an AWR location when the product and petrochemical raw materials (except those which are piped) are shipped by rail. In the instances when only a disadvantage exists, the smallest disadvantage is indicated and is identified by a minus sign.

Columns 9 and 10 of Table 15 record relevant materials on economies of scale. Column 9 lists the advantages of selected combinations over a combination which involves all small units. Column 10 lists the disadvantages (minus signs) of selected combinations over a combination which contains all large units. So far as possible the relevant combinations for each product have been selected in such a way that in any row the top figure in column 9 and the bottom figure in column 10 (minus sign disregarded) are of the same order of magnitude as the rail transport advantages listed for market sites. This permits an easy identification of that "minimum scale natural gas site combination" whose economies of scale relative to a small-small ... market site combination would offset the rail transport advantage enjoyed by the market site location. Also, one can identify the "minimum scale market site combination" whose rail transport advantage would overbalance its diseconomies of scale relative to a large-large ... natural gas site combination. As an example, consider the production of ethyl alcohol from ethane. In column 9 of the ethyl alcohol row of Table 15 the top figure listed is $0.71 and relates to a small-medium combination. The rail transport advantages of a market site location as listed in columns 5, 6, 7, and 8 range from $1.47 to $0.67. We conclude therefore that any natural gas site combination with a scale greater than small-medium will obtain scale economies more than sufficient in most cases to counterbalance the rail transport advantage of a small-small market site combination. On the other hand, in the ethyl alcohol row the middle figure in column 10 is $1.09 and is associated with a medium-medium combination. This indicates that for all markets, save New York, a market site combination must have a scale larger than medium-medium, or else its rail transport cost advantage will be more than balanced by its diseconomies of scale vis-a-vis a large-large natural gas site combination.

It will be noted that in some instances the top figure in any given row of column 9 is considerably larger than any of the rail transport differentials in the same row. In all such cases the column 9 figure relates to a combination one degree larger than small-small ..., e.g., small-medium or small-small-small-medium. In these instances any natural gas site combination with a scale of larger than small-small ... can secure economies of scale much more than sufficient to offset the rail transport advantage of a small-small ... market site combination.

In a few instances the rail transport advantage figures are negative. This indicates that there is a rail transport advantage in favor of the natural gas site locations, and that any scale economies of a natural gas site location or scale diseconomies of a market site location would simply strengthen the already existing pull toward the natural gas site location.

The combinations selected in each case are identified by the symbols S, M, and L; where S stands for small units, M for medium size units and L for large units. Since the manufacture of the products listed in Table 15 require from one-unit to seven-unit combinations, the number of corresponding symbols ranges from one to seven. The first symbol refers to the size of the final product unit; the second and others in order to the successively lower stages of manufacture. For example, in the production of acetaldehyde from ethane the symbols SSM indicate a combination including a small acetaldehyde unit, a small ethyl alcohol unit, and a medium ethylene unit.

Finally, in columns 11, 12, and 13, we list, respectively, maximum direct labor cost differentials, maximum indirect labor cost differentials, and maximum power cost differentials. These are derived as indicated above.

Table 16 differs from Table 15 in that a 14th column is added which indicates the maximum chlorine or HCl differential due to power account. The significance of the data in this column has already been discussed in connection with the location of ethylene glycol plants using the chlorhydrin process.

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[99] In connection with the production of ethylene oxide, formaldehyde, and acetaldehyde (Table 15) and methyl chloride (Table 16) we deviate somewhat from the above practice in ways to be noted below.

13. Distribution of Individual Petrochemical Expansions Among Natural Gas Areas

In any analysis of the location of a particular process the geographic distribution of markets is a critical factor. In the case of an industry such as the automobile industry the market is easily established once the geographic distribution of population is effectively weighted by income, family type, occupation, and a few other strategic variables. With petrochemicals, however, the determination of the geographic distribution of markets is much more complicated. One petrochemical feeds into another, and ultimately into non-petrochemical products, some of which in turn feed into still other non-petrochemical products. It is beyond the terms of reference of this report to consider the geographic distribution of production facilities for non-petrochemicals, which effectively becomes the geographic distribution of markets for those petrochemical products which directly enter into the non-petrochemical products. In the case of ethylene glycol, we could roughly determine the geographic distribution of the market for that portion of ethylene glycol which entered into antifreeze production by observing the geographic distribution of cold-weather population. Also, we had some information on the future geographic pattern of dacron production which was helpful to some extent in estimating the geographic pattern of expansion of ethylene glycol facilities to serve new dacron plants. However, we did not possess any information on the future geographic distribution of expansions in the diverse plants which consume ethylene glycol and which account for the "other uses" of ethylene glycol. Since the determination of the future geographic distribution of these expansions does not fall within the scope of this report and would require resources well beyond those available for this study, we were forced to make a simplifying assumption. Lacking a better alternative we postulated that the future geographic distribution of these expansions would correspond to the current geographic distribution of population.[100] Likewise, we shall be forced to use this assumption for other petrochemical products which enter into non-petrochemical production, when we do not possess any information on the future geographic distribution of relevant non-petrochemical expansions.

To minimize the errors which creep into the analysis because of simplifying assumptions of this type it is clearly desirable to begin with those petrochemical products which directly enter into non-petrochemical production. Then we proceed backward in order through tertiary, secondary, and primary petrochemical intermediates, determining for each one its geographic pattern of production and thus the geographic market pattern of the next lower intermediate.

Acrylonitrile:[101] One petrochemical which feeds into what we have defined as a non-petrochemical is acrylonitrile. Relevant data on location forces in acrylonitrile production are given in rows 2, 3, 4 and 5 of Table 15 and row 2 of Table 16. Each row refers either to production from a different set of raw materials or to production in which different numbers of stages are combined. Thus, row 2 of Table 15 refers to acrylonitrile production based on acetylene manufactured from ethane and HCN manufactured from natural gas via ammonia. The basic raw materials are ethane and natural gas, and the number of productive stages or units is four: the acrylonitrile unit, the acetylene unit, the HCN unit, and the ammonia unit.

Row 3 of Table 15 presents data relative to the production of acrylonitrile based upon (1) acetylene manufactured from natural gas and (2) HCN manufactured from natural gas via ammonia. For such production again a combination of four units is required. Such a combination contains an acrylonitrile unit, an acetylene unit, an HCN unit, and an ammonia unit.

Row 4 of Table 15 relates to the production of acrylonitrile from a different major raw material, ethane based ethylene oxide (instead of acetylene), together with natural gas based HCN. The relevant production combination in this case contains five units, each of which yields one of the following products: acrylonitrile, ethylene oxide, ethylene, HCN, and ammonia.

Row 2 of Table 16 also concerns the production of acrylonitrile from ethane based ethylene oxide and natural gas based HCN. Here the ethylene oxide is produced by the chlorhydrin process. Thus the chlorine differential becomes significant and must be calculated. The process involves five units which are the same as the ones listed for the process described immediately above.

Finally, row 5 of Table 15 relates to the production of acrylonitrile from ethylene oxide and natural gas (for HCN). This process differs from the two just described in that production begins with the intermediate, ethylene oxide, rather than with the basic raw material, ethane (from which ethylene and thence ethylene oxide are produced). It is necessary to analyze such a process because in assessing the attractiveness of a market site location we must determine whether it is more favorable to import the basic ethane raw material and integrate all operations at the market; or to import the intermediate ethylene oxide and thus eliminate from a market complex the ethylene and ethylene oxide units. It is clear from the data in Table 15 that from a rail transport and market location standpoint the process which starts from ethylene oxide is definitely less favorable than the process which starts from ethane. The rail transport advantages of the latter contrast with the rail transport disadvantages of the former. Since both processes suffer transport disadvantages relative to natural gas site locations when

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[100] It was on the basis of this market assumption that we proceeded to distribute among regions the expansion of ethylene glycol facilities to meet the requirements of these "other users."

[101] For an interesting description and comparison of the different methods of producing acrylonitrile, see R.F. Messing and H.L. James, "Acrylonitrile: CIW Report." *Chemical Industries Week* Vol. 68, January 27, 1951, pp. 19-24.

water shipment of product is feasible a comparison of the two on this basis is not significant. We conclude that in general any acrylonitrile production which may develop *outside natural gas site locations* should start with ethane and not with ethylene oxide *provided the acrylonitrile unit is of large scale or provided economies of scale and chlorine advantages in the production of ethylene oxide in the AWR and other regions do not dictate otherwise*.[102]

Certain location forces are clear-cut in the production of acrylonitrile. One is the major transport advantage of a natural gas site when water shipment of the product is feasible. For example, the minimum such advantage in any of the relevant five rows of Tables 15 and 16 is 23¢ (row 2, Table 16). A second is the relatively small transport advantage of market sites when rail shipment is used. Row 2 of Table 16 shows the maximum such advantage of all five rows; this advantage ranges from 67¢ to 84¢. A third relates to the major economies of scale which are obtainable. For example, the data of row 2 of Table 15 show that a combination of three medium units and one large unit realizes economies of scale relative to a combination of all small units of $7.90 per hundred pounds acrylonitrile. These factors suggest a strong orientation of acrylonitrile production to natural gas sites.

This interpretation of the data requires qualification. To the extent that chlorine processes are utilized in the production of acrylonitrile, the pull of the AWR region relative to a large-large ... combination in the Ohio Valley is less pronounced. Also, to the extent that acetylene is produced by the calcium carbide process which can utilize the coal deposits and the cheap power of the Ohio Valley, the pull of the AWR relative to the Ohio Valley is once again overstated.

In the light of these data and qualifications as well as numerous other relations, and on the assumption of no major change in technological structure, it is our considered judgment that at least 70% of the increase in national demand for acrylonitrile will be met by expansion of facilities in the Gulf Coast and AWR regions. This 70% is to be divided between these regions in much the same manner as were the new facilities designed to produce ethylene glycol required by new dacron and other plants (excluding antifreeze). The new acrylonitrile will be used in the production of synthetic fibers, synthetic rubber, and plastics.

Consequently, as a starting point, we employ 58.9% and 41.1% (hereafter called the standard percentages) to represent the shares of the increases in both the national market and the Southern demand for synthetic polymers to be served by the Gulf Coast area and the AWR area, respectively, if all production were at natural gas sites. However, 30% of acrylonitrile production is expected to be outside the natural gas regions; and more specifically, 21.4% in the Ohio Valley at the expense of the AWR region, and 8.6% in other locations at the expense of the Gulf Coast region. Thus, it is estimated that 50.3% of the increase in the national demand for acrylonitrile will be served by the Gulf Coast area, and 19.7% by the AWR region. Multiplying these percentages by 1,275 million pounds (the estimated expansion of annual acrylonitrile production from 1950 to 1975) yields figures of 641 million annual pounds for the Gulf Coast and 251 million annual pounds for the AWR. If it is assumed that the AWR share will be produced in five plants, each of 50 million pounds annual capacity, we estimate that 205 new employees will be engaged in operations and maintenance work.

Hydrogen Cyanide:[103] The production of acrylonitrile requires hydrogen cyanide (HCN). For practical purposes HCN is non-transportable. Hence, the HCN output required by an acrylonitrile plant must be produced in a unit regionally juxtaposed to the acrylonitrile plant.

We have estimated that acrylonitrile expansions in the Gulf Coast and the AWR regions will be 641 million annual pounds and 251 million annual pounds, respectively. Since approximately 0.66 pounds of HCN are required per pound acrylonitrile, we expect HCN capacity in the Gulf Coast and AWR regions to increase by 423 million annual pounds and 166 million annual pounds, respectively.[104] It is estimated that the expansion in the AWR region will employ 42 laborers for operations and maintenance work, on the assumption that the HCN is produced in three plants of from 50-60 million annual pounds capacity.

Ethanolamines: Both acrylonitrile and ethylene glycol are estimated to be major users of ethylene oxide in the future. Ethanolamines, a set of products which serve diverse end uses, is estimated to be a smaller, but still a substantial user of ethylene oxide.

The data in rows 6 and 7 of Table 15 and row 3 of Table 16 present a clear-cut picture of major advantage of Gulf Coast and AWR locations for ethanolamines production. There are: (1) large transport cost differentials in favor of natural gas sites when water transportation is feasible; (2) modest transport disadvantages, and even in some cases positive transport advantages, for natural gas sites when rail shipment is used; and (3) major economies of scale. We therefore estimate that 75% of the expansion in ethanolamines production (120 million annual pounds from 1950 to 1975) will occur in the Gulf Coast and AWR regions. Applying our standard percentages for dividing up a diversified national market between Gulf Coast and AWR locations, and allowing for the Ohio Valley's possible chlorine advantage rel-

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[102] There could also have been included in Table 15 data pertaining to processes wherein acrylonitrile production starts with the intermediate, ammonia (for HCN production), rather than the raw material, natural gas; and either ethylene oxide or ethane. We have in fact carried out such analyses, but in all cases such processes have proved less favorable for a market location than the processes listed in Table 15. They are therefore not included. In general, the same holds true for all the different products and processes we analyze. Processes have been omitted which are definitely less advantageous from a market location standpoint than others which yield the same product from the same raw materials. It should be noted that this problem does not arise in the consideration of natural gas site production. In such production the raw materials for all intermediates and products are available at the natural gas sites. Hence all production is assumed to start with the basic raw materials.

[103] Sources of relevant technical and process information are: James A. Lee, "Hydrogen Cyanide Production," *Chemical Engineering*, Vol. 56, February 1949, pp. 134-136; and Norman Updegraff, "Hydrogen Cyanide," *Petroleum Refiner*, Vol. 32, September 1953, pp. 197-201.

[104] Other uses of HCN in the production of petrochemicals and related products have not yet been clearly identified.

ative to the AWR region,[105] we anticipate that 48.1% and 27.9% of the national expansion will fall in the Gulf Coast and AWR regions, respectively. This yields expansions of 58 million annual pounds for the Gulf Coast and 33 million annual pounds for the AWR region. We estimate that 16 laborers would be employed in operations and maintenance work in an AWR ethanolamines plant of approximately 33 million pounds annual capacity.

Ethylene Oxide:[106] In addition to use in ethylene glycol, acrylonitrile, and ethanolamines production, ethylene oxide is consumed in units manufacturing a host of other chemical products whose output is small volume-wise and which we shall not discuss in this report. Therefore we are in a position to project likely expansion of ethylene oxide in the AWR region.

For obvious reasons, it is our belief that all the ethylene oxide required for AWR production of ethylene glycol, acrylonitrile, and ethanolamines will be produced in the AWR region. Given current practices, the expansion of 145 million annual pounds of ethylene glycol production will require approximately 100 million annual pounds of ethylene oxide; and the expansion of 33 million annual pounds of ethanolamines will require 26 million annual pounds of ethylene oxide.

It is not clear how much of the acrylonitrile expansion will be dependent upon ethylene oxide, and how much upon acetylene. Informed persons have indicated that the acetylene process for producing acrylonitrile will be more efficient than the ethylene oxide process if expectations on the feasibility of producing cheap tonnage acetylene materialize. Since there is no firm assurance that such cheap acetylene will be available, we arbitrarily posit that 50% of the acrylonitrile will be produced from acetylene and 50% from ethylene oxide.[107] Consequently, we estimate that approximately 128 million annual pounds of ethylene oxide will be required to produce 125 million annual pounds of acrylonitrile (one-half the AWR acrylonitrile expansion).

In addition, the AWR region may produce ethylene oxide for use in the new acrylonitrile and ethanolamines facilities which will be erected outside the AWR region.[108] This is especially so since Coast Guard restrictions, which are likely to remain in force, forbid the shipment of ethylene oxide on the high seas. As a result, AWR natural gas sites can generally out-compete Gulf Coast sites for all major markets in the United States except those in the Gulf Coast area itself.

Row 8 of Table 15 and row 4 of Table 16 indicate that it is only on scale account that the AWR has any clearcut advantage in the production of ethylene oxide for markets outside the Gulf Coast and AWR regions. Generally speaking, the AWR's transport situation is disadvantageous both by rail and water, and relative to the Ohio Valley, the AWR's position is probably disadvantageous in chlorine production. We therefore estimate that there will be produced in the AWR region only 15% of the 219 million annual pounds of ethylene oxide required to produce the 191 million annual pounds of acrylonitrile (50% of the acrylonitrile expansion) and 30 million annual pounds of ethanolamines in areas outside the Gulf Coast and AWR regions.

Finally, an expansion of 250 million annual pounds of ethylene oxide is estimated to be required by 1975 by such diverse chemicals as polyglycols, glycol ethers, and detergents. Since in supplying these markets the AWR is in a superior position to the Gulf Coast area, and since the AWR has a scale advantage but not a transport advantage over market sites, we estimate that at least 25% of the expansion of ethylene oxide for these needs will be provided from AWR production.

In sum, given the validity of the assumptions we are forced to make, we expect that there will be an expansion of 350 million annual pounds of ethylene oxide capacity in the AWR by 1975.[109] Assuming that five plants of approximately 70 million pounds annual capacity are constructed, we estimate that 218 laborers will be required to operate and maintain these plants.

Ammonia:[110] In absolute terms ammonia will experience the greatest expansion of all petrochemicals, according to industry experts. From 1951 to 1975 an expansion in capacity of 6,800 million annual pounds is expected.

The data in the ammonia row of table 15 depict marked transport advantages for market sites whether shipment is by water or rail. Economies of scale are small, and further, since ammonia demands are usually large in major metropolitan regions and their hinterlands, it is to be expected that AWR locations will not have any significant scale advantages over major metropolitan regions. We therefore conclude that the AWR plants will serve AWR needs and a very small fraction of needs outside the AWR region. We estimate that at least 7 1/2%, 510 million annual pounds, of national expansion in ammonia production will occur in the AWR region.[111] Two plants, each of 250-260 million pounds annual capacity would require approximately a total of 122 laborers for operations and maintenance work.

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[105] With respect to the chlorhydrin process for producing ethylene oxide.

[106] In Table 15 the symbols in the first column of the row for ethylene oxide from ethane (oxidation process) relate only to the most favorable locations for serving interior markets. Because of the Coast Guard restrictions on high-seas shipment of ethylene oxide, no computation was made of water transport cost differentials for locations serving the Eastern Seaboard markets.

Material balances, utilities requirements, and other process information relative to ethylene oxide production can be found in *B.I.O.S., Final Report*, No. 1059, item No. 22-30; J.R. Skeen, "Ethylene Oxide," *Chemical Engineering*, Vol. 57, July 1950, pp. 321, 322, 324; and the Lummus Co., *op.cit.*

[107] The reader who postulates otherwise can easily alter the figures on ethylene oxide and acetylene expansions in the AWR to be consistent with his evaluation of this competitive situation. In any case, the ethylene oxide or acetylene input will tend to be produced in the AWR region.

[108] For several technical reasons, ethylene oxide and ethylene glycol production tend to be spatially linked. Thus, we do not consider the export of ethylene oxide from the AWR region for use in ethylene glycol plants and elsewhere.

[109] Assuming that the Gulf Coast region will account for 15% of the expansion in such diverse chemicals as polyglycols, glycol ethers and detergents, and that the Gulf Coast region will produce the ethylene oxide required for its new facilities to produce these products as well as ethylene glycol, acrylonitrile, and ethanolamines, we estimate for the Gulf Coast area an expansion in the output of ethylene oxide of 596 million annual pounds.

[110] For additional materials see L.C. Skinner, H.R. Batchelder and S. Katell, "Comparative Cost Study of Ammonia Plants," *Industrial and Engineering Chemistry*, Vol. 44, October 1952, pp. 2381-2385; and W.H. Shearon, Jr., and H.L. Thompson, "Ammonia at 1,000 Atmospheres," *Ibid.*, Vol. 44, February 1952, pp. 254-264.

[111] A conservative estimate would allocate 15% of the expected national expansion in ammonia facilities (1,020 million annual pounds) to the Gulf Coast region.

Acetic Anhydride:[112] Currently, rayon plants are the largest consumers of acetic anhydride. It is expected that by 1975 their consumption will rise by 900 million annual pounds. Use of acetic anhydride in plastics and resins and other products will mount by at least 100 million annual pounds.

The data in the rows corresponding to acetic anhydride in Table 15 reveal: (1) clear-cut transport advantage for natural gas site locations when the product is shipped by water; (2) transport advantage for market site locations when the product is shipped by rail, except when produced from acetic acid; and (3) major economies of scale. Considering the historical pattern of production, the current concentration of new rayon facilities in the South and various other forces at play, we judge that at least 55% of the new expansion in acetic anhydride facilities will occur in the Gulf Coast and AWR regions. Applying our standard percentages we obtain expected expansions of 324 million annual pounds and 226 million annual pounds in the Gulf Coast and AWR regions respectively, by 1975. The AWR expansion would require 75 laborers for operation and maintenance work if the annual capacity of the new plants to be constructed is taken to be 110-115 million pounds.

Acetic Acid:[113] The major use of acetic acid is for the production of acetic anhydride.[114] We calculate that 289 million annual pounds of acetic acid will be required to produce the 226 million annual pounds of acetic anhydride by which AWR production is expected to expand by 1975. The data of the acetic acid rows in Table 15 strongly suggest that the 289 million annual pounds is likely to be produced in the AWR region. In addition, the AWR will undoubtedly produce the 180 million annual pounds of acetic acid required by its estimated expansion of vinyl acetate production (253 million annual pounds by 1975).[115]

Finally, the AWR region may export acetic acid to other regions (except the Gulf Coast) for the production of acetic anhydride and for use as a solvent in acetate production. We estimate that the requirements for acetic acid in expanded acetic anhydride production in areas outside the Gulf Coast and AWR regions will be at least 576 million annual pounds, and that the additional requirements for acetic acid as a solvent and for other diverse uses will be 500 million annual pounds. It appears from the pertinent rows in Table 15 that the natural gas locations possess both major scale advantages and substantial advantages in transport when water shipment obtains. However, in view of the historical pattern of production and in view of the alternative of exporting ethyl alcohol rather than acetic acid for conversion into acetic anhydride, we judge that at least 25% of the expanded acetic acid requirements in markets outside the Gulf Coast and AWR regions will be met by production in these latter two regions. Applying our standard percentages we obtain additional capacity expansion in the AWR of 110 million annual pounds.

Altogether, we except the AWR expansion in acetic acid production to be 579 million annual pounds by 1975.[116] Approximately 99 laborers in operations and maintenance work will be required to produce this output in plants of 130-140 million annual pounds capacity.

Acetaldehyde:[117] The major uses of acetaldehyde are for the production of acetic acid and acetic anhydride. The geographic linkages between acetaldehyde and its derivatives are strong; and it is traditional for companies producing acetaldehyde to use the acetaldehyde in the same plant for further processing into other chemicals, primarily acetic anhydride and acetic acid. It is therefore our judgment that the Gulf Coast and AWR regions will produce the acetaldehyde they require and together export only a very small fraction of the acetaldehyde required by other regions, advantages of scale notwithstanding. New exports of acetaldehyde from the Gulf Coast and AWR regions are thus projected to be negligible.

Hence, we expect acetaldehyde production in the Gulf Coast and AWR regions to expand by 665 and 447 million annual pounds, respectively. The AWR expansion would entail an increase in employment of 227 laborers for operations and maintenance work, if six new plants (three ethanol-acetaldehyde plants and three acetylene-acetaldehyde plants) were erected, each having an annual capacity of approximately 75 million pounds.

Ethyl Alcohol:[118] It is estimated that ethyl alcohol production will expand by at least 4,000 million pounds from 1950 to 1975. Of this, at least 60% will be based on ethylene and will consume raw materials from primarily natural gas areas.

We judge that the ethyl alcohol required for the expansion in acetaldehyde production in the Gulf Coast and AWR regions will be produced by these regions. On this account alone, the increase in the production of ethyl alcohol in the Gulf Coast and AWR regions would be 316 and 245 million annual pounds, respectively.[119]

The data in the ethyl alcohol row of Table 15 do not depict the presence of any clearcut water transport advantage for either market or natural gas sites. They indicate transport advantage of

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[112] Pertinent data on the production of acetic anhydride from acetic acid are found in *B.I.O.S., Final Report*, No. 1600, item No. 22.

[113] Raw materials and other requirements for the production of acetic acid from acetaldehyde are given in *B.I.O.S., Final Report*, No. 1032, item No. 22.

[114] A second important use is as a solvent in acetate production. In addition, there are a number of other, diverse uses.

[115] See section below on vinyl chloride and vinyl acetate for basis of this vinyl acetate estimate.

[116] By similar calculations, we expect the Gulf Coast expansion in acetic acid production to be 864 million annual pounds by 1975.

[117] In Table 15 the symbols in the first column of the rows for acetaldehyde from ethane (via ethylene-ethanol) and for acetaldehyde from ethanol indicate that under conditions of low gas transmission rates the first process is more favorable than the second from the standpoint of minimum transport costs. But under conditions of high gas transmission rates, the second process is in a more favorable transport situation than the first to supply the requirements of interior markets for acetaldehyde produced from AWR raw materials. The most favorable *location* for production is indicated as usual by the type of symbol which characterizes each case.

For useful information on the production of acetaldehyde from acetylene see *B.I.O.S., Final Reports*, No. 75, item No. 22, and No. 370, item No. 22.

[118] Raw material and utilities balances, chemical reactions and other technical data on the production of ethylene-based ethyl alcohol are presented in Faith, Keyes, and Clark, *op.cit.*, pp. 306-312.

[119] Assuming one half of total acetaldehyde is produced via ethanol.

market sites under conditions of rail shipment. Considering these relations, the economies of scale attainable at natural gas sites, and other factors, we judge that at least 25% of the nation's increase in requirements for ethylene based ethyl alcohol (excluding requirements for acetaldehyde production in the Gulf Coast and AWR regions) will be furnished by the Gulf Coast and AWR regions. Application of our standard percentages and the appropriate addition of the Gulf Coast's and AWR's acetaldehyde requirements for ethyl alcohol yield figures of 587 and 434 million annual pounds. These are our estimates of the Gulf Coast and AWR shares of the expansion in annual ethyl alcohol production, 1950-75. If three new plants, each with an annual capacity of 140-145 million pounds, were erected in the AWR region, approximately 133 laborers would be required for operations and maintenance work under conditions of continuous operations.

Formaldehyde (37%):[120] Major uses of formaldehyde are in the production of phenolic resins and plastics, and urea resins and plastics. These together with other uses are expected to raise requirements for 37% formaldehyde by 2,648 million annual pounds, from 1950 to 1975.

It is clear from the data in the formaldehyde rows in Table 15 that market sites have definite transport advantages under conditions of both rail and water shipment. Further, economies of scale are rather small in the production of this chemical. We therefore judge that a minimum of 15% of the national expansion in formaldehyde production will occur in the Gulf Coast and AWR regions. Applying our standard percentages yields 234 and 163 million pounds as estimates of the required new annual capacity for 37% formaldehyde in the Gulf Coast and AWR regions respectively. The corresponding increase in employment in the AWR region for operations and maintenance work should be approximately 33 laborers, if we assume one new plant of 160-165 million pounds annual capacity.

Methanol:[121] The chief current uses and expected future uses for methanol are in the production of formaldehyde and antifreeze.

We expect the methanol requirements for increases in formaldehyde output in both the Gulf Coast and AWR regions to be produced in these regions. Further, in view of (1) the lack of any clearcut transport cost differentials under conditions of water shipment, (2) the transport advantage of market points under conditions of rail shipment, and (3) the relatively small economies of scale, we judge that a minimum of 25% of the expansion in requirements for methanol for various uses (excluding requirements for formaldehyde production in the Gulf Coast and AWR regions) will be furnished by producers in the Gulf Coast and AWR regions.

From 1950 to 1975 the expansion in requirements of methanol for all uses is expected to be 1,968 million annual pounds. Our estimate of expansion in requirements of methanol for increases in formaldehyde production in the Gulf Coast and AWR regions is 175 million annual pounds. Therefore, we obtain, after applying our standard percentages, and after appropriately adding requirements for new Gulf Coast and AWR formaldehyde production, expansions in production of methyl alcohol in the Gulf Coast and the AWR regions of 367 and 256 million annual pounds, respectively. The AWR expansion would entail an increase in employment of 65 laborers for operations and maintenance work in a methanol plant of approximately 256 million pounds annual capacity.

Phthalic Anhydride: Currently, phthalic anhydride is produced primarily from naphthalene, a coal chemical. In the future it is expected to be produced increasingly from ortho-xylene, a petroleum derivative. As already indicated, we do not anticipate much expansion of petroleum refining in the AWR region. Further, under usual circumstances only relatively small quantities of ortho-xylene are derived from a barrel of crude oil. As a consequence, large refinery operations are generally required to yield modest amounts of ortho-xylene. Hence it is our belief that there is no firm basis for projecting any significant expansion of phthalic anhydride in the AWR region.

Polyvinyl Acetate and Polyvinyl Chloride:[122] It is difficult at the present time to predict which of the two polyvinyl products, polyvinyl acetate and polyvinyl chloride, will dominate the future production of vinyl plastics. For this reason treatment of the two as a single aggregate is desirable. The President's Materials Policy Commission anticipates that from 1950 to 1975 the expansion in the production of these vinyl plastics may be as much as 1,619 million annual pounds.

Examination of the data in the rows corresponding to polyvinyl acetate in Table 15 and polyvinyl chloride in Table 16 indicates: (1) significant transport cost differentials in favor of natural gas sites under conditions of water shipment, except in the case of polyvinyl chloride produced from ethane via ethylene dichloride; (2) transport cost differentials in favor of market sites under conditions of water shipment; and (3) marked economies of scale. Should polyvinyl chloride be produced in large quantities in the future, the chlorine or HCl differential due to power will probably favor the Ohio Valley at the expense of the AWR region. At the same time the AWR and the Gulf Coast will have a chlorine advantage relative to a number of other regions.

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[120] In Table 15 the symbols in the first column of the rows for formaldehyde from natural gas and formaldehyde from methanol indicate that under conditions of low gas transmission rates the first process is in a more favorable water transport situation than the second to supply the requirements of coastal markets for formaldehyde produced from Gulf Coast raw materials. However, for serving all markets under conditions of high gas transmission rates, and for serving interior markets (using AWR raw materials) under conditions of low transmission rates, the second process is more favorable than the first, from a minimum water transport cost standpoint. In all cases the most favorable *location* is at the market.

Useful references on formaldehyde production are: *B.I.O.S., Final Report*, No. 978, item No. 22; and R.N. Hader, R.D. Wallace, and R.W. McKinney, "Formaldehyde from Methanol," *Industrial and Engineering Chemistry*, Vol. 44, June 1952, pp. 1508-1518.

[121] For supporting materials see Vulcan Engineering Division, The Vulcan Copper and Supply Co., "Methanol," *Petroleum Refiner*, Vol. 32, September 1953, pp. 191-193.

[122] For general technical information and process descriptions relating to the production of the various polyvinyls, see Calvin E. Schildknecht, *Vinyl and Related Polymers*, New York, 1952. Polymerization of vinyl chloride is described in S.G. Bankoff and R.N. Shreve, "Vinyl Chloride Polymerization Procedure," *Industrial and Engineering Chemistry*, Vol. 45, February 1953, pp. 270-276. Yield figures and utilities requirements for the production of polyvinyl chloride from vinyl chloride are given in *B.I.O.S., Final Reports*, No. 101, item No. 22, and No. 999, item No. 22.

Considering all factors we judge that at least 65% of the increase in production of these polyvinyl products will be accounted for by new plants in the Gulf Coast and AWR regions. Applying our standard percentages and allowing for a greater deviation of production to the Ohio Valley from the AWR region than from the Gulf Coast area,[123] we estimate an increase in production of polyvinyls of 784 and 269 million annual pounds for the Gulf Coast and AWR regions respectively. The operation and maintenance in the AWR of two new polyvinyl chloride plants and two new polyvinyl acetate plants, each of 65-70 million pounds annual capacity, would require approximately 177 laborers.

Vinyl Acetate and Vinyl Chloride:[124] Since it is infeasible to identify separately the future magnitudes of the production of polyvinyl acetate and polyvinyl chloride, it is likewise infeasible to identify separately the future magnitudes of the production of vinyl acetate and vinyl chloride, which are the respective intermediates. Analysis must proceed in terms of the aggregate of these two products.

Both the rows on vinyl acetate in Table 15 and on vinyl chloride in Table 16 indicate marked economies of scale. However, when we consider transport cost differentials under conditions of water shipment, vinyl chloride definitely favors market locations whereas vinyl acetate definitely favors natural gas sites. These two seemingly different sets of location forces do not result, however, in conflicting location patterns.

It has already been indicated that 65% of the new capacity of polyvinyl chloride and polyvinyl acetate will be at natural gas sites. Since the geographic pattern of production of polyvinyl chloride and of polyvinyl acetate is the geographic pattern of markets for vinyl chloride and vinyl acetate, we have a situation where both markets and raw material sites largely coincide, and coincide at the natural gas sites in the AWR and Gulf Coast regions. Bearing in mind that as much as 15% of the expansion in vinyl chloride and vinyl acetate may flow into synthetic fibers, and weighing the major economies of scale and other considerations, we judge that at least 75% of the national expansion in vinyl chloride and vinyl acetate production will occur in the Gulf Coast and AWR regions. Application of our standard percentages, qualified as in the case of the polyvinyls by consideration of the Ohio Valley's greater pull away from the AWR than from the Gulf Coast, yields estimated expansions of vinyl chloride and vinyl acetate production in the Gulf Coast and AWR of 1,038 and 506 million annual pounds, respectively. In the AWR, 173 additional laborers would be required for operations and maintenance work, if we assume the construction of 2 new plants to produce vinyl chloride from ethylene dichloride, 2 new plants to produce vinyl chloride from acetylene, and 4 new plants to produce vinyl acetate.[125]

Urea:[126] Urea is a petrochemical which finds its chief uses in the production of fertilizers and plastics. By 1975 we estimate that the requirements of urea will have risen to at least 760 million annual pounds, an increase of 500 million over 1950.

The data in the urea row of Table 15 do not show any definite transport advantage, either for market sites or natural gas sites, under conditions of water transport. There are transport advantages for market sites under conditions of rail shipment. And there are modest economies of scale in the production of urea. In the light of these and other considerations, and of the linkage of ammonia and urea plants, it is our belief that at least 20% of the national expansion in urea production will take place in the Gulf Coast and AWR regions. Applying our standard percentages, we estimate increases in urea capacity of 59 and 41 million annual pounds in the Gulf Coast and AWR regions respectively. The AWR increase, if it were confined to a single plant, would require the employment of 33 laborers for operations and maintenance work.

Polyethylene: Another petrochemical whose production is expected to expand very rapidly, especially for use in plastics, is polyethylene. Row 40 of Table 15 presents the relevant data for an evaluation of the location forces affecting future polyethylene plants. Again the situation is rather precise. When bulk water shipment of the finished product is feasible the natural gas areas possess a transport advantage. Since these areas tend to enjoy significant economies of scale, we are led to the conclusion that they are likely to attract a sizeable fraction of new polyethylene production. This conclusion is to be qualified by the transport advantages which market sites would possess if polyethylene were shipped by rail. Considering all factors we judge that 60% of the estimated new national expansion in polyethylene production (950 million annual pounds from 1950 to 1975) will fall in the Gulf Coast and AWR regions. Applying our standard percentages we obtain 35.3% and 24.7% of the national expansion as the shares of the Gulf Coast and AWR regions, respectively. These percentages correspond to expansions of 338 and 232 million annual pounds in polyethylene production in the Gulf Coast and AWR regions, respectively. On the assumption that the increase in polyethylene output in the AWR will be produced in two plants of 110-120 million pounds annual capacity each, we estimate that the operations and maintenance staffs will consist of a total of 115 laborers.

Polystyrene:[127] Polystyrene finds its chief use in the production of plastics. By 1975 it is estimated that the annual production of polystyrene will attain a level of 1,365 million pounds, an increase of 1,104 million pounds over 1950.

The data of the polystyrene row of Table 15 depict a clearcut case of raw material orientation.

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[123] Refer to the above discussion of acrylonitrile and ethylene oxide.

[124] C.E. Schildknecht, *op.cit.* pp. 323-329 discusses physical and chemical properties of vinyl acetate and describes the productive process. Also, see P.W. Sherwood, "Aliphatic Building Blocks for Petrochemical Textiles; the Monomers," *Petroleum Processing*, Vol. 7, Dec. 1950, pp. 1809-1816.

[125] Each plant is assumed to have an annual capacity of 60-65 million pounds.

[126] For supplementary materials on urea see W.F. Bland, "New Urea Synthesis Process," *Petroleum Processing*, Vol. 7, October 1952, pp. 1457-60; and A. Rouseboom, "Urea: A Process Survey," *Chemical Engineering*, Vol. 58, March 1951, pp. 111-114.

[127] Relevant process descriptions and product utilization patterns are discussed in N.N.T. Samaras and E. Perry, "Commercial Production of Polystyrene," *Journal of Applied Chemistry*, Vol. 1, June 1951, pp. 243-248.

Both from a water and a rail transport standpoint it is desirable to locate polystyrene production at the source of the feedstock, styrene. The data on economies of scale point in the same direction. These forces pulling location to the source of raw material are even further strengthened when we consider the geographic integration of polystyrene and styrene plants based on the ultimate raw materials of ethane and benzene. In this connection more will be said in the following sections on ethylbenzene and styrene.

We therefore conclude that at least 80% of the expansion in polystyrene capacity will be located at sources of styrene. Hence, before we can estimate expansion of polystyrene production in the Gulf Coast and AWR regions, we must estimate the expansion of styrene facilities.

GR-S Rubber:[128] GR-S (synthetic) rubber exhibits a pattern of location forces similar to that characterizing polystyrene: general transport advantage of raw material sites both in rail and water shipment, and modest economies of scale. We therefore estimate that at least 70% of the expansion in GR-S rubber facilities will be geographically associated with the sources of the raw materials, butadiene and styrene, and especially with sites where both raw materials are available. Therefore, we cannot allocate to the Gulf Coast and AWR regions any of the expected expansion of 2,680 million annual pounds in GR-S rubber production (1950-1975) until we treat in the following sections the factors affecting the geographic pattern of expansion in both butadiene and styrene production.

Styrene: Styrene currently has and is expected to have in the future two major uses: (1) for the production of polystyrene; and (2) for the production of synthetic rubber. By 1975 it is estimated that the annual production of styrene will have increased to a figure of 2,635 million pounds, an increase of 2,096 million pounds over 1950.

Like polystyrene, styrene is based upon one chief raw material. In the case of styrene, it is ethylbenzene. And again like polystyrene, both rail and water transport cost differentials and economies of scale definitely favor location of styrene facilities at the sources of ethylbenzene. We therefore judge that 80% of the new capacity for styrene production will be regionally juxtaposed to ethylbenzene production facilities. Hence, we must estimate new ethylbenzene capacity in the Gulf Coast and AWR regions before we can estimate new styrene capacity.

Ethylbenzene:[129] Ethylbenzene, like GR-S rubber, is produced from two basic raw materials. Unlike GR-S rubber production, ethylbenzene production does not show nearly as strong a tendency to locate at the source of the raw materials. Economies of scale are marked, but the water cost transport differentials in favor of raw material sites are more modest.

One of the raw materials in ethylbenzene production is ethane, of which all natural gas sites qualify as a source. The other is benzene, which is primarily a petroleum and coal derivative. By weight, approximately twice as much benzene as ethane is required per unit of ethylene benzene output.

We have already indicated that we do not expect the AWR region to be a major source of new supplies of petroleum derivatives such as benzene. Further, we have no strong reason for expecting any large independent market for ethylbenzene to be established in the AWR region.[130] Hence, because of a lack of market and probably of new supplies of the more important raw material, we have no firm basis for expecting much expansion of ethylbenzene facilities in the AWR region. One might be inclined to expect perhaps as much as 7 1/2% of national expansion to take place in the AWR region. However, considering the data on economies of scale, and the fact that the importance of economies of scale increases as polystyrene and GR-S facilities agglomerate around styrene facilities, and styrene facilities in turn around ethyl benzene facilities, we hesitate to project any expansion of the ethylbenzene—styrene—GR-S rubber—polystyrene complex in the AWR region, either as a whole, or in parts. This is not to deny that such expansion may take place. Non-economic motives of certain businessmen, or other economic considerations which affect the location of non-petrochemical operations such as plastic and rubber goods manufacture may establish in the AWR region a major independent market for polystyrene and GR-S rubber. To treat the impact of such factors as these, however, is beyond the scope of this report.

Phenol:[131] Phenol, like phthalic anhydride, is a product whose feedstock is a petroleum or coal derivative; in the case of phenol, the major feedstock is benzene. Again, since we do not expect much expansion of petroleum refining operations in the AWR region, we lack a firm basis for anticipating expansion in the production of phenol in this region.

Ethylene Dichloride: One of the major users of ethylene dichloride is vinyl chloride. It is to be expected that the requirements of ethylene dichloride for future expansion of vinyl chloride production in the AWR region will be furnished by the AWR region. This is a consequence of the coincidence in this situation of both market sites and raw material sites for ethylene dichloride production. On this account we expect AWR ethylene dichloride capacity to expand by 1975 by 132 million annual pounds.[132]

It is also to be anticipated that the AWR region will not export any large quantities of ethylene dichloride for use in new vinyl chloride facilities outside the Gulf Coast and the AWR re-

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[128] Extensive information on GR-S rubber is contained in United States Rubber Producing Facilities Disposal Commission, "*Government-Owned Synthetic Rubber Facility, Plancor 706 Lake Charles, La.*" report No. RD-1, Washington, D. C., 1953.

[129] For interesting descriptive materials, see Anon., "How Koppers Makes Ethylbenzene," *Petroleum Processing*, Vol. 8, July 1953, pp. 1048-1049.

[130] Styrene, for example, is tied to ethylbenzene, rather than ethylbenzene to styrene.

[131] Relevant materials and data appear in *B.I.O.S., Final Report*, No. 507, item Nos. 22, 30; and P. W. Sherwood, "Synthetic Phenol Manufacture," *Petroleum Processing*, Vol. 8, September 1953, pp. 1348-1354.

[132] Assuming that half of the future expansion in polyvinyls will be polyvinyl chloride and that half of the polyvinyl chloride production will be based on ethylene dichloride.

gions. These vinyl chloride facilities are likely to be of large scale. Their requirements of ethylene dichloride will probably be of such a magnitude that ethylene dichloride facilities spatially juxtaposed would be of a large enough size to reap most of the economies of scale. Further, the data in the ethylene dichloride row of Table 16 indicate both water and rail transport cost differentials in favor of market sites.

The President's Materials Policy Commission has estimated that by 1975 the requirements of ethylene dichloride for uses other than in vinyl chloride production will have increased by 560 million annual pounds. The data in the ethylene dichloride row of Table 16 indicate that the advantages of natural gas sites for serving markets outside the Gulf Coast and AWR regions are: (1) scale advantage from larger plants; and (2) power cost advantage, particularly in the production of chlorine, when these natural gas sites enjoy a fuel advantage as they probably will continue to do, except with respect to the Ohio Valley and the Pacific Northwest. Considering also the magnitude of the market for ethylene dichloride in the Gulf Coast and AWR regions, we estimate that 30% of the expansion of ethylene dichloride for uses other than in vinyl chloride will take place in these regions. Since the production of the diverse products into which ethylene dichloride flows, especially of anti-knock gasoline additives, is likely to be concentrated in the Gulf Coast region, we anticipate that 7 1/2% of the expanded requirements for non-vinyl chloride uses will be met by the AWR region. This yields an increase of 42 million annual pounds of capacity in the AWR region.

Altogether we expect an expansion of 174 million annual pounds of ethylene dichloride production in the AWR region by 1975.[133] A total labor force of 39 men should be required to operate and maintain two ethylene dichloride plants, each of 85-90 million pounds annual capacity.

Ethyl Chloride:[134] The chief use by far for ethyl chloride is in the manufacture of tetraethyllead. A secondary use is in the manufacture of ethyl cellulose; and there are various other end uses. By 1975 it is estimated that the annual requirements for ethyl chloride will reach 1,250 million pounds, an increase of 900 million pounds over 1950.

It is likely that there will be a marked concentration of tetraethyllead plants in the Gulf Coast area and to a lesser extent in other areas in which petroleum refining is expanding. Since the ethyl chloride rows of Table 16 record marked water and rail transport cost differentials in favor of market sites, and since the Gulf Coast possesses natural gas as well and any other primary advantage which the AWR region might possess, we find no firm basis for projecting any major expansion in ethyl chloride production in the AWR region.

Methyl Chloride:[135] Methyl chloride is a relatively small tonnage petrochemical with diverse end uses. In 1951 annual production was 38 million pounds. By 1975 it may rise to as much as 120 million pounds.

The last three rows of Table 16 indicate substantial water and rail transport cost differentials in favor of market sites. Since the production of this petrochemical will not be of sufficient volume to justify water shipment, the rail transport cost differentials are the relevant ones. Large economies of scale are also indicated.

No clearcut future location pattern of new methyl chloride facilities is suggested. Considering general chlorine advantages and the relative scattering of national markets, we expect that 10% of the expansion in methyl chloride capacity will be in the AWR region.[136] This corresponds to an increase in annual capacity of 8.2 million pounds and to an employment of 16 additional laborers for operations and maintenance work, on the assumption that all production is from one plant.

Ethylene and Acetylene:[137] As indicated above, ethylene and acetylene are non-transportables from an economic standpoint. They must in general be produced in the region in which they are to be consumed. Only insignificant amounts can be expected to be exported from one region to another.

Hence, to estimate the expansion of ethylene and acetylene facilities in the AWR region, we need: (1) to calculate the requirements of ethylene and of acetylene to permit the expansion of production expected in the AWR region for every petrochemical product listed above; and (2) to total for each these several requirements.

One complication arises. Acetylene and ethylene are substitute feedstocks for many of the petrochemicals. It is impossible at the moment to predict which will be the economically superior feedstock. Our procedure has been to assume that each will serve as feedstock for equal amounts of any petrochemical product which may feasibly be processed from each. The reader may wish to adopt another procedure, and if so can easily alter the total requirements which we obtain for each.

We estimate for the AWR region annual increases in ethylene requirements by 1975 by type of petrochemical as follows:

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[133] In similar manner, we estimate that the Gulf Coast expansion in ethylene dichloride production will be 406 million annual pounds by 1975.

[134] A useful reference is R. F. Warren, "Ethyl Chloride," *Chemical Engineering*, Vol. 58, May 1951, pp. 319-320.

[135] The symbols in the first column of the rows for methyl chloride from methanol and methyl chloride from natural gas (via methanol) indicate that under conditions of low gas transmission rates the second process is in a more favorable water transport situation than the first for supplying the methyl chloride requirements of coastal markets. However, for producing the requirements of all markets under conditions of high gas transmission rates, and the requirements of interior markets under conditions of low gas transmission rates, the first process is in a more favorable water transport situation than the second. In all cases the most favorable *location* is at the market.

[136] A conservative estimate would allocate 20% of the expected national expansion in methyl chloride facilities (16.4 million annual pounds) to the Gulf Coast region.

[137] For a series of articles which present a general technical discussion of commercial ethylene production processes see Peter W. Sherwood, "Production of Ethylene from Petroleum Sources," *Petroleum Refiner*, Vol. 30, September 1951, pp. 220-222; Vol. 30, November 1951, pp. 157-160; and Vol. 31, January 1952, pp. 126-130. Pertinent data and discussion relative to acetylene production and potential use are presented in Werner, *op.cit.*, and Aries and Copulsky, *op.cit.*

	Increase in AWR annual production, 1950-75, by type petrochemical	Increase in AWR annual requirements of ethylene by type petrochemical
Ethylene oxide...	350 MM lbs	340 MM lbs
Ethyl alcohol....	434 MM lbs	265 MM lbs
Polyethylene.....	232 MM lbs	244 MM lbs
Ethylene dichloride............	174 MM lbs	52 MM lbs
Total.........	....	901 MM lbs

The total estimated increase in annual ethylene requirements for 1975 over 1950 amounts to approximately 901 million pounds. This would entail an increase in employment of 257 laborers for operations and maintenance work, if one assumes the erection of five new ethylene plants, each of approximately 180 million pounds annual capacity.

We estimate for the AWR increases in annual acetylene requirements (1975 over 1950) by type of petrochemical as follows:

	Increase in AWR annual production, 1950-75, by type petrochemical	Increase in AWR annual requirements of acetylene by type petrochemical
Acrylonitrile....	125 MM lbs	83 MM lbs
Vinyl chloride...	126 MM lbs	54 MM lbs
Vinyl acetate....	253 MM lbs	81 MM lbs
Acetaldehyde.....	223 MM lbs	140 MM lbs
Total.........	....	358 MM lbs

The total estimated increase in annual requirements of acetylene by 1975 amounts to 358 million pounds. The corresponding estimated increase in employment is 132 laborers for operations and maintenance work, when one assumes that the total required acetylene will be produced in 2 plants, each with an annual capacity of approximately 180 million pounds.[138]

14. Conclusions

Table 17 sums up by type petrochemical product the expected expansions in capacities and associated increases in employment in the AWR region, approximately for the period 1950-75. The overall increase in employment in operations and maintenance work is estimated at 2,210 laborers.[139] For obvious reasons the overall total figure is in general more firm than the employment figures listed by type petrochemical product. It is likely that with respect to a few petrochemical products the data and our analysis are qualitatively poor and misleading. It is much less likely that this is the case for the petrochemicals taken as a whole.[140]

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[138] For the Gulf Coast we estimate that 1,413 million annual pounds of ethylene will be required to support the expected expansions in ethylene oxide, ethyl alcohol, polyethylene, and ethylene dichloride production. We also estimate that 697 million annual pounds of acetylene will be required to support the expected expansions in acrylonitrile, vinyl chloride, vinyl acetate and acetaldehyde production. The reader is reminded that these figures do not indicate the full extent of expansion in ethylene and acetylene production which may be expected for the Gulf Coast. Increases in production of ethylene- and acetylene-consuming petrochemicals other than those mentioned above will take place in the Gulf Coast region and will require additional ethylene and acetylene feedstock.

[139] This does not take into account the decrease in employment to be expected in the AWR region in carbon black production.

It is of interest to note that this report illustrates a fruitful use of the substitution framework in location analysis. Essentially there are two basic substitution points which govern the location pattern of non-chlorinated petrochemicals. (An additional substitution point is involved for chlorinated petrochemicals.) The first is the substitution point between transport (distance) inputs on raw material and fuel gas and transport (distance) inputs on finished product. The second is the substitution point between transport outlays and production outlays where differences in production outlays are primarily the result of economies of scale. It will be demonstrated in forthcoming manuscript that these two substitution points are likewise of primary significance for analysis of location patterns of the oil refining industry and of industrial complexes oriented to oil and natural gas as raw material sources.

For a discussion of the substitution framework in location analysis, see W. Isard, "Distance Inputs and the Space-Economy," the *Quarterly Journal of Economics*, Vol. 65, May and August, 1951, pp. 181-198; 373-399.

[140] In considering future expansions in the AWR region of various petrochemicals, we have obtained as by-products estimates of future expansions in the Gulf Coast region of a number of petrochemicals. These are tabulated below together with corresponding increases in labor force for operations and maintenance work. The increase in labor force associated with the expansion of any given petrochemical product is based on the same size plants as were postulated for the AWR region.

Partial Estimates of Capacity Expansion and New Employment in the Gulf Coast Region, by Type Petrochemical

Product	Capacity expansion (millions of lbs.)	Increase in production workers
Ethylene glycol..........	267	77
Acrylonitrile............	641	524
Hydrogen cyanide.........	423	107
Ethanolamines............	58	28
Ethylene oxide...........	596	371
Ammonia..................	1,020	244
Acetic anhydride.........	324	108
Acetic acid..............	864	148
Acetaldehyde.............	665	338
Ethyl alcohol............	587	180
Formaldehyde (37%).......	234	47
Methanol.................	367	93
Phthalic anhydride.......	Not estimated	
Polyvinyl acetate........	784	516
Polyvinyl chloride.......		
Vinyl acetate............	1,038	355
Vinyl chloride...........		
Urea.....................	59	47
Polyethylene.............	338	168
Polystyrene..............	Not estimated	
GR-S rubber..............		
Styrene..................		
Ethylbenzene.............		
Phenol...................		
Ethylene dichloride......	406	91
Ethyl chloride...........	Not estimated	
Methyl chloride..........	16	32
Ethylene (incomplete requirements)............	1,413	403
Acetylene................	697	257
Total................	10,797	4,134

The reader is cautioned against an unqualified use of the above table. This table contains only a partial statement of future petrochemical expansion in the Gulf Coast region. All petrochemicals based on propylene, butylene, aromatic feedstocks, and crude oil are not included. Further, the ethylene required jointly with certain aromatics as feedstock is not recorded. Finally, because of the procedures followed in the report, these Gulf Coast estimates are not firm minimum estimates, as are those for the AWR.

Table 17.—FIRM MINIMUM ESTIMATES OF CAPACITY EXPANSION AND NEW EMPLOYMENT IN THE AWR REGION, BY TYPE PETROCHEMICAL

Product	Capacity expansion (millions of lbs)	Increase in production workers
Ethylene glycol	145	33
Acrylonitrile	251	205
Hydrogen cyanide	166	42
Ethanolamines	33	16
Ethylene oxide	350	218
Ammonia	510	122
Acetic anhydride	226	75
Acetic acid	579	99
Acetaldehyde	447	227
Ethyl alcohol	434	133
Formaldehyde (37%)	163	33
Methanol	256	65
Phthalic anhydride	0	0
Polyvinyl acetate	269	177
Polyvinyl chloride		
Vinyl acetate	506	173
Vinyl chloride		
Urea	41	33
Polyethylene	232	115
Polystyrene	0	0
GR-S rubber	0	0
Styrene	0	0
Ethylbenzene	0	0
Phenol	0	0
Ethylene dichloride	174	39
Ethyl chloride	0	0
Methyl chloride	8	16
Ethylene	901	257
Acetylene	358	132
Total	6,049	2,210

In general our analysis suggests the following statements on the future geographic pattern of petrochemical expansion in the United States.

(1) Production will tend to be associated with large-scale plants.

(2) Large-tonnage petrochemicals will tend to be shipped by water from production sites to major distribution points (when the production sites and distribution points do not coincide).

(3) The major portion of expansion in natural gas-based petrochemicals will take place in natural gas areas.

(4) Some expansion in natural gas-based petrochemicals, especially in complexes of related petrochemicals, will occur at or near major metropolitan market areas and gateway points. This is partly the result of the development of long-distance pipeline transmission of natural gas. Also, because of its power cost advantage in chlorinated chemicals production the Ohio Valley particularly qualifies as a desirable market-gateway point location.

(5) The future pattern of natural gas-based petrochemical expansions is therefore likely to be somewhat less concentrated in the natural gas producing areas than is current capacity.

(6) Expansions in petrochemicals based on propylene, butylene, and aromatic and naphthenic feedstocks are likely to continue to be closely linked to refinery locations.

(7) Major expansions in the production of these petrochemicals are likely to occur in the Gulf Coast area where current oil refinery capacity is concentrated and where major expansion in refinery facilities is to be expected in the future. However, whether or not the geographic pattern of expansions of these petrochemicals will be less concentrated than is current capacity will depend heavily upon the future geographic pattern of refinery expansions.[141]

It is probably unnecessary to remind the reader that these statements as well as the firm minimum projections of new employment in petrochemicals in the AWR region are based on a number of specific assumptions. Also, we have generally postulated that, except for changes noted, the technological structure of today remains in force during the next quarter century, that the major raw material sources remain unchanged, and that consumption habits of 1975 will be substantially those of today, after allowance for major increases in per capita real income.

We fully realize the tenuous character and unreality of our various assumptions. One thing is certain. Major changes will take place. Yet not knowing what the shape and form of these changes may be, one must select the best set of assumptions he can, however anemic they may be, in order to reach as objective an analysis as possible for policy purposes *today*.

Decisions are constantly being made by the petrochemicals industry and by a number of related industries on plant expansions, their scales and locations, on integration of units, on new products to be developed, on market areas to be tapped, on raw material sources to be utilized, and on numerous other questions. Decisions are constantly being made by various governmental authorities on irrigation projects, on the construction of power systems, on flood control and water supply, on the construction of highways and other transportation facilities, on the development of community centers, educational systems and on a host of other urban and rural facilities. To make wise decisions, to make decisions which will result in the most effective use of our diverse national, regional, and urban resources, information on the future geographic distribution of population and industry is essential. Hence, whatever light can be cast on the future geographic pattern of a basic industry and on the future industrial base of a region and its associated employment and population, however dim this light may be, is better than none at all. It is in this connection that we hope our study is useful.

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[141] A study of the future geographic pattern of refinery expansion, which is outside the scope of this report, is currently being undertaken at the Urban and Regional Studies Section. M.I.T

APPENDIX A

Tables on Input Requirements

INDEX

PRODUCTION OF ACRYLONITRILE FROM NATURAL GAS (VIA ACETYLENE AND HCN)

	Requirements per hundred pounds of output	
Selecter inputs:		
Natural gas..................	8,498	cu.ft.
Utilities:		
Steam....................	4,029	lbs.
Cooling water...........	17,902	gals.
Electric power..........	87	kwh.
Fuel gas................	-2,324	cu.ft.[*]
Direct labor.................	0.36	manhours.[**]

[*] Minus sign signifies production.

[**] For acrylonitrile plant with annual capacity of 20 MM lbs.

acetylene	80
HCN	40
ammonia	264

PRODUCTION OF ACRYLONITRILE FROM ETHANE AND NATURAL GAS (VIA ETHYLENE OXIDE, CHLORHYDRIN PROCESS: AND HCN)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane.......................	100	lbs.
Natural gas..................	2,165	cu.ft.
Utilities:		
Steam....................	1,941	lbs.
Cooling water...........	13,422	gals.
Electric power..........	82	kwh.
Fuel gas................	412	cu.ft.
Chemicals:		
Chlorine................	171	lbs.
Direct labor.................	0.39	manhours.[*]

[*] For acrylonitrile plant with annual capacity of 20 MM lbs.

HCN	40
ammonia	264
ethylene oxide	40
ethylene	66

PRODUCTION OF ACRYLONITRILE FROM ETHANE AND NATURAL GAS (VIA ACETYLENE AND HCN)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane.......................	135	lbs.
Natural gas..................	2,802	cu.ft.
Utilities:		
Steam....................	3,335	lbs.
Cooling water...........	11,779	gals.
Electric power..........	82	kwh.
Fuel gas................	-627	cu.ft.[*]
Direct labor.................	0.36	manhours.[**]

[*] Minus sign signifies production.

[**] For acrylonitrile plant with annual capacity of 20 MM lbs.

acetylene	80
HCN	40
ammonia	264

PRODUCTION OF ACRYLONITRILE FROM ETHYLENE OXIDE AND NATURAL GAS (VIA HCN)

	Requirements per hundred pounds of output	
Selected Inputs:		
Ethylene oxide...............	102	lbs.
Natural gas..................	2,165	cu.ft.
Utilities:		
Steam....................	1,094	lbs.
Cooling water...........	5,548	gals.
Electric power..........	75	kwh.
Fuel gas................	250	cu.ft.
Direct labor.................	0.30	manhours.[*]

[*] For acrylonitrile plant with annual capacity of 20 MM lbs.

HCN	40
ammonia	264

PRODUCTION OF ACRYLONITRILE FROM ETHANE AND NATURAL GAS (VIA ETHYLENE OXIDE, OXIDATION PROCESS: AND HCN)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane.......................	157	lbs.
Natural gas..................	2,165	cu.ft.
Utilities:		
Steam....................	2,205	lbs.
Cooling water...........	16,444	gals.
Electric power..........	83	kwh.
Fuel gas................	795	cu.ft.
Direct labor.................	0.45	manhours.[*]

[*] For acrylonitrile plant with annual capacity of 20 MM lbs.

HCN	40
ammonia	264
ethylene oxide	40
ethylene	66

PRODUCTION OF ETHANOLAMINES FROM ETHANE AND NATURAL GAS (VIA ETHYLENE OXIDE, OXIDATION PROCESS: AND AMMONIA)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane.......................	128	lbs.
Natural gas..................	325	cu.ft.
Utilities:		
Steam....................	1,220	lbs.
Cooling water...........	22,153	gals.
Electric power..........	31	kwh.
Fuel gas................	2,533	cu.ft.
Direct labor.................	0.26	manhours.[**]

[*] Of total output, 40% by weight is mono-ethanolamine, 40% by weight is tri-ethanolamine, and 20% by weight is di-ethanolamin.

[**] For ethanolamines plant with annual capacity of 16 MM lbs.

ethylene oxide	40
ammonia	264

PRODUCTION OF ETHANOLAMINES FROM ETHANE AND NATURAL GAS (VIA ETHYLENE OXIDE, CHLORHYDRIN PROCESS: AND AMMONIA)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	81	lbs.
Natural gas	325	cu.ft.
Utilities:		
Steam	1,005	lbs.
Cooling water	19,052	gals.
Electric power	30	kwh.
Fuel gas	2,222	cu.ft.
Chemicals:		
Chlurine	139	lbs.
Direct labor	0.34	manhours.*

*For ethanolamines plant with annual capacity of 16 MM lbs.
ethylene oxide 40
ethylene 66
ammonia 264

PRODUCTION OF ETHANOLAMINES FROM ETHYLENE OXIDE AND NATURAL GAS (AMMONIA)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethylene oxide	83	lbs.
Natural gas	325	cu.ft.
Utilities:		
Steam	316	lbs.
Cooling water	13,286	gals.
Electric power	24	kwh.
Fuel gas	2,090	cu.ft.
Direct labor	0.14	manhours.*

*For ethanolamines plant with annual capacity of 16 MM lbs.
ammonia 264

PRODUCTION OF ETHANOLAMINES FROM ETHYLENE OXIDE AND AMMONIA

	Requirements per hundred pounds of output	
Selected inputs:		
Ethylene oxide	83	lbs.
Ammonia	19	lbs.
Utilities:		
Steam	246	lbs.
Cooling water	12,761	gals.
Electric power	15	kwh.
Fuel gas	2,090	cu.ft.
Direct labor	0.13	manhours.*

*For ethanolamines plant with annual capacity of 16 MM lbs.

PRODUCTION OF ETHYLENE OXIDE FROM ETHANE (VIA OXIDATION PROCESS)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	154	lbs.
Utilities:		
Steam	1,089	lbs.
Cooling water	10,682	gals.
Electric power	8.7	kwh.
Fuel gas	534	cu.ft.
Direct labor	0.26	manhours.*

*For oxide plant with annual capacity of 40 MM lbs.
ethylene 66

PRODUCTION OF ETHYLENE OXIDE FROM ETHANE (VIA CHLORHYDRIN PROCESS)

	Requirements per hundred pounds of output*	
Selected inputs:		
Ethane	98	lbs.
Utilities:		
Steam	830	lbs.
Cooling water	6,946	gals.
Electric power	7.6	kwh.
Fuel gas	159	cu.ft.
Chemicals:		
Chlorine	168	lbs.
Quick lime	134	lbs.
Caustic soda	1.6	lbs.
Sulfuric acid	1.8	lbs.
Direct labor	0.21	manhours.**

*Of total output, 70% by weight is ethylene oxide, 20% by weight is ethylene dichloride, and 10% by weight is polyglycols and chloroethers.

**For ethylene oxide plant with annual capacity of 40 MM lbs.
ethylene 66

PRODUCTION OF AMMONIA FROM NATURAL GAS

	Requirements per hundred pounds of output	
Selected inputs:		
Natural gas (process and fuel)	1,700	cu.ft.
Utilities:		
Steam	367	lbs.
Cooling water	2,750	gals.
Electric power	48	kwh.
Direct labor	0.04	manhours.*

*For ammonia plant with annual capacity of 264 MM lbs.

PRODUCTION OF ACETIC ANHYDRIDE FROM NATURAL GAS (VIA ACETYLENE—ACETALDEHYDE—ACETIC ACID)

	Requirements per hundred pounds of output	
Selected inputs:		
Natural gas	5,413	cu.ft.
Utilities:		
Steam	1,824	lbs.
Cooling water	27,570	gals.
Electric power	28	kwh.
Fuel gas	-1,993	cu.ft.*
Direct labor	0.36	manhours.**

*Minus sign signifies production.

**For acetic anhydride plant with annual capacity of 40 MM lbs.

acetic acid	80
acetaldehyde	40
acetylene	80

PRODUCTION OF ACETIC ANHYDRIDE FROM ETHANOL (VIA ACETALDEHYDE—ACETIC ACID)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethanol	103	lbs.
Utilities:		
Steam	1,708	lbs.
Cooling water	11,189	gals.
Electric power	19	kwh.
Fuel gas	709	cu.ft.
Direct labor	0.25	manhours.*

*For acetic anhydride plant with annual capacity of 40 MM lbs.

acetic acid	80
acetaldehyde	40

PRODUCTION OF ACETIC ANHYDRIDE FROM ETHANE (VIA ACETYLENE—ACETALDEHYDE—ACETIC ACID)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	127	lbs.
Utilities:		
Steam	1,593	lbs.
Cooling water	21,809	gals.
Electric power	24	kwh.
Fuel gas	-380	cu.ft.*
Direct labor	0.36	manhours.**

*Minus sign signifies production.

**For acetic anhydride plant with annual capacity of 40 MM lbs.

acetic acid	80
acetaldehyde	40
acetylene	80

PRODUCTION OF ACETIC ANHYDRIDE FROM ACETALDEHYDE (VIA ACETIC ACID)

	Requirements per hundred pounds of output	
Selected inputs:		
Acetaldehyde	99	lbs.
Utilities:		
Steam	584	lbs.
Cooling water	8,525	gals.
Electric power	13	kwh.
Fuel gas	216	cu.ft.
Direct labor	0.15	manhours.*

*For acetic anhydride plant with annual capacity of 40 MM lbs.

acetic acid	60

PRODUCTION OF ACETIC ANHYDRIDE FROM ETHANE (VIA ETHYLENE—ETHANOL—ACETIC ACID)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	85	lbs.
Utilities:		
Steam	2,207	lbs.
Cooling water	18,352	gals.
Electric power	21	kwh.
Fuel gas	895	cu.ft.
Direct labor	0.36	manhours.*

*For acetic anhydride plant with annual capacity of 40 MM lbs.

acetic acid	80
acetaldehyde	40
ethanol	120
ethylene	66

PRODUCTION OF ACETIC ANHYDRIDE FROM ACETIC ACID

	Requirements per hundred pounds of output	
Selected inputs:		
Acetic acid	128	lbs.
Utilities:		
Steam	200	lbs.
Cooling water	6,605	gals.
Electric power	5	kwh.
Fuel gas	216	cu.ft.
Direct labor	0.10	manhours.*

*For acetic anhydride plant with annual capacity of 40 MM lbs.

PRODUCTION OF ACETIC ACID FROM NATURAL GAS (VIA ACETYLENE—ACETALDEHYDE)

	Requirements per hundred pounds of output	
Selected inputs:		
Natural gas	4,229	cu.ft.
Utilities:		
Steam	1,269	lbs.
Cooling water	16,379	gals.
Electric power	18	kwh.
Fuel gas	-1,726	cu.ft.*
Direct labor	0.20	manhours.**

*Minus sign signifies production.

**For acetic acid plant with annual capacity of 80 MM lbs.
acetaldehyde 40
acetylene 80

PRODUCTION OF ACETIC ACID FROM ETHANOL (VIA ACETALDEHYDE)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethanol	85	lbs.
Utilities:		
Steam	1,178	lbs.
Cooling water	3,577	gals.
Electric power	11	kwh.
Fuel gas	385	cu.ft.
Direct labor	0.12	manhours.*

*For acetic acid plant with annual capacity of 80 MM lbs.
acetaldehyde 40

PRODUCTION OF ACETIC ACID FROM ETHANE (VIA ACETYLENE—ACETALDEHYDE)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	99	lbs.
Utilities:		
Steam	1,038	lbs.
Cooling water	11,878	gals.
Electric power	15	kwh.
Fuel gas	-466	cu.ft.*
Direct labor	0.20	manhours.**

*Minus sign signifies production.

**For acetic acid plant with annual capacity of 80 MM lbs.
acetaldehyde 40
acetylene 80

PRODUCTION OF ACETIC ACID FROM ACETALDEHYDE

	Requirements per hundred pounds of output	
Selected inputs:		
Acetaldehyde	77	lbs.
Utilities:		
Steam	500	lbs
Cooling water	1,500	gals.
Electric power	6	kwh.
Direct labor	0.04	manhours.*

*For acetic acid plant with annual capacity of 80 MM lbs.

PRODUCTION OF ACETIC ACID FROM ETHANE (VIA ETHYLENE—ETHANOL—ACETALDEHYDE)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	67	lbs.
Utilities:		
Steam	1,568	lbs.
Cooling water	9,177	gals.
Electric power	12	kwh.
Fuel gas	530	cu.ft.
Direct labor	0.21	manhours.*

*For acetic acid plant with annual capacity of 80 MM lbs.
acetaldehyde 40
ethanol 120
ethylene 66

PRODUCTION OF ACETALDEHYDE FROM NATURAL GAS (VIA ACETYLENE)

	Requirements per hundred pounds of output	
Selected inputs:		
Natural gas	5,437	cu.ft.
Utilities:		
Steam	1,686	lbs.
Cooling water	19,324	gals.
Electric power	16	kwh.
Fuel gas	-2,219	cu.ft.**
Direct labor	0.21	manhours.*

*For acetaldehyde plant with annual capacity of 40 MM lbs.
acetylene 80

**Minus sign signifies production.

PRODUCTION OF ACETALDEHYDE FROM ETHANE (VIA ACETYLENE)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	129	lbs.
Utilities:		
Steam	1,023	lbs.
Cooling water	13,479	gals.
Electric power	11	kwh.
Fuel gas	-599	cu.ft.**
Direct labor	0.21	manhours.*

*For acetaldehyde plant with annual capacity of 40 MM lbs.
acetylene 80

**Minus sign signifies production.

PRODUCTION OF ETHYL ALCOHOL FROM ETHANE

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	79	lbs.
Utilities:		
Steam	461	lbs.
Cooling water	6,612	gals.
Electric power	1.6	kwh.
Fuel gas	171	cu.ft.
Direct labor	0.11	manhours.*

*For ethyl alcohol plant with annual capacity of 120 MM lbs.
ethylene 65

PRODUCTION OF ACETALDEHYDE FROM ETHANE (VIA ETHYL ALCOHOL)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	87	lbs.
Utilities:		
Steam	1,647	lbs.
Cooling water	9,970	gals.
Electric power	8	kwh.
Fuel gas	688	cu.ft.
Direct labor	0.21	manhours.*

*For acetaldehyde plant with annual capacity of 40 MM lbs.
ethyl alcohol 120
ethylene 66

PRODUCTION OF FORMALDEHYDE (37%) FROM NATURAL GAS (VIA METHANOL)

	Requirements per hundred pounds of output	
Selected inputs:		
Natural gas	992	cu.ft.
Utilities:		
Steam	82	lbs.
Cooling water	2,850	gals.
Electric power	25	kwh.
Direct labor	0.06	manhours.*

*For formaldehyde plant with annual capacity of 120 MM lbs.
methanol 240

PRODUCTION OF ACETALDEHYDE FROM ETHANOL

	Requirements per hundred pounds of output	
Selected inputs:		
Ethanol	110	lbs.
Utilities:		
Steam	1,140	lbs.
Cooling water	2,697	gals.
Electric power	6	kwh.
Fuel gas	500	cu.ft.
Direct labor	0.10	manhours.*

*For acetaldehyde plant with annual capacity of 40 MM lbs.

PRODUCTION OF FORMALDEHYDE (37%) FROM METHANOL

	Requirements per hundred pounds of output	
Selected inputs:		
Methanol	44	lbs.
Utilities:		
Steam	38	lbs.
Cooling water	998	gals.
Electric power	9	kwh.
Direct labor	0.04	manhours.*

*For formaldehyde plant with annual capacity of 120 MM lbs.

PRODUCTION OF METHANOL FROM NATURAL GAS

	Requirements per hundred pounds of product	
Selected inputs:		
Natural gas:		
For process	1,181	cu.ft.
For fuel	1,078	cu.ft.
Utilities:		
Steam	100	lbs.
Cooling water	4,219	gals.
Electric power	37	kwh.
Direct labor	0.04	manhours.*

*For methanol plant with annual capacity of 240 MM lbs.

PRODUCTION OF PHTHALIC ANHYDRIDE FROM ORTHO-XYLENE

	Requirements per hundred pounds of output	
Selected inputs:		
Ortho-xylene	142	lbs.
Utilities:		
Steam	- 558	lbs.*
Cooling water	1,435	gals.
Electric power	57	kwh.
Fuel gas	1,644	cu.ft.
Direct labor	0.12	manhours.**

*Minus sign signifies production.

**For phthalic anhydride plant with annual capacity of 40 MM lbs.

PRODUCTION OF POLYVINYL ACETATE FROM NATURAL GAS (VIA ACETYLENE, AND ACETYLENE—ACETIC ACID)

	Requirements per hundred pounds of output	
Selected inputs:		
Natural gas	5,880	cu.ft.
Utilities:		
Steam	1,791	lbs.
Cooling water	18,299	gals.
Electric power	26	kwh.
Fuel gas	- 2,399	cu.ft.*
Direct labor	0.50	manhours.**

*Minus sign signifies production.

**For polyvinyl acetate plant with annual capacity of 20 MM lbs.

vinyl acetate	20
acetic acid	80
acetaldehyde	40
acetylene	80

PRODUCTION OF POLYVINYL ACETATE FROM ETHANE (VIA ACETYLENE; AND ACETYLENE—ACETIC ACID)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	139	lbs.
Utilities:		
Steam	1,315	lbs.
Cooling water	11,921	gals.
Electric power	21	kwh.
Fuel gas	- 648	cu.ft.*
Direct labor	0.50	manhours.**

*Minus sign signifies production.

**For polyvinyl acetate plant with annual capacity of 20 MM lbs.

vinyl acetate	20
acetic acid	80
acetaldehyde	40
acetylene	80

PRODUCTION OF POLYVINYL ACETATE FROM ETHANE AND NATURAL GAS (VIA ETHYLENE—ETHANOL—ACETIC ACID; AND ACETYLENE)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	49	lbs.
Natural gas	2,817	cu.ft.
Utilities:		
Steam	1,998	lbs.
Cooling water	12,993	gals.
Electric power	22	kwh.
Fuel gas	- 766	cu.ft.*
Direct labor	0.52	manhours.**

*Minus sign signifies production.

**For polyvinyl acetate plant with annual capacity of 20 MM lbs.

vinyl acetate	20
acetic acid	80
acetaldehyde	40
ethanol	120
ethylene	66
acetylene	80

PRODUCTION OF POLYVINYL ACETATE FROM ETHANE (VIA ETHYLENE—ETHANOL—ACETIC ACID; AND ACETYLENE)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	115	lbs.
Utilities:		
Steam	1,663	lbs.
Cooling water	9,565	gals.
Electric power	19	kwh.
Fuel gas	73	cu.ft.
Direct labor	0.52	manhours.*

*For polyvinyl acetate plant with annual capacity of 20 MM lbs.

vinyl acetate	20
acetic acid	80
acetaldehyde	40
ethanol	120
ethylene	66
acetylene	80

PRODUCTION OF POLYVINYL ACETATE FROM ETHANOL AND NATURAL GAS (VIA ACETALDEHYDE—ACETIC ACID; AND ACETYLENE)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethanol	61	lbs.
Natural gas	2,817	cu.ft.
Utilities:		
Steam	1,715	lbs.
Cooling water	8,946	gals.
Electric power	20	kwh.
Fuel gas	-871	cu.ft.*
Direct labor	0.46	manhours.**

*Minus sign signifies production.

**For polyvinyl acetate plant with annual capacity of 20 MM lbs.

vinyl acetate	20
acetic acid	80
acetaldehyde	40
acetylene	80

PRODUCTION OF POLYVINYL ACETATE FROM ETHANOL AND ETHANE (VIA ACETALDEHYDE—ACETIC ACID; AND ACETYLENE)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethanol	61	lbs.
Ethane	66	lbs.
Utilities:		
Steam	1,382	lbs.
Cooling water	5,911	gals.
Electric power	17	kwh.
Fuel gas	-32	cu.ft.*
Direct labor	0.46	manhours.**

*Minus sign signifies production.

**For polyvinyl acetate plant with annual capacity of 20 MM lbs.

vinyl acetate	20
acetic acid	80
acetaldehyde	40
acetylene	80

PRODUCTION OF POLYVINYL ACETATE FROM ACETALDEHYDE AND NATURAL GAS (VIA ACETIC ACID; AND ACETYLENE)

	Requirements per hundred pounds of output	
Selected inputs:		
Acetaldehyde	56	lbs.
Natural gas	2,817	cu.ft.
Utilities:		
Steam	1,079	lbs.
Cooling water	7,442	gals.
Electric power	17	kwh.
Fuel gas	-1,149	cu.ft.*
Direct labor	0.37	manhours.**

*Minus sign signifies production.

**For polyvinyl acetate plant with annual capacity of 20 MM lbs.

vinyl acetate	20
acetic acid	80
acetylene	80

PRODUCTION OF POLYVINYL ACETATE FROM ACETIC ACID AND NATURAL GAS ACETYLENE

	Requirements per hundred pounds of output	
Selected inputs:		
Acetic acid	72	lbs.
Natural gas	2,817	cu.ft.
Utilities:		
Steam	852	lbs.
Cooling water	6,356	gals.
Electric power	13	kwh.
Fuel gas	-1,149	cu.ft.*
Direct labor	0.35	manhours.**

*Minus sign signifies production.

**For polyvinyl acetate plant with annual capacity of 20 MM lbs.

vinyl acetate	20
acetylene	80

PRODUCTION OF POLYVINYL ACETATE FROM ACETIC ACID AND ETHANE ACETYLENE

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	66	lbs.
Acetic acid	72	lbs.
Utilities:		
Steam	528	lbs.
Cooling water	3,320	gals.
Electric power	13	kwh.
Fuel gas	-310	cu.ft.*
Direct labor	0.36	manhours.**

*Minus sign signifies production.

**For polyvinyl acetate plant with annual capacity of 20 MM lbs.

vinyl acetate	20
acetylene	80

PRODUCTION OF POLYVINYL ACETATE FROM VINYL ACETATE

	Requirements per hundred pounds of output	
Selected inputs:		
Vinyl acetate	102	lbs.
Utilities:		
Steam	70	lbs.
Cooling water	204	gals.
Electric power	3	kwh.
Direct labor	0.20	manhours.*

*For polyvinyl acetate plant with annual capacity of 20 MM lbs.

PRODUCTION OF POLYVINYL CHLORIDE FROM NATURAL GAS (VIA ACETYLENE)

	Requirements per hundred pounds of output	
Selected inputs:		
Natural gas	4,082	cu.ft.
Utilities:		
Steam	2,032	lbs.
Cooling water	18,509	gals.
Electric power	35	kwh.
Fuel gas	- 1,557	cu.ft.*
Chemicals:		
Hydrogen chloride	76	lbs.
Direct labor	0.24	manhours.**

*Minus sign signifies production.

**For polyvinyl chloride plant with annual capacity of 40 MM lbs.

vinyl chloride	70
acetylene	60

PRODUCTION OF POLYVINYL CHLORIDE FROM ETHANE (VIA ACETYLENE)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	97	lbs.
Utilities:		
Steam	1,535	lbs.
Cooling water	14,121	gals.
Electric power	32	kwh.
Fuel gas	- 341	cu.ft.*
Chemicals:		
Hydrogen chloride	76	lbs.
Direct labor	0.24	manhours.**

*Minus sign signifies production.

**For polyvinyl chloride plant with annual capacity of 40 MM lbs.

vinyl chloride	70
acetylene	60

PRODUCTION OF POLYVINYL CHLORIDE FROM ETHANE (VIA ETHYLENE DICHLORIDE)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	44	lbs.
Utilities:		
Steam	776	lbs.
Cooling water	6,480	gals.
Electric power	17	kwh.
Fuel gas	339	cu.ft.
Chemicals:		
Chlorine	84	lbs.
Direct labor	0.32	manhours.*

*For polyvinyl chloride plant with annual capacity of 40 MM lbs.

vinyl chloride	40
ethylene dichloride	70
ethylene	65

PRODUCTION OF POLYVINYL CHLORIDE FROM ETHYLENE DICHLORIDE

	Requirements per hundred pounds of output	
Selected inputs:		
Ethylene dichloride	116	lbs.
Utilities:		
Steam	676	lbs.
Cooling water	4,276	gals.
Electric power	16	kwh.
Fuel gas	268	cu.ft.
Direct labor	0.24	manhours.*

*For polyvinyl chloride plant with annual capacity of 40 MM lbs.

vinyl chloride	40

PRODUCTION OF POLYVINYL CHLORIDE FROM VINYL CHLORIDE

	Requirements per hundred pounds of output	
Selected inputs:		
Vinyl chloride	110	lbs.
Utilities:		
Steam	542	lbs.
Cooling water	3,385	gals.
Electric power	15	kwh.
Fuel gas	108	cu.ft.
Direct labor	0.14	manhours.*

*For polyvinyl chloride plant with annual capacity of 40 MM lbs.

PRODUCTION OF VINYL ACETATE FROM NATURAL GAS (VIA ACETYLENE AND ACETYLENE—ACETIC ACID)

	Requirements per hundred pounds of output	
Selected inputs:		
Natural gas	5,765	cu.ft.
Utilities:		
Steam	1,687	lbs.
Cooling water	17,652	gals.
Electric power	22	kwh.
Fuel gas	- 2,352	cu.ft.*
Direct labor	0.29	manhours.**

*Minus sign signifies production.

**For vinyl acetate plant with annual capacity of 20 MM lbs.

acetic acid	80
acetaldehyde	40
acetylene	60

PRODUCTION OF VINYL ACETATE FROM ETHANE (VIA ACETYLENE AND ACETYLENE—ACETIC ACID)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	136	lbs.
Utilities:		
Steam	1,221	lbs.
Cooling water	11,487	gals.
Electric power	17	kwh.
Fuel gas	- 635	cu.ft.*
Direct labor	0.29 manhours.**	

*Minus sign signifies production.

**For vinyl acetate plant with annual capacity of 20 MM lbs.

acetic acid	80
acetaldehyde	40
acetylene	60

PRODUCTION OF VINYL ACETATE FROM ETHANOL AND NATURAL GAS (VIA ACETALDEHYDE—ACETIC ACID, AND ACETYLENE)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethanol	60	lbs.
Natural gas	2,762	cu.ft.
Utilities:		
Steam	1,613	lbs.
Cooling water	8,571	gals.
Electric power	17	kwh.
Fuel gas	- 854	cu.ft.*
Direct labor	0.25 manhours.**	

*Minus sign signifies production.

**For vinyl acetate plant with annual capacity of 20 MM lbs.

acetic acid	80
acetaldehyde	40
acetylene	80

PRODUCTION OF VINYL ACETATE FROM ETHANE AND NATURAL GAS (VIA ETHYLENE—ETHANOL—ACETIC ACID, AND ACETYLENE)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	98	lbs.
Natural gas	2,762	cu.ft.
Utilities:		
Steam	1,890	lbs.
Cooling water	12,538	gals.
Electric power	18	kwh.
Fuel gas	- 751	cu.ft.*
Direct labor	0.31 manhours.**	

*Minus sign signifies production.

**For vinyl acetate plant with annual capacity of 20 MM lbs.

acetic acid	80
acetaldehyde	40
ethanol	120
ethylene	66
acetylene	80

PRODUCTION OF VINYL ACETATE FROM ETHANOL AND ETHANE (VIA ACETALDEHYDE—ACETIC ACID, AND ACETYLENE)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethanol	60	lbs.
Ethane	65	lbs.
Utilities:		
Steam	1,286	lbs.
Cooling water	5,595	gals.
Electric power	14	kwh.
Fuel gas	- 31	cu.ft.*
Direct labor	0.25 manhours.**	

*Minus sign signifies production.

**For vinyl acetate plant with annual capacity of 20 MM lbs.

acetic acid	80
acetaldehyde	40
acetylene	60

PRODUCTION OF VINYL ACETATE FROM ETHANE (VIA ETHYLENE—ETHANOL—ACETIC ACID, AND ACETYLENE)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	113	lbs.
Utilities:		
Steam	1,562	lbs.
Cooling water	9,570	gals.
Electric power	15	kwh.
Fuel gas	72	cu.ft.
Direct labor	0.31 manhours.*	

*For vinyl acetate plant with annual capacity of 20 MM lbs.

acetic acid	60
acetaldehyde	40
ethanol	120
ethylene	66
acetylene	60

PRODUCTION OF VINYL ACETATE FROM ACETALDEHYDE AND NATURAL GAS ACETYLENE

	Requirements per hundred pounds of product	
Selected inputs:		
Acetaldehyde	55	lbs.
Natural gas	2,762	cu.ft.
Utilities:		
Steam	989	lbs.
Cooling water	7,095	gals.
Electric power	14	kwh.
Fuel gas	-1,127	cu.ft.*
Direct labor	0.17 manhours.**	

*Minus sign signifies production.

**For vinyl acetate plant with annual capacity of 20 MM lbs.

acetic acid	60
acetylene	60

PRODUCTION OF VINYL ACETATE FROM ACETIC ACID AND NATURAL GAS ACETYLENE

	Requirements per hundred pounds of output	
Selected inputs:		
Acetic acid	71	lbs.
Natural gas	2,762	cu.ft.
Utilities:		
Steam	776	lbs.
Cooling water	6,031	gals.
Electric power	10	kwh.
Fuel gas	-1,127	cu.ft.*
Direct labor	0.16	manhours.**

*Minus sign signifies production.

**For vinyl acetate plant with annual capacity of 20 MM lbs.
acetylene
80

PRODUCTION OF VINYL ACETATE FROM ACETIC ACID AND ETHANE ACETYLENE

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	826	cu.ft.
Acetic acid	71	lbs.
Utilities:		
Steam	449	lbs.
Cooling water	3,055	gals.
Electric power	7	kwh.
Fuel gas	-304	cu.ft.*
Direct labor	0.16	manhours.**

*Minus sign signifies production.

**For vinyl acetate plant with annual capacity of 20 MM lbs.
acetylene
80

PRODUCTION OF VINYL CHLORIDE FROM NATURAL GAS (VIA ACETYLENE)

	Requirements per hundred pounds of output	
Selected inputs:		
Natural gas	3,711	cu.ft.
Utilities:		
Steam	1,355	lbs.
Cooling water	13,749	gals.
Electric power	19	kwh.
Fuel gas	-1,514	cu.ft.*
Chemicals:		
Hydrogen chloride	69	lbs.
Direct labor	0.09	manhours.**

*Minus sign signifies production.

**For vinyl chloride plant with annual capacity of 70 MM lbs.
acetylene
80

PRODUCTION OF VINYL CHLORIDE FROM ETHANE (VIA ACETYLENE)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	88	lbs.
Utilities:		
Steam	903	lbs.
Cooling water	9,760	gals.
Electric power	15	kwh.
Fuel gas	-409	cu.ft.*
Chemicals:		
Hydrogen chloride	69	lbs.
Direct labor	0.09	manhours.**

*Minus sign signifies production.

**For vinyl chloride plant with annual capacity of 70 MM lbs.
acetylene
80

PRODUCTION OF VINYL CHLORIDE FROM ETHANE (VIA ETHYLENE DICHLORIDE)

	Requirements per hundred pounds of output**	
Selected inputs:		
Ethane	40	lbs.
Utilities:		
Steam	213	lbs.
Cooling water	2,814	gals.
Electric power	1.8	kwh.
Fuel gas	210	cu.ft.
Chemicals:		
Chlorine	76	lbs.
Direct labor	0.16	manhours.*

*For vinyl chloride plant with annual capacity of 40 MM lbs.
ethylene dichloride
70
ethylene
66

**Of total output 61% weight is vinyl chloride, 39% by weight is anhydrous HCL.

PRODUCTION OF VINYL CHLORIDE FROM ETHYLENE DICHLORIDE

	Requirements per hundred pounds of output*	
Selected inputs:		
Ethylene dichloride	105	lbs.
Utilities:		
Steam	122	lbs.
Cooling water	810	lbs.
Electric power	1	kwh.
Fuel gas	145	cu.ft.
Direct labor	0.09	manhours.**

*Of total output 61% by weight is vinyl chloride, 39% by weight is anhydrous HCL.

**For vinyl chloride plant with annual capacity of 40 MM lbs.

PRODUCTION OF UREA FROM NATURAL GAS
(VIA AMMONIA)

	Requirements per hundred pounds of output	
Selected inputs:		
Natural gas	986	cu.ft.
Utilities:		
Steam	488	lbs.
Cooling water	3,995	gals.
Electric power	31	kwh.
Fuel gas	225	cu.ft.
Direct labor	0.10	manhours.*

*For urea plant with annual capacity of 60 MM lbs.
ammonia 254

PRODUCTION OF POLYSTYRENE FROM ETHYLBENZENE
(VIA STYRENE)

	Requirements per hundred pounds of output	
Selected inputs:		
Ethylbenzene	133	lbs.
Utilities:		
Steam	4,076	lbs.
Cooling water	2,190	gals.
Electric power	25	kwh.
Fuel gas	963	cu.ft.
Direct labor	0.27	manhours.*

*For polystyrene plant with annual capacity of 80 MM lbs.
styrene 120

PRODUCTION OF POLYETHYLENE FROM ETHANE

	Requirements per hundred pounds of output	
Selected inputs:		
Ethane	138	lbs.
Utilities:		
Steam	570	lbs.
Cooling water	8,117	gals.
Electric power	42	kwh.
Fuel gas	222	cu.ft.
Direct labor	0.21	manhours.*

*For polyethylene plant with annual capacity of 60 MM lbs.
ethylene 55

PRODUCTION OF POLYSTYRENE FROM STYRENE

	Requirements per hundred pounds of output	
Selected inputs:		
Styrene	110	lbs.
Utilities:		
Steam	2,000	lbs.
Cooling water	650	gals.
Electric power	18	kwh.
Direct labor	0.14	manhours.*

*For polystyrene plant with annual capacity of 80 MM lbs.

PRODUCTION OF POLYSTYRENE FROM ETHANE AND BENZENE
(VIA STYRENE)

	Requirements per hundred pounds of output	
Selected inputs:		
Benzene	105	lbs.
Ethane	51	lbs.
Utilities:		
Steam	4,574	lbs.
Cooling water	4,067	gals.
Electric power	33	kwh.
Fuel gas	1,455	cu.ft.
Direct labor	0.35	manhours.*

*For polystyrene plant with annual capacity of 60 MM lbs.
styrene 120
ethylbenzene 120
ethylene .63

PRODUCTION OF GR-S RUBBER FROM BUTADIENE, BENZENE AND ETHANE
(VIA ETHYLENE—ETHYLBENZENE—STYRENE)

	Requirements per hundred pounds of output	
Selected inputs:		
Butadiene	80	lbs.
Benzene	19	lbs.
Ethane	9	lbs.
Utilities:		
Steam	2,468	lbs.
Cooling water	28,621	gals.
Electric power	23	kwh.
Fuel gas	265	cu.ft.
Direct labor	0.16	manhours.*

For GR-S plant with annual capacity of 160 MM lbs.
styrene 120
ethylbenzene 120
ethylene 66

PRODUCTION OF GR-S RUBBER FROM BUTADIENE AND ETHYLBENZENE (VIA STYRENE)

	Requirements per hundred pounds of output	
Selected inputs:		
Butadiene	80	lbs.
Ethylbenzene	24	lbs.
Utilities:		
Steam	2,377	lbs.
Cooling water	28,280	gals.
Electric power	21	kwh.
Fuel gas	175	cu.ft.
Direct labor	0.14	manhours.*

*For GR-S plant with annual capacity of 160 MM lbs.
styrene 120

PRODUCTION OF STYRENE FROM ETHYLBENZENE

	Requirements per hundred pounds of output	
Selected inputs:		
Ethylbenzene	121	lbs.
Utilities:		
Steam	1,887	lbs.
Cooling water	1,400	gals.
Electric power	7	kwh.
Fuel gas	875	cu.ft.
Direct labor	0.12	manhours.*

*For styrene plant with annual capacity of 120 MM lbs.

PRODUCTION OF GR-S RUBBER FROM BUTADIENE AND STYRENE

	Requirements per hundred pounds of output	
Selected inputs:		
Butadiene	80	lbs.
Styrene	20	lbs.
Rock salt	20	lbs.
Utilities:		
Steam	2,000	lbs.
Cooling water	28,000	gals.
Electric power	20	kwh.
Direct labor	0.10	manhours.*

*For GR-S rubber plant with annual capacity of 160 MM lbs.

PRODUCTION OF ETHYLBENZENE FROM ETHANE AND BENZENE

	Requirements per hundred pounds of product	
Selected inputs:		
Ethane	37	lbs.
Benzene	79	lbs.
Utilities:		
Steam	373	lbs.
Cooling water	2,879	gals.
Electric power	6	kwh.
Fuel gas	370	cu.ft.
Direct labor	0.06	manhours.*

*For ethylbenzene plant with annual capacity of 120 MM lbs.
ethylene 56

PRODUCTION OF STYRENE FROM ETHANE AND BENZENE (VIA ETHYLBENZENE)

	Requirements per hundred pounds of output	
Selected inputs:		
Benzene	95	lbs.
Ethane	46	lbs.
Utilities:		
Steam	2,340	lbs.
Cooling water	3,106	gals.
Electric power	13	kwh.
Fuel gas	1,324	cu.ft.
Direct labor	0.19	manhours.*

*For styrene plant with annual capacity of 120 MM lbs.
ethylbenzene 120
ethylene 66

PRODUCTION OF PHENOL FROM BENZENE (RASCHIG PROCESS)

	Requirements per hundred pounds of output	
Selected inputs:		
Benzene	97	lbs.
Utilities:		
Steam	1,650	lbs.
Cooling water	4,494	gals.
Electric power	16	kwh.
Fuel gas	570	cu.ft.
Chemicals:		
Hydrochloric acid (32%)	24	lbs.
Direct labor	0.22	manhours.*

*For phenol plant with annual capacity of 53 MM lbs.

PRODUCTION OF ETHYLENE DICHLORIDE FROM ETHANE

	Requirements per hundred pounds of output
Selected inputs:	
Ethane	39 lbs.
Utilities:	
Steam	87 lbs.
Cooling water	1,909 gals.
Electric power	0.8 kwh.
Fuel gas	62 cu.ft.
Chemicals:	
Chlorine	72 lbs.
Direct labor	0.37 manhours.*

---

*For ethylene dichloride plant with annual capacity of 70 MM lbs. ethylene
66

PRODUCTION OF METHYL CHLORIDE FROM METHANE (VIA CHLORINATION)

	Requirements per hundred pounds of output*
Selected inputs:	
Methane	435 cu.ft.
Utilities:	
Steam	400 lbs.
Cooling water	1,000 gals.
Electric power	3.5 kwh.
Fuel gas	100 cu.ft.
Chemicals:	
Chlorine	87 lbs.
Direct labor	0.27 manhours.**

---

*Of total output, 47% by weight is methyl chloride, 41% by weight is hydrogen chloride, 8% by weight is methylene chloride, and 4% by weight is chloroform and carbon tetrachloride.

**For methyl chloride plant with annual capacity of 10 MM lbs.

PRODUCTION OF ETHYL CHLORIDE FROM ETHANE (VIA CHLORINATION OF ETHANE)

	Requirements per hundred pounds of output*
Selected inputs:	
Ethane	54 lbs.
Utilities:	
Steam	286 lbs.
Cooling water	2,166 gals.
Electric power	2.4 kwh.
Fuel gas	-6 cu.ft.**
Chemicals:	
Chlorine	57 lbs.
Direct labor	0.06 manhours.***

---

*Of total output 89% by weight is ethyl chloride, 9% by weight is ethylene dichloride, and 2% by weight is light ends and aqueous HCL.

**Minus sign signifies production.

***For ethyl chloride plant with annual capacity of 120 MM lbs.

PRODUCTION OF METHYL CHLORIDE FROM NATURAL GAS (VIA METHANOL)

	Requirements per hundred pounds of output
Selected inputs:	
Natural gas	1,581 cu.ft.
Utilities:	
Steam	270 lbs.
Cooling water	4,353 gals.
Electric power	29 kwh.
Fuel gas	140 cu.ft.
Chemicals:	
Hydrogen chloride	80 lbs.
Direct labor	0.29 manhours.*

---

*For methyl chloride plant with annual capacity of 10 MM lbs. methanol
240

PRODUCTION OF ETHYL CHLORIDE FROM ETHANE (VIA ETHYLENE AND HCl)

	Requirements per hundred pounds of output
Selected inputs:	
Ethane	60 lbs.
Utilities:	
Steam	278 lbs.
Cooling water	3,327 gals.
Electric power	3.4 kwh.
Fuel gas	197 cu.ft.
Chemicals:	
Hydrogen chloride	60 lbs.
Direct labor	0.08 manhours.*

---

*For ethyl chloride plant with annual capacity of 120 MM lbs. ethylene
66

PRODUCTION OF METHYL CHLORIDE FROM METHANOL

	Requirements per hundred pounds of output
Selected inputs:	
Methanol	70 lbs.
Utilities:	
Steam	200 lbs.
Cooling water	1,400 gals.
Electric power	3 kwh.
Fuel gas	140 cu.ft.
Chemicals:	
Hydrogen chloride	80 lbs.
Direct labor	0.26 manhours.*

---

*For methyl chloride plant with annual capacity of 10 MM lbs.

PRODUCTION OF HYDROGEN CHLORIDE (HCl)

	Requirements per hundred pounds 100% HCl
Inputs: Salt	165 lbs.
Hydrogen	4 lbs.
Chemicals	8 lbs.
Utilities: Steam	69 lbs.
Cooling water	35,000 gals.
Electric power	165 kwh.
Direct labor	0.23 manhours.*
Cost differentials (maximum) per 100 lbs HCl (100 %):	
Power	100 cents.
Steam	2.6 cents.
Direct labor	16 cents.
Indirect labor	15 cents.

*For HCl plant with annual capacity of 40 MM lbs.
chlorine 66

PRODUCTION OF AMMONIUM NITRATE FROM NATURAL GAS

	Requirements per hundred pounds of output
Selected Inputs:	
Natural gas (process and fuel)	776 cu.ft.
Utilities:	
Steam	232 lbs.
Cooling water	1,945 gals.
Electric power	33 kwh.
Direct labor	0.10 manhours.*

*For ammonium nitrate plant with annual capacity of 200 MM lbs.
nitric acid 40
ammonia 264

PRODUCTION OF NITRIC ACID FROM NATURAL GAS

	Requirements per hundred pounds of output
Selected inputs:	
Natural gas (process and fuel)	485 cu.ft.
Utilities:	
Steam	105 lbs.
Cooling water	1,572 gals.
Electric power	26 kwh.
Direct labor	0.08 manhours.*

*For nitric acid plant with annual capacity of 40 MM lbs.
ammonia 264

PRODUCTION OF AMMONIUM NITRATE FROM AMMONIA (VIA NITRIC ACID)

	Requirements per hundred pounds of output
Selected Inputs:	
Ammonia	46 lbs.
Utilities:	
Steam	65 lbs.
Cooling water	688 gals.
Electric power	11 kwh.
Direct labor	0.08 manhours.*

*For ammonium nitrate plant with annual capacity of 200 MM lbs.
nitric acid 40

PRODUCTION OF NITRIC ACID FROM AMMONIA

	Requirements per hundred pounds of output
Selected inputs:	
Ammonia	29 lbs.
Utilities:	
Cooling water	785 gals.
Electric power	12 kwh.
Direct labor	0.07 manhours.*

*For nitric acid plant with annual capacity of 40 MM lbs.

PRODUCTION OF AMMONIUM NITRATE FROM AMMONIA AND NITRIC ACID

	Requirements per hundred pounds of output
Selected inputs:	
Ammonia	24 lbs.
Nitric acid	76 lbs.
Utilities:	
Steam	65 lbs.
Cooling water	91 gals.
Electric power	2 kwh.
Direct labor	0.03 manhours.*

*For ammonium nitrate plant with annual capacity of 200 MM lbs.

APPENDIX B

Tables on Economies of Scale

INDEX

ACRYLONITRILE (EX ACETYLENE)
Economies of Scale Calculation
[Plant factor 0.76, labor factor 0.25]

Plant capacity(MM lbs/yr)	5	10	20	50
Plant investment(in $000)	$543	$920	$1,558	$3,126
Labor manhours per year..	34,500	41,030	48,790	61,360
Selected costs per year (in $000):				
Operating labor.......	95	113	134	169
Supervision...........	9	11	13	17
Plant maintenance.....	22	37	62	125
Equipment and operating supplies.........	3	6	9	19
Payroll overhead......	17	21	27	37
Indirect production cost.................	65	83	110	165
General office overhead.................	13	17	22	33
Depreciation..........	54	92	156	313
Taxes.................	5	9	16	31
Insurance.............	5	9	16	31
Interest..............	22	37	62	125
Total..............	$311	$435	$627	$1,064
Selected costs per 100 lbs.................	$6.22	$4.35	$3.13	$2.13
Difference between consecutive columns in selected costs per 100 lbs..........	$1.87	$1.22	$1.00	

Note: Minor discrepancies exist owing to the rounding of figures.

HYDROGEN CYANIDE
Economies of Scale Calculation
[Plant factor 0.7, labor factor 0.2]

Plant capacity(MM lbs/yr)	10	20	40	70	100
Plant investment(in $000)	$782	$1,270	$2,062	$3,051	$3,917
Labor manhours per year..	13,540	15,560	17,870	19,990	21,470
Selected costs per year (in $000):					
Operating labor.......	37	43	49	55	59
Supervision...........	4	4	5	5	6
Plant maintenance.....	31	51	82	122	157
Equipment and operating supplies.........	5	8	12	18	24
Payroll overhead......	8	11	14	18	21
Indirect production cost.................	38	53	74	100	123
General office overhead.................	8	11	15	20	25
Depreciation..........	78	127	206	305	392
Taxes.................	8	13	21	31	39
Insurance.............	8	13	21	31	39
Interest..............	31	51	82	122	155
Total..............	$257	$383	$582	$828	$1,040
Selected costs per 100 lbs.................	$2.57	$1.91	$1.46	$1.18	$1.04
Difference between consecutive columns in selected costs per 100 lbs..........	$0.66	$0.45	$0.28	$0.14	

Note: Minor discrepancies exist owing to the rounding of figures.

ACRYLONITRILE (EX ETHYLENE OXIDE)
Economies of Scale Calculation
[Plant factor 0.7, labor factor 0.2]

Plant capacity(MM lbs/yr)	5	10	20	50
Plant investment(in $000)	$423	$686	$1,115	$2,117
Labor manhours per year..	37,740	43,350	49,790	59,810
Selected costs per year (in $000):				
Operating labor.......	104	119	137	164
Supervision...........	10	12	14	16
Plant maintenance.....	17	27	45	85
Equipment and operating supplies.........	3	4	7	13
Payroll overhead......	18	22	26	33
Indirect production cost.................	67	81	101	139
General office overhead.................	13	16	20	28
Depreciation..........	42	69	112	212
Taxes.................	4	7	11	21
Insurance.............	4	7	11	21
Interest..............	17	27	45	85
Total..............	$300	$392	$527	$818
Selected costs per 100 lbs.................	$6.00	$3.92	$2.64	$1.64
Difference between consecutive columns in selected costs per 100 lbs..........	$2.08	$1.28	$1.00	

Note: Minor discrepancies exist owing to the rounding of figures.

ETHANOLAMINES
Economies of Scale Calculation
[Plant factor 0.6, labor factor 0.2]

Plant capacity(MM lbs/yr)	4	8	16	30	40
Plant investment(in $000)	$1,525	$2,312	$3,504	$5,110	$6,073
Labor manhours per year..	16,070	18,460	21,200	24,050	25,470
Selected costs per year (in $000):					
Operating labor.......	44	51	58	66	70
Supervision...........	4	5	6	7	7
Plant maintenance.....	61	92	140	204	243
Equipment and operating supplies.........	9	14	21	31	36
Payroll overhead......	12	15	20	26	30
Indirect production cost.................	59	81	113	154	178
General office overhead.................	12	16	23	31	36
Depreciation..........	153	231	350	511	607
Taxes.................	15	23	35	51	61
Insurance.............	15	23	35	51	61
Interest..............	61	92	140	204	243
Total..............	$446	$645	$941	$1,336	$1,572
Selected costs per 100 lbs.................	$11.15	$8.06	$5.88	$4.45	$3.93
Difference between consecutive column in selected costs per 100 lbs..........	$3.09	$2.18	$1.43	$0.52	

Note: Minor discrepancies exist owing to the rounding of figures.

ETHYLENE OXIDE (OXIDATION PROCESS)
Economies of Scale Calculation

[Plant factor 0.625 labor factor 0.22]

Plant capacity (MM lbs/yr)	10	20	40	60	80
Plant investment (in $000)	$2,558	$3,946	$6,086	$7,841	$9,385
Labor manhours per year..	45,710	53,251	62,022	67,810	72,240
Selected costs per year (in $000):					
Operating labor.......	126	146	171	186	199
Supervision...........	13	15	17	19	20
Plant maintenance.....	102	158	243	314	375
Equipment and operating supplies.........	15	24	37	47	56
Payroll overhead......	28	36	46	54	61
Indirect production cost.................	128	171	234	283	325
General office overhead.................	26	34	47	57	65
Depreciation..........	256	395	609	784	939
Taxes.................	26	39	61	78	94
Insurance.............	20	39	61	78	94
Interest..............	102	158	243	314	375
Total..............	$847	$1,215	$1,768	$2,214	$2,603
Selected costs per 100 lbs................	$8.47	$6.08	$4.42	$3.69	$3.25
Difference between consecutive columns in selected costs per 100 lbs..........	$2.39	$1.66	$0.73	$0.44	

Note: Minor discrepancies exist owing to the rounding of figures.

AMMONIA (EX NATURAL GAS)
Economies of Scale Calculation

[Plant factor 0.81, labor factor 0.4]

Plant capacity (MM lbs/yr)	66	132	264	528	792
Plant investment (in $000)	$5,467	$9,584	$16,803	$29,460	$40,912
Labor manhours per year..	55,222	72,866	96,148	126,870	149,210
Selected costs per year (in $000):					
Operating labor.......	152	200	264	349	410
Supervision...........	15	20	26	35	41
Plant maintenance.....	219	383	672	1,178	1,636
Equipment and operating supplies.........	33	53	101	177	245
Payroll overhead......	41	62	94	146	190
Indirect production cost.................	209	331	532	869	1,167
General office overhead.................	42	66	106	174	233
Depreciation..........	247	958	1,680	2,946	4,091
Taxes.................	55	96	168	295	409
Insurance.............	55	96	168	295	409
Interest..............	219	383	672	1,178	1,636
Total..............	$1,536	$2,653	$4,485	$7,642	$10,470
Selected costs per 100 lbs................	$2.40	$2.01	$1.70	$1.45	$1.32
Difference between consecutive columns in selected costs per 100 lbs..........	$0.39	$0.31	$0.25	$0.13	

Note: Minor discrepancies exist owing to the rounding of figures.

ETHYLENE OXIDE (CHLORHYDRIN PROCESS)
Economies of Scale Calculation

[Plant factor 0.625, labor factor 0.22]

Plant capacity (MM lbs/yr)	10	20	40	80
Plant investment (in $000)	$2,051	$3,163	$4,878	$7,523
Labor manhours per year..	40,616	47,306	55,099	64,176
Selected costs per year (in $000):				
Operating labor.......	112	130	152	176
Supervision...........	11	13	15	18
Plant maintenance.....	82	127	195	301
Equipment and operating supplies.........	12	19	29	45
Payroll overhead......	25	31	40	52
Indirect production cost.................	109	144	196	270
General office overhead.................	22	29	39	54
Depreciation..........	205	316	488	752
Taxes.................	21	32	49	75
Insurance.............	21	32	49	75
Interest..............	82	127	195	301
Total..............	$700	$999	$1,446	$2,120
Selected costs per 100 lbs................	$7.00	$4.99	$3.61	$2.65
Difference between consecutive columns in selected costs per 100 lbs..........	$2.01	$1.38	$0.96	

Note: Minor discrepancies exist owing to the rounding of figures.

ACETIC ANHYDRIDE (EX ACETIC ACID)
Economies of Scale Calculation

[Plant factor 0.67, labor factor 0.2]

Plant capacity (MM lbs/yr)	10	20	40	70	100
Plant Investment (in $000)	$760	$1,210	$1,925	$2,601	$3,557
Labor manhours per year..	31,570	36,260	41,650	46,590	50,030
Selected costs per year (in $000):					
Operating labor.......	37	100	115	128	138
Supervision...........	9	10	11	13	14
Plant maintenance.....	30	48	77	112	142
Equipment and operating supplies.........	5	7	12	17	21
Payroll overhead......	17	20	25	30	33
Indirect production cost.................	65	83	107	135	157
General office overhead.................	13	17	21	27	31
Depreciation..........	76	121	193	280	356
Taxes.................	8	12	19	28	36
Insurance.............	8	12	19	28	36
Interest..............	30	48	77	112	142
Total..............	$347	$478	$676	$909	$1,106
Selected costs per 100 lbs................	$3.47	$2.39	$1.69	$1.30	$1.11
Difference between consecutive column in selected costs per 100 lbs..........	$1.08	$0.70	$0.39	$0.19	

Note: Minor discrepancies exist owing to the rounding of figures.

ACETIC ACID (EX ACETALDEHYDE)
Economies of Scale Calculation
[Plant factor 0.67, labor factor 0.2]

Plant capacity(MM lbs/yr)	10	20	40	80	150
Plant investment(in $000)	$374	$595	$947	$1,507	$2,256
Labor manhours per year..	21,740	24,980	28,690	32,960	37,370
Selected costs per year (in $000):					
Operating labor.......	60	69	79	91	103
Supervision...........	6	7	8	9	10
Plant maintenance.....	15	24	38	60	92
Equipment and operating supplies.........	2	4	6	9	14
Payroll overhead......	11	13	16	19	24
Indirect production cost.................	41	51	65	85	109
General office overhead................	8	10	13	17	22
Depreciation..........	37	60	95	151	230
Taxes.................	4	6	9	15	23
Insurance.............	4	6	9	15	23
Interest..............	15	24	38	60	92
Total..............	$204	$273	$276	$531	$741
Selected costs per 100 lbs.................	$2.04	$1.37	$0.94	$0.66	$0.49
Difference between consecutive columns in selected costs per 100 lbs..........	$0.67	$0.43	$0.28	$0.17	

Note: Minor discrepancies exist owing to the rounding of figures.

ACETALDEHYDE (EX ACETYLENE)
Economies of Scale Calculation
[Plant factor 0.72, labor factor 0.25]

Plant capacity(MM lbs/yr)	10	20	40	70	100
Plant investment(in $000)	$377	$620	$1,022	$1,529	$1,977
Labor manhours per year..	40,040	47,610	56,620	65,120	71,190
Selected costs per year (in $000):					
Operating labor.......	110	131	156	179	195
Supervision...........	11	13	16	18	20
Plant maintenance.....	15	25	41	61	79
Equipment and operating supplies.........	2	4	6	9	12
Payroll overhead......	19	23	29	34	38
Indirect production cost.................	69	86	109	134	153
General office overhead................	14	17	22	27	31
Depreciation..........	38	62	102	153	193
Taxes.................	4	6	10	15	20
Insurance.............	4	6	10	15	20
Interest..............	15	25	41	61	79
Total..............	$301	$399	$542	$705	$845
Selected costs per 100 lbs.................	$3.01	$1.99	$1.35	$1.01	$0.84
Difference between consecutive columns in selected costs per 100 lbs..........	$1.02	$0.64	$0.34	$0.17	

Note: Minor discrepancies exist owing to the rounding of figures.

ACETALDEHYDE (EX ETHANOL)
Economies of Scale Calculation
[Plant factor 0.67, labor factor 0.2]

Plant capacity(MM lbs/yr)	10	20	40	70
Plant investment(in $000)	$315	$501	$797	$1,159
Labor manhours per year..	31,760	36,480	41,910	46,870
Selected costs per year (in $000):				
Operating labor.......	87	100	115	129
Supervision...........	9	10	12	13
Plant maintenance.....	13	20	32	46
Equipment and operating supplies.........	2	3	5	7
Payroll overhead......	15	18	21	25
Indirect production cost.................	55	67	82	98
General office overhead................	11	13	16	20
Depreciation..........	32	50	80	116
Taxes.................	3	5	8	12
Insurance.............	3	5	8	12
Interest..............	13	20	32	46
Total..............	$243	$312	$410	$522
Selected costs per 100 lbs.................	$2.42	$1.56	$1.03	$0.75
Difference between consecutive columns.. in selected costs per 100 lbs..........	$0.86	$0.53	$0.28	

Note: Minor discrepancies exist owing to the rounding of figures.

ETHYL ALCOHOL
Economies of Scale Calculation
[Plant factor 0.70, labor factor 0.25]

Plant capacity(MM lbs/yr)	30	60	120	200
Plant investment(in $000)	$1,710	$2,778	$4,513	$6,454
Labor manhours per year..	45,050	53,560	63,710	72,380
Selected costs per year (in $000):				
Operating labor.......	124	147	175	199
Supervision...........	12	15	18	20
Plant maintenance.....	68	111	181	258
Equipment and operating supplies.........	10	17	27	39
Payroll overhead......	26	33	42	52
Indirect production cost.................	107	145	200	258
General office overhead................	21	29	40	52
Depreciation..........	171	278	451	645
Taxes.................	17	28	45	65
Insurance.............	17	28	45	65
Interest..............	68	111	181	258
Total..............	$643	$941	$1,405	$1,910
Selected costs per 100 lbs.................	$2.14	$1.57	$1.17	$0.96
Difference between consecutive column in selected costs per 100 lbs..........	$0.57	$0.40	$0.21	

Note: Minor discrepancies exist owing to the rounding of figures.

FORMALDEHYDE (37%) (EX METHANOL)

Economies of Scale Calculation

[Plant factor 0.67, labor factor 0.2]

Plant capacity(MM lbs/yr)	30	60	120	240
Plant investment(in $000)	$280	$446	$710	$1,129
Labor manhours per year..	36,000	41,350	47,500	54,570
Selected costs per year (in $000):				
Operating labor.......	99	114	131	150
Supervision...........	10	11	13	15
Plant maintenance.....	11	18	28	45
Equipment and operating supplies.........	2	3	4	7
Payroll overhead......	17	20	24	28
Indirect production cost.................	61	73	98	109
General office overhead.................	12	15	18	22
Depreciation..........	28	45	71	113
Taxes.................	3	4	7	11
Insurance.............	3	4	7	11
Interest..............	11	18	28	45
Total..............	$257	$324	$419	$556
Selected costs per 100 lbs.................	$0.85	$0.54	$0.35	$0.23
Difference between consecutive columns in selected costs per 100 lbs..........	$0.31	$0.19	$0.12	

Note: Minor discrepancies exist owing to the rounding of figures.

METHYL ALCOHOL (METHANOL)

Economies of Scale Calculation

[Plant factor 0.81, labor factor 0.4]

Plant capacity(MM lbs/yr)	60	120	240	450	600
Plant investment(in $000)	$5,544	$9,720	$17,040	$28,360	$35,800
Labor manhours per year..	55,700	73,490	96,970	124,700	139,900
Selected costs per year (in $000):					
Operating labor.......	153	202	267	343	385
Supervision...........	15	20	27	34	38
Plant maintenance.....	222	389	682	1,134	1,432
Equipment and operating supplies.........	33	58	102	170	215
Payroll overhead......	42	63	95	142	171
Indirect production cost.................	212	335	539	841	1,035
General office overhead.................	42	67	108	168	207
Depreciation..........	554	972	1,704	2,836	3,580
Taxes.................	55	97	170	284	358
Insurance.............	55	97	170	284	358
Interest..............	222	389	682	1,134	1,432
Total..............	$1,607	$2,689	$4,545	$7,370	$9,211
Selected costs per 100 lbs.................	$2.68	$2.24	$1.89	$1.64	$1.54
Difference between consecutive columns in selected costs per 100 lbs..........	$0.44	$0.35	$0.25	$0.10	

Note: Minor discrepancies exist owing to the rounding of figures.

PHTHALIC ANHYDRIDE (EX O-XYLENE)

Economies of Scale Calculation

[Plant factor 0.67, labor factor 0.3]

Plant capacity(MM lbs/yr)	10	20	40	70	100
Plant investment(in $000)	$2,617	$4,164	$6,625	$9,639	$12,240
Labor manhours per year..	32,140	39,560	48,710	57,610	64,130
Selected costs per year (in $000):					
Operating labor.......	88	109	134	158	176
Supervision...........	9	11	13	16	18
Plant maintenance.....	105	167	265	386	490
Equipment and operating supplies.........	16	25	40	58	73
Payroll overhead......	22	30	42	55	66
Indirect production cost.................	109	156	226	309	379
General office overhead.................	22	31	45	62	76
Depreciation..........	262	416	663	964	1,224
Taxes.................	26	42	66	96	122
Insurance.............	26	42	66	96	122
Interest..............	105	167	265	386	490
Total..............	$789	$1,195	$1,825	$2,566	$3,235
Selected costs per 100 lbs.................	$7.89	$5.97	$4.56	$3.69	$3.24
Difference between consecutive columns in selected costs per 100 lbs..........	$1.92	$1.41	$0.87	$0.45	

Note: Minor discrepancies exist owing to the rounding of figures.

POLYVINYL ACETATE

Economies of Scale Calculation

[Plant factor 0.75, labor factor 0.35]

Plant capacity(MM lbs/yr)	5	10	20	40	60
Plant investment(in $000)	$1,238	$2,081	$3,500	$5,886	$7,979
Labor manhours per year..	25,420	32,400	41,300	52,640	60,660
Selected costs per year (in $000):					
Operating labor.......	70	89	114	145	167
Supervision...........	7	9	11	14	17
Plant maintenance.....	50	83	140	235	319
Equipment and operating supplies.........	7	12	21	35	46
Payroll overhead......	15	21	29	42	51
Indirect production cost.................	67	97	143	215	275
General office overhead.................	13	19	29	43	55
Depreciation..........	124	208	350	589	798
Taxes.................	12	21	35	59	80
Insurance.............	12	21	35	59	80
Interest..............	50	83	140	235	319
Total..............	$427	$664	$1,047	$1,671	$2,209
Selected costs per 100 lbs.................	$8.55	$6.64	$5.23	$4.18	$3.68
Difference between consecutive column in selected costs per 100 lbs..........	$1.91	$1.41	$1.05	$0.50	

Note: Minor discrepancies exist owing to the rounding of figures.

POLYVINYL CHLORIDE
Economies of Scale Calculation

[Plant factor 0.76, labor factor 0.4]

Plant capacity(MM lbs/yr)	20	40	80	100
Plant investment(in $000)	$3,500	$5,927	$10,040	$11,890
Labor manhours per year..	43,040	56,790	74,910	81,940
Selected costs per year (in $000):				
Operating labor.......	118	156	206	225
Supervision...........	12	16	21	23
Plant maintenance.....	140	237	402	476
Equipment and operating supplies.........	21	36	60	71
Payroll overhead......	30	44	64	73
Indirect production cost................	146	222	344	397
General office overhead.................	29	44	69	79
Depreciation..........	350	553	1,004	1,169
Taxes.................	35	59	100	119
Insurance.............	35	59	100	119
Interest..............	140	237	402	476
Total..............	$1,056	$1,703	$2,772	$3,247
Selected costs per 100 lbs.................	$5.26	$4.26	$3.47	$3.25
Difference between consecutive columns in selected costs per 100 lbs..........	$1.02	$0.79	$0.22	

Note: Minor discrepancies exist owing to the rounding of figures.

VINYL CHLORIDE (EX ACETYLENE)
Economies of Scale Calculation

[Plant factor 0.72, labor factor 0.2]

Plant capacity(MM lbs/yr)	20	40	70	100
Plant investment(in $000)	$4,344	$7,155	$10,710	$13,840
Labor manhours per year..	22,780	26,170	29,270	31,440
Selected costs per year (in $000):				
Operating labor.......	63	72	80	86
Supervision...........	6	7	8	9
Plant maintenance.....	174	286	428	554
Equipment and operating supplies.........	26	43	64	83
Payroll overhead......	23	33	45	56
Indirect production cost................	134	204	291	366
General office overhead.................	27	41	58	73
Depreciation..........	434	716	1,071	1,384
Taxes.................	43	72	107	138
Insurance.............	43	72	107	138
Interest..............	174	286	428	554
Total..............	$1,148	$1,831	$2,689	$3,441
Selected costs per 100 lbs.................	$5.74	$4.58	$3.84	$3.44
Difference between consecutive columns in selected costs per 100 lbs..........	$1.16	$0.74	$0.40	

Note: Minor discrepancies exist owing to the rounding of figures.

VINYL ACETATE
Economies of Scale Calculation

[Plant factor 0.72, labor factor 0.3]

Plant capacity(MM lbs/yr)	5	10	20	40	60
Plant investment(in $000)	$1,779	$2,930	$4,826	$7,949	$10,640
Labor manhours per year..	16,970	20,890	25,720	31,660	35,760
Selected costs per year (in $000):					
Operating labor.......	47	57	71	87	98
Supervision...........	5	6	7	9	10
Plant maintenance.....	71	117	193	318	426
Equipment and operating supplies.........	11	18	29	48	64
Payroll overhead......	13	18	26	38	48
Indirect production cost................	67	99	150	231	299
General office overhead.................	13	20	30	46	60
Depreciation..........	178	293	483	795	1,064
Taxes.................	18	29	48	79	106
Insurance.............	18	29	48	79	106
Interest..............	71	117	193	318	426
Total..............	$511	$804	$1,278	$2,048	$2,707
Selected costs per 100 lbs.................	$10.21	$8.04	$6.39	$5.12	$4.51
Difference between consecutive columns in selected costs per 100 lbs..........	$2.17	$1.65	$1.27	$0.61	

Note: Minor discrepancies exist owing to the rounding of figures.

VINYL CHLORIDE (EX ETHYLENE DICHLORIDE)
Economies of Scale Calculation

[Plant factor 0.67, labor factor 0.2]

Plant capacity(MM lbs/yr)	20	40	70	100
Plant investment(in $000)	$4,699	$7,476	$10,880	$13,810
Labor manhours per year..	31,190	35,830	40,070	43,030
Selected costs per year (in $000):				
Operating labor.......	$86	$99	$110	$118
Supervision...........	9	10	11	12
Plant maintenance.....	183	299	435	552
Equipment and operating supplies.........	28	45	65	83
Payroll overhead......	28	39	51	61
Indirect production cost................	155	226	311	383
General office overhead.................	31	45	62	77
Depreciation..........	470	748	1,038	1,381
Taxes.................	47	75	109	138
Insurance.............	47	75	109	138
Interest..............	183	299	435	552
Total..............	$1,277	$1,958	$2,786	$3,495
Selected costs per 100 lbs.................	$6.38	$4.90	$3.98	$3.50
Difference between consecutive column in selected costs per 100 lbs..........	$1.48	$0.92	$0.48	

Note: Minor discrepancies exist owing to the rounding of figures.

UREA
Economies of Scale Calculation
[Plant factor 0.67, labor factor 0.2]

Plant capacity(MM lbs/yr)	30	60	125
Plant investment(in $000)	$1,498	$2,383	$3,896
Labor manhours per year..	40,570	46,600	53,970
Selected costs per year (in $000):			
Operating labor.......	112	128	148
Supervision...........	11	13	15
Plant maintenance.....	60	95	156
Equipment and operating supplies.........	9	14	23
Payroll overhead......	23	28	36
Indirect production cost.................	96	125	171
General office overhead.................	19	25	34
Depreciation..........	150	238	390
Taxes.................	15	24	39
Insurance.............	15	24	39
Interest..............	60	95	156
Total..............	$569	$811	$1,207
Selected costs per 100 lbs................	$1.90	$1.35	$0.97
Difference between consecutive columns in selected costs per 100 lbs..........	$0.55	$0.38	

Note: Minor discrepancies exist owing to the rounding of figures.

POLYSTYRENE
Economies of Scale Calculation
[Plant factor 0.82, labor factor 0.5]

Plant capacity(MM lbs/yr)	20	40	80	140	200
Plant investment(in $000)	$3,500	$6,179	$10,910	$17,260	$23,120
Labor manhours per year..	56,570	80,000	113,100	149,700	178,900
Selected costs per year (in $000):					
Operating labor.......	$156	$220	$311	$412	$492
Supervision...........	16	22	31	41	49
Plant maintenance.....	140	247	436	690	925
Equipment and operating supplies.........	21	37	65	104	139
Payroll overhead......	36	55	84	120	151
Indirect production cost.................	166	263	422	623	802
General office overhead.................	33	53	84	125	160
Depreciation..........	350	618	1,091	1,726	2,312
Taxes.................	35	62	109	173	231
Insurance.............	35	62	109	173	231
Interest..............	$140	$247	$436	$690	$925
Total..............	$1,128	$1,885	$3,180	$4,676	$6,417
Selected costs per 100 lbs................	$5.64	$4.71	$3.98	$3.48	$3.21
Difference between consecutive columns in selected costs per 100 lbs..........	$0.93	$0.73	$0.50	$0.27	

Note: Minor discrepancies exist owing to the rounding of figures.

POLYETHYLENE
Economies of Scale Calculation
[Plant factor 0.81 labor factor 0.4]

Plant capacity(MM lbs/yr)	15	30	60	100	150
Plant investment(in $000)	$6,161	$10,800	$18,940	$28,640	$39,770
Labor manhours per year..	38,910	50,020	66,000	80,960	95,220
Selected costs per year (in $000):					
Operating labor.......	107	138	182	223	262
Supervision...........	11	14	18	22	26
Plant maintenance.....	246	432	758	1,146	1,591
Equipment and operating supplies.........	37	65	114	172	239
Payroll overhead......	36	55	87	123	163
Indirect production cost.................	201	324	535	781	1,059
General office overhead.................	40	65	107	156	212
Depreciation..........	616	1,080	1,894	2,864	3,977
Taxes.................	62	108	189	286	398
Insurance.............	62	108	189	286	398
Interest..............	246	432	758	1,146	1,591
Total..............	$1,664	$2,820	$4,831	$7,205	$9,914
Selected costs per 100 lbs................	$11.10	$9.40	$8.10	$7.20	$6.60
Difference between consecutive columns in selected costs per 100 lbs..........	$1.70	$1.30	$0.90	$0.60	

Note: Minor discrepancies exist owing to the rounding of figures.

GR-S RUBBER
Economies of Scale Calculation
[Plant factor 0.82, labor factor 0.5]

Plant capacity(MM lbs/yr)	40	80	160	320	400
Plant investment(in $000)	$6,179	$10,910	$19,260	$34,000	$40,820
Labor manhours per year..	80,000	113,100	160,000	226,000	253,000
Selected costs per year (in $000):					
Operating labor.......	$220	$311	$440	$622	$696
Supervision...........	22	31	44	62	70
Plant maintenance.....	247	436	770	1,360	1,633
Equipment and operating supplies.........	37	65	116	204	245
Payroll overhead......	55	84	130	205	237
Indirect production cost.................	263	422	685	1,124	1,322
General office overhead.................	53	84	137	225	264
Depreciation..........	618	1,091	1,926	3,400	4,082
Taxes.................	62	109	193	340	408
Insurance.............	62	109	193	340	408
Interest..............	247	436	770	1,360	1,633
Total..............	$1,885	$3,160	$5,404	$9,241	$10,997
Selected costs per 100 lbs................	$4.71	$3.98	$3.38	$2.89	$2.75
Difference between consecutive column in selected costs per 100 lbs..........	$0.73	$0.60	$0.49	$0.14	

Note: Minor discrepancies exist owing to the rounding of figures.

STYRENE
Economies of Scale Calculation

[Plant factor 0.50, labor factor 0.15]

Plant capacity(MM lbs/yr)	30	60	120	200
Plant investment(in $000)	$7,955	$10,545	$14,910	$19,250
Labor manhours per year..	114,500	127,000	140,900	152,160
Selected costs per year (in $000):				
Operating labor.......	315	349	387	418
Supervision...........	31	35	39	42
Plant maintenance.....	298	422	596	770
Equipment and operating supplies.........	45	63	89	116
Payroll overhead......	79	89	109	127
Indirect production cost................	345	435	556	673
General office overhead................	69	87	111	135
Depreciation..........	746	1,055	1,491	1,925
Taxes.................	75	105	149	193
Insurance.............	75	105	149	193
Interest..............	298	422	596	770
Total..............	$2,370	$3,167	$4,274	$5,360
Selected costs per 100 lbs.................	$7.90	$5.28	$3.56	$2.68
Difference between consecutive columns in selected costs per 100 lbs..........	$2.62	$1.72	$0.88	

Note: Minor discrepancies exist owing to the rounding of figures.

PHENOL (BENZENE—RASCHIG PROCESS)
Economics of Scale Calculation

[Plant factor 0.67, labor factor 0.2]

Plant capacity(MM lbs/yr)	13	26	53	100
Plant investment(in $000)	$3,019	$4,795	$7,630	$11,630
Labor manhours per year..	87,862	100,930	115,930	131,500
Selected costs per year (in $000):				
Operating labor.......	242	278	319	362
Supervision...........	24	28	32	36
Plant maintenance.....	121	192	305	465
Equipment and operating supplies.........	18	29	46	70
Payroll overhead......	49	60	75	95
Indirect production cost................	202	263	351	466
General office overhead................	40	53	70	93
Depreciation..........	301	480	763	1,163
Taxes.................	30	48	76	116
Insurance.............	30	48	76	116
Interest..............	121	192	305	465
Total..............	$1,178	$1,669	$2,419	$3,448
Selected costs per 100 lbs.................	$9.01	$6.42	$4.56	$3.45
Difference between consecutive columns in selected costs per 100 lbs..........	$2.64	$1.86	$1.11	

Note: Minor discrepancies exist owing to the rounding of figures.

ETHYLBENZENE
Economies of Scale Calculation

[Plant factor 0.55, labor factor 0.15]

Plant capacity(MM lbs/yr)	30	60	120	200
Plant investment(in $000)	$4,925	$7,211	$10,560	$13,960
Labor manhours per year..	28,730	31,880	35,370	38,190
Selected costs per year (in $000):				
Operating labor.......	79	85	97	105
Supervision...........	8	9	10	11
Plant maintenance.....	197	288	422	559
Equipment and operating supplies.........	30	43	63	84
Payroll overhead......	28	36	48	59
Indirect production cost................	157	214	296	379
General office overhead................	31	43	59	76
Depreciation..........	493	721	1,056	1,399
Taxes.................	49	72	106	140
Insurance.............	49	72	106	140
Interest..............	197	288	422	559
Total..............	$1,317	$1,875	$2,686	$3,510
Selected costs per 100 lbs.................	$4.39	$3.12	$2.24	$1.75
Difference between consecutive columns.. in selected costs per 100 lbs..........	$1.27	$0.88	$0.49	

Note: Minor discrepancies exist owing to the rounding of figures.

ETHYLENE DICHLORIDE
Economies of Scale Calculation

[Plant factor 0.70, labor factor 0.25]

Plant capacity(MM lbs/yr)	20	40	70	100
Plant Investment(in $000)	$4,483	$7,282	$10,770	$13,830
Labor manhours per year..	20,470	24,340	28,000	30,610
Selected costs per year (in $000):				
Operating labor.......	56	67	77	84
Supervision...........	6	7	8	8
Plant maintenance.....	179	291	431	553
Equipment and operating supplies.........	27	44	65	83
Payroll overhead......	23	33	45	55
Indirect production cost................	134	204	290	364
General office overhead................	27	41	58	73
Depreciation..........	448	728	1,077	1,353
Taxes.................	45	73	108	138
Insurance.............	45	73	108	138
Interest..............	179	291	431	553
Total..............	$1,169	$1,852	$2,696	$3,434
Selected costs per 100 lbs.................	$3.65	$4.63	$5.65	$3.43
Difference between consecutive column in selected costs per 100 lbs..........	$1.22	$0.78	$0.42	

Note: Minor discrepancies exist owing to the rounding of figures.

ETHYL CHLORIDE (EX ETHYLENE)
Economies of Scale Calculation

[Plant factor 0.67, labor factor 0.2]

Plant capacity(MM lbs/yr)	30	60	120	200	300
Plant investment(in $000)	$6,165	$9,809	$15,610	$21,980	$28,840
Labor manhours per year..	33,130	38,050	43,710	48,410	52,510
Selected costs per year (in $000):					
Operating labor.......	91	105	120	133	144
Supervision...........	9	10	12	13	14
Plant maintenance.....	247	392	624	879	1,154
Equipment and operating supplies.........	37	59	94	132	173
Payroll overhead......	34	47	67	88	110
Indirect production cost.................	192	283	425	579	743
General office overhead.................	38	57	85	116	149
Depreciation..........	617	981	1,561	2,198	2,884
Taxes.................	62	98	156	220	288
Insurance.............	62	98	156	220	288
Interest..............	247	392	624	879	1,154
Total..............	$1,634	$2,522	$3,925	$5,457	$7,102
Selected costs per 100 lbs.................	$5.45	$4.20	$3.27	$2.73	$2.37
Difference between consecutive columns in selected costs per 100 lbs.........	$1.25	$0.93	$0.54	$0.36	

Note: Minor discrepancies exist owing to the rounding of figures.

METHYL CHLORIDE (EX METHANOL)
Economies of Scale Calculation

[Plant factor 0.67, labor factor 0.2]

Plant capacity(MM lbs/yr)	1	5	10	20
Plant investment(in $000)	$56	$164	$260	$414
Labor manhours per year..	16,780	23,150	26,590	30,550
Selected costs per year (in $000):				
Operating labor.......	46	64	73	84
Supervision...........	5	6	7	8
Plant maintenance.....	2	7	10	17
Equipment and operating supplies.........	(*)	1	2	2
Payroll overhead......	8	11	13	15
Indirect production cost.................	27	39	46	56
General office overhead.................	5	8	9	11
Depreciation..........	6	16	26	41
Taxes.................	1	2	3	4
Insurance.............	1	2	3	4
Interest..............	2	7	10	17
Total..............	$102	$161	$202	$260
Selected costs per 100 lbs.................	$10.20	$3.20	$2.00	$1.30
Difference between consecutive columns in selected costs per 100 lbs.........	$7.00	$1.20	$0.70	

*336.00

Note: Minor discrepancies exist owing to the rounding of figures.

ETHYL CHLORIDE (CHLORINATION OF ETHANE)
Economies of Scale Calculation

[Plant factor 0.65, labor factor 0.35]

Plant capacity(MM lbs/yr)	30	60	120	200
Plant investment(in $000)	$6,310	$9,902	$15,540	$21,660
Labor manhours per year..	45,400	57,870	73,760	88,200
Selected costs per year (in $000):				
Operating labor.......	125	159	203	243
Supervision...........	12	16	20	24
Plant maintenance.....	252	396	622	866
Equipment and operating supplies.........	38	59	93	130
Payroll overhead......	40	56	80	105
Indirect production cost.................	219	315	469	632
General office overhead.................	43	63	94	126
Depreciation..........	631	990	1,554	2,166
Taxes.................	63	99	155	217
Insurance.............	63	99	155	217
Interest..............	252	396	622	866
Total..............	$1,733	$2,649	$4,067	$5,592
Selected costs per 100 lbs.................	$5.78	$4.42	$3.39	$2.80
Difference between consecutive columns.. in selected costs per 100 lbs..........	$1.36	$1.03	$0.59	

Note: Minor discrepancies exist owing to the rounding of figures.

METHYL CHLORIDE (EX METHANE)
Economies of Scale Calculation

[Plant factor 0.67, labor factor 0.2]

Plant capacity(MM lbs/yr)	1	5	10	20
Plant investment(in $000)	$525	$1,544	$2,457	$3,910
Labor manhours per year..	16,780	23,150	26,590	30,550
Selected costs per year (in $000):				
Operating labor.......	46	64	73	84
Supervision...........	5	8	7	8
Plant maintenance.....	21	62	98	156
Equipment and operating supplies.........	3	9	15	23
Payroll overhead......	9	15	19	26
Indirect production cost.................	37	71	97	136
General office overhead.................	7	14	19	27
Depreciation..........	53	154	246	391
Taxes.................	5	15	25	39
Insurance.............	5	15	25	39
Interest..............	21	62	98	156
Total..............	$213	$488	$722	$1,087
Selected costs per 100 lbs.................	$21.30	$9.76	$7.22	$5.43
Difference between consecutive column in selected costs per 100 lbs..........	$11.54	$2.54	$1.79	

Note: Minor discrepancies exist owing to the rounding of figures.

AMMONIUM NITRATE
Economies of Scale Calculation
[Plant factor 0.68, labor factor 0.27]

Plant capacity(MM lbs/yr)	50	100	200	400
Plant investment(in $000)	$380	$603	$975	$1,562
Labor manhours per year..	31,210	37,640	45,380	54,720
Selected costs per year (in $000):				
Operating labor.......	86	104	125	150
Supervision...........	9	10	12	15
Plant maintenance.....	15	24	39	62
Equipment and operating supplies.........	2	4	6	9
Payroll overhead......	15	19	24	30
Indirect production cost.................	56	71	91	119
General office overhead.................	11	14	18	24
Depreciation..........	38	61	93	156
Taxes.................	4	6	10	16
Insurance.............	4	6	10	16
Interest..............	15	24	39	62
Total..............	$255	$343	$471	$659
Selected costs per 100 lbs.................	$0.51	$0.34	$0.24	$0.16
Difference between consecutive columns in selected costs per 100 lbs..........	$0.17	$0.10	$0.08	

Note: Minor discrepancies exist owing to the rounding of figures.

NITRIC ACID
Economies of Scale Calculation
[Plant factor 0.63, labor factor 0.2]

Plant capacity(MM lbs/yr)	10	20	40	80	100
Plant investment(in $000)	$1,360	$2,105	$3,258	$5,042	$5,803
Labor manhours per year..	21,830	25,080	28,810	33,090	34,600
Selected costs per year (in $000):					
Operating labor.......	60	69	79	91	95
Supervision...........	6	7	8	9	10
Plant maintenance.....	54	84	130	202	232
Equipment and operating supplies.........	8	12	20	30	35
Payroll overhead......	14	18	23	30	33
Indirect production cost.................	64	85	119	165	186
General office overhead.................	13	17	24	33	37
Depreciation..........	136	211	326	504	580
Taxes.................	14	21	33	50	58
Insurance.............	14	21	33	50	58
Interest..............	54	84	130	202	232
Total..............	$437	$631	$923	$1,368	$1,556
Selected costs per 100 lbs.................	$4.37	$3.15	$2.31	$1.71	$1.56
Difference between consecutive columns in selected costs per 100 lbs..........	$1.22	$0.84	$0.60	$0.15	

Note: Minor discrepancies exist owing to the rounding of figures.

ACETYLENE (EX NATURAL GAS)
Economies of Scale Calculation
[Plant factor 0.67, labor factor 0.15]

Plant capacity(MM lbs/yr)	10	20	40	80	120	160	200
Plant investment(in $000)	$2,172	$3,456	$5,499	$8,749	$11,480	$13,920	$16,165
Labor manhours per year..	64,330	71,379	79,200	87,878	93,339	97,507	100,830
Selected costs per year (in $000):							
Operating labor.......	177	196	218	242	257	268	277
Supervision...........	18	20	22	24	26	27	28
Plant maintenance.....	87	138	220	350	459	557	647
Equipment and operating supplies.........	13	21	33	52	69	84	97
Payroll overhead......	36	43	52	65	77	86	94
Indirect production cost.................	147	187	246	334	405	468	524
General office overhead.................	29	37	49	67	81	94	105
Depreciation..........	217	346	550	875	1,148	1,392	1,617
Taxes.................	22	35	55	87	115	139	162
Insurance.............	22	35	55	87	115	139	162
Interest..............	87	138	220	350	459	557	647
Total..............	$854	$1,196	$1,720	$2,535	$3,211	$3,810	$4,358
Selected costs per 100 lbs.................	$8.54	$5.98	$4.30	$3.17	$2.68	$2.38	$2.18
Difference between consecutive columns in selected costs per 100 lbs..........	$2.56	$1.68	$1.13	$0.49	$0.30	$0.20	

Note: Minor discrepancies exist owing to the rounding of figures.

ACETYLENE (EX ETHANE)
Economies of Scale Calculation

[Plant factor 0.66, labor factor 0.15]

Plant capacity (MM lbs/yr)	10	20	40	80	120	160	200
Plant investment (in $000)	$1,621	$2,561	$4,047	$6,394	$8,356	$10,103	$11,706
Labor manhours per year	64,330	71,379	79,200	87,878	93,389	97,507	100,830
Selected costs per year (in $000):							
Operating labor	177	196	218	242	257	268	277
Supervision	18	20	22	24	26	27	28
Plant maintenance	65	102	162	256	334	404	468
Equipment and operating supplies	10	15	24	38	50	61	70
Payroll overhead	34	40	48	59	67	75	81
Indirect production cost	135	167	213	280	333	380	422
General office overhead	27	33	43	56	67	76	84
Depreciation	162	256	405	.639	836	1,010	1,171
Taxes	16	26	40	64	84	101	117
Insurance	16	26	40	64	84	101	117
Interest	65	102	162	256	334	404	468
Total	$724	$984	$1,377	$1,978	$2,471	$2,907	$3,303
Selected costs per 100 lbs	$7.24	$4.92	$3.44	$2.47	$2.06	$1.82	$1.65
Difference between consecutive columns in selected costs per 100 lbs	$2.32	$1.48	$0.97	$0.41	$0.24	$0.17	

Note: Minor discrepancies exist owing to the rounding of figures.

APPENDIX C

Tables on Transport Cost Differentials

INDEX

ACRYLONITRILE FROM ETHANE (ACETYLENE) AND NATURAL GAS (HCN): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	Natural gas site		Market site	
						34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York.....	1. Amarillo	Via— Rail...	*$2.06	Amarillo source $1.22	$1.59	....	....	$0.84	$0.47
	2. Monroe...	Rail...	1.69	Monroe source 0.89	1.17	....	....	0.80	0.52
	3. Houston..	Rail...	1.93	Monroe source 0.89	1.17	....	....	1.04	0.76
		Ship...	0.39			0.50	0.78	....	....
Cincinnati....	1. Amarillo	Rail...	1.50	Amarillo source 0.78	1.01	....	....	0.72	0.49
	2. Monroe...	Rail...	1.17	Monroe source 0.49	0.64	....	....	0.68	0.53
		Barge..	0.16			0.33	0.48	....	....
Chicago.......	1. Amarillo	Rail...	1.37	Amarillo source 0.70	0.91	....	....	0.67	0.46
	2. Monroe...	Rail...	1.18	Monroe source 0.54	0.71	....	....	0.64	0.47
		Barge..	0.16			0.38	0.55	....	....
St. Louis.....	1. Amarillo	Rail...	1.23	Amarillo source 0.53	0.70	....	....	0.70	0.53
	2. Monroe...	Rail...	0.93	Monroe source 0.34	0.44	....	....	0.59	0.49
		Barge..	0.11			0.23	0.33	....	....

*All rail rates for acrylonitrile are uniform classification rates.

ACRYLONITRILE FROM NATURAL GAS (VIA ACETYLENE AND HCN): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	Natural gas site		Market site	
						34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York.....	1. Amarillo	Via— Rail...	$2.06	Amarillo source $2.44	$3.19	$0.38	$1.13	....	....
	2. Monroe...	Rail...	1.69	Monroe source 1.79	2.34	0.10	0.65	....	....
	3. Houston..	Rail...	1.93	Monroe source 1.79	2.34	....	0.41	0.14	....
		Ship...	0.39			1.40	1.95	....	....
Cincinnati....	1. Amarillo	Rail...	1.50	Amarillo source 1.56	2.04	0.06	0.54	....	....
	2. Monroe...	Rail...	1.17	Monroe source 0.98	1.29	....	0.12	0.19	
		Barge..	0.16			0.82	1.13	....	....
Chicago.......	1. Amarillo	Rail...	1.37	Amarillo source 1.40	1.83	0.03	0.46	....	....
	2. Monroe...	Rail...	1.18	Monroe source 1.08	1.42	....	0.24	0.10	....
		Barge..	0.16			0.92	1.26	....	....
St. Louis.....	1. Amarillo	Rail...	1.23	Amarillo source 1.07	1.40	....	0.17	0.16	....
	2. Monroe...	Rail...	0.93	Monroe source 0.68	0.89	....	....	0.25	0.04
		Barge..	0.11			0.57	0.78	....	....

ACRYLONITRILE FROM ETHANE (ETHYLENE OXIDE, OXIDATION PROCESS) AND NATURAL GAS (HCN): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......	1. Amarillo	Via— Rail...	$2.06	Amarillo source $1.65	$2.16	....	0.10	$0.41	....
	2. Monroe...	Rail...	1.69	Monroe source 1.21	1.58	....	....	0.48	$0.11
	3. Houston..	Rail... Ship...	1.93 0.39	Monroe source 1.21	.... 1.58	.... 0.82	.... 1.19	0.72	0.35
Cincinnati....	1. Amarillo	Rail...	1.50	Amarillo source 1.05	1.38	....	....	0.45	0.12
	2. Monroe...	Rail... Barge..	1.17 0.16	Monroe source 0.67	0.87	.... 0.51	.... 0.71	0.50	0.30
Chicago.......	1. Amarillo	Rail...	1.37	Amarillo source 0.95	1.24	....	....	0.42	0.13
	2. Monroe...	Rail... Barge..	1.18 0.16	Monroe source 0.73	0.96	.... 0.57	.... 0.80	0.45	0.22
St. Louis.....	1. Amarillo	Rail...	1.23	Amarillo source 0.73	0.95	....	....	0.50	0.28
	2. Monroe...	Rail... Barge..	0.93 0.11	Monroe source 0.46	0.60	.... 0.35	.... 0.49	0.47	0.33

ACRYLONITRILE FROM ETHANE (ETHYLENE OXIDE—CHLORHYDRIN PROCESS) AND NATURAL GAS (HCN): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......	1. Amarillo	Via— Rail...	$2.06	Amarillo source $1.35	$1.77	....	....	$0.71	$0.29
	2. Monroe...	Rail...	1.69	Monroe source 0.99	1.30	....	....	0.70	0.39
	3. Houston..	Rail... Ship...	1.93 0.39	Monroe source 0.99	1.30	.... 0.60	.... 0.91	0.94	0.63
Cincinnati....	1. Amarillo	Rail...	1.50	Amarillo source 0.86	1.13	....	....	0.64	0.37
	2. Monroe...	Rail... Barge..	1.17 0.16	Monroe source 0.54	0.71	.... 0.38	.... 0.55	0.63	0.46
Chicago.......	1. Amarillo	Rail...	1.37	Amarillo source 0.78	1.01	....	....	0.59	0.36
	2. Monroe...	Rail... Barge..	1.18 0.16	Monroe source 0.60	0.78	.... 0.44	.... 0.62	0.58	0.40
St. Louis.....	1. Amarillo	Rail...	1.23	Amarillo source 0.59	0.78	....	....	0.64	0.45
	2. Monroe...	Rail... Barge..	0.93 0.11	Monroe source 0.38	0.49	.... 0.27	.... 0.39	0.55	0.44

ACRYLONITRILE FROM ETHYLENE OXIDE, AND NATURAL GAS (HCN): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	$2.06	[a]$2.91	[a]$3.16	0.85	1.10	....	....
				Monroe source					
	2. Monroe...	Rail...	1.69	[a]2.31	[a]2.50	0.62	0.81	....	....
				Monroe source					
	3. Houston..	Rail...	1.93	[b]2.55	[b]2.75	0.63	0.82	....	....
		Ship...	0.39	....	....	....	....	....	....
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.50	[a]2.05	[a]2.21	0.55	0.71	....	....
				Monroe source					
	2. Monroe...	Rail...	1.17	[a]1.52	[a]1.62	0.35	0.45	....	....
		Barge..	0.16	[c]0.75	[c]0.85	0.59	0.69	....	....
				Amarillo source					
Chicago.......	1. Amarillo	Rail...	1.37	[a]1.87	[a]2.01	0.50	0.64	....	....
				Monroe source					
	2. Monroe...	Rail...	1.18	[a]1.56	[a]1.67	0.38	0.49	....	....
		Barge..	0.16	[c]0.81	[c]0.92	0.65	0.76	....	....
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	1.23	[a]1.61	[a]1.72	0.38	0.49	....	....
				Monroe source					
	2. Monroe...	Rail...	0.93	[a]1.18	[a]1.24	0.25	0.31	....	....
		Barge..	0.11	[c]0.53	[c]0.59	0.42	0.48	....	....

[a] Ethylene oxide shipped by rail; fuel and feedstock gas by pipeline. [b] Ethylene oxide shipped by rail from Houston; fuel and feedstock gas by pipeline from Monroe. [c] Ethylene oxide shipped by barge; fuel and feedstock gas by pipeline.

ETHANOLAMINES FROM ETHANE (ETHYLENE OXIDE, OXIDATION PROCESS) AND NATURAL GAS (AMMONIA): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	*$2.06	$1.26	$1.65	....	....	$0.80	$0.41
				Monroe source					
	2. Monroe...	Rail...	1.69	0.93	1.21	....	....	0.76	0.48
				Monroe source					
	3. Houston..	Rail...	1.93	0.93	1.21	....	....	1.00	0.72
		Ship...	0.39			0.54	0.82	....	....
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.50	0.80	1.05	....	....	0.70	0.45
				Monroe source					
	2. Monroe...	Rail...	1.17	0.51	0.67	....	....	0.66	0.50
		Barge..	0.16			0.35	0.51	....	....
				Amarillo source					
Chicago.......	1. Amarillo	Rail...	1.37	0.72	0.95	....	....	0.65	0.42
				Monroe source					
	2. Monroe...	Rail...	1.18	0.56	0.73	....	....	0.62	0.45
		Barge..	0.16			0.40	0.57	....	....
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	1.23	0.55	0.72	....	....	0.68	0.51
				Monroe source					
	2. Monroe...	Rail...	0.93	0.35	0.46	....	....	0.58	0.47
		Barge..	0.11			0.24	0.35	....	....

*All rail rates for ethanolamines are uniform classification rates.

ETHANOLAMINES FROM ETHANE (ETHYLENE OXIDE—CHLORHYDRIN PROCESS) AND NATURAL GAS (AMMONIA): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	Natural gas site		Market site	
						34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	$2.06	$1.02	$1.33	....	....	$1.04	$0.73
				Monroe source					
	2. Monroe...	Rail...	1.69	0.74	0.97	....	....	0.95	0.72
				Monroe source					
	3. Houston..	Rail...	1.93	0.74	0.97	....	....	1.19	0.95
		Ship...	0.39			0.35	0.58	....	....
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.50	0.65	0.85	....	....	0.85	0.65
				Monroe source					
	2. Monroe...	Rail...	1.17	0.41	0.54	....	....	0.76	0.63
		Barge..	0.16			0.25	0.35	....	....
				Amarillo source					
Chicago.......	1. Amarillo	Rail...	1.37	0.58	0.76	....	....	0.79	0.61
				Monroe source					
	2. Monroe...	Rail...	1.18	0.45	0.59	....	....	0.73	0.59
		Barge..	0.16			0.29	0.43	....	....
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	1.23	0.45	0.58	....	....	0.78	0.65
				Monroe source					
	2. Monroe...	Rail...	0.93	0.28	0.37	....	....	0.65	0.56
		Barge..	0.11			0.17	0.26	....	....

ETHANOLAMINES FROM ETHYLENE OXIDE AND NATURAL GAS (AMMONIA): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	Natural gas site		Market site	
						34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	$2.06	[a]$2.29	[a]$2.46	$0.23	$0.40	....	....
				Monroe source					
	2. Monroe...	Rail...	1.69	[a]1.82	[a]1.95	0.13	0.26	....	....
				Monroe source					
	3. Houston..	Rail...	1.93	[b]2.02	[b]2.15	0.09	0.22	....	....
		Ship...	0.39	....	....	....	....	....	....
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.50	[a]1.62	[a]1.73	0.12	0.23	....	....
				Monroe source					
	2. Monroe...	Rail...	1.17	[a]1.20	[a]1.27	0.03	0.10	....	....
		Barge..	0.16	[c]0.57	[c]0.64	0.41	0.48	....	....
				Amarillo source					
Chicago.......	1. Amarillo	Rail...	1.37	[a]1.47	[a]1.57	0.10	0.20	....	....
				Monroe source					
	2. Monroe...	Rail...	1.18	[a]1.24	[a]1.32	0.06	0.14	....	....
		Barge..	0.16	[c]0.63	[c]0.71	0.47	0.55	....	....
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	1.23	[a]1.27	[a]1.35	0.04	0.12	....	....
				Monroe source					
	2. Monroe...	Rail...	0.93	[a]0.93	[a]0.98	0.00	0.05	....	....
		Barge..	0.11	[c]0.40	[c]0.45	0.29	0.34	....	....

[a] Ethylene oxide shipped by rail; fuel and feedstock gas by pipeline.

[b] Ethylene oxide shipped by rail from Houston; fuel and feedstock gas by pipeline from Monroe.

[c] Ethylene oxide shipped by barge; fuel and feedstock gas by pipeline.

ETHYLENE OXIDE FROM ETHANE (OXIDATION PROCESS): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......	1. Amarillo	Via— Rail...	*$2.06	Amarillo source $0.82	$1.08	....	....	$1.24	$0.98
	2. Monroe...	Rail...	1.69	Monroe source 0.60	0.79	....	....	1.09	0.90
	3. Houston..	Rail... Ship...	1.93	Monroe source 0.60	0.79	....	....	1.33	1.14 ....
Cincinnati....	1. Amarillo	Rail...	1.50	Amarillo source 0.53	0.69	....	....	0.97	0.81
	2. Monroe...	Rail... Barge..	1.17 0.41	Monroe source 0.33	0.43	....	.... 0.02	0.84 0.08	0.74 ....
Chicago.......	1. Amarillo	Rail...	1.37	Amarillo source 0.47	0.62	....	....	0.90	0.75
	2. Monroe...	Rail... Barge..	1.18 0.44	Monroe source 0.37	0.48	....	.... 0.04	0.81 0.07	0.70 ....
St. Louis.....	1. Amarillo	Rail...	1.23	Amarillo source 0.36	0.47	....	....	0.87	0.76
	2. Monroe...	Rail... Barge..	0.93 0.29	Monroe source 0.23	0.30	....	.... 0.01	0.70 0.06	0.63 ....

*All rail rates for ethylene oxide are uniform classification rates.

ETHYLENE OXIDE FROM ETHANE (CHLORHYDRIN PROCESS): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......	1. Amarillo	Via— Rail...	$2.06	Amarillo source $0.53	$0.69	....	....	$1.53	$1.37
	2. Monroe...	Rail...	1.69	Monroe source 0.39	0.51	....	....	1.30	1.18
	3. Houston..	Rail... Ship...	1.93	Monroe source 0.39	0.51	....	....	1.54	1.42 ....
Cincinnati....	1. Amarillo	Rail...	1.50	Amarillo source 0.34	0.44	....	....	1.16	1.06
	2. Monroe...	Rail... Barge..	1.17 0.41	Monroe source 0.21	0.28	....	....	0.96 0.20	0.89 0.13
Chicago.......	1. Amarillo	Rail...	1.37	Amarillo source 0.30	0.40	....	....	1.31	1.21
	2. Monroe...	Rail... Barge..	1.18 0.44	Monroe source 0.24	0.31	....	....	0.94 0.20	0.87 0.13
St. Louis.....	1. Amarillo	Rail...	1.23	Amarillo source 0.23	0.30	....	....	1.00	0.93
	2. Monroe...	Rail... Barge..	0.93 0.29	Monroe source 0.15	0.19	....	....	0.78 0.14	0.74 0.10

AMMONIA FROM NATURAL GAS: TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......	1. Amarillo	Via— Rail...	*$2.06	Amarillo source $0.45	$0.59	....	....	$1.61	$1.47
	2. Monroe...	Rail...	1.69	Monroe source 0.33	0.43	....	....	1.36	1.26
	3. Houston..	Rail...	1.33	Monroe source 0.33	0.43	....	....	1.60	1.50
		Ship...	0.61			....	....	0.28	0.18
Cincinnati....	1. Amarillo	Rail...	1.50	Amarillo source 0.29	0.37	....	....	1.21	1.13
	2. Monroe...	Rail...	1.17	Monroe source 0.18	0.24	....	....	0.99	0.93
		Barge..	0.41			....	....	0.23	0.17
Chicago.......	1. Amarillo	Rail...	1.37	Amarillo source 0.26	0.34	....	....	1.11	1.03
	2. Monroe...	Rail...	1.18	Monroe source 0.20	0.26	....	....	0.98	0.93
		Barge..	0.44			....	....	0.24	0.18
St. Louis.....	1. Amarillo	Rail...	1.23	Amarillo source 0.20	0.26	....	....	1.03	0.97
	2. Monroe...	Rail...	0.93	Monroe source 0.12	0.16	....	....	0.81	0.77
		Barge..	0.29			....	....	0.17	0.13

*All rail rates for ammonia are uniform classification rates.

ACETIC ANHYDRIDE FROM NATURAL GAS (ACETYLENE): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......	1. Amarillo	Via— Rail...	*$1.79	Amarillo source $1.23	$1.61	....	....	$0.56	$0.18
	2. Monroe...	Rail...	1.47	Monroe source 0.90	1.18	....	....	0.57	0.29
	3. Houston..	Rail...	1.68	Monroe source 0.90	1.18	....	....	0.78	0.50
		Ship...	0.45			0.45	0.73	....	....
Cincinnati....	1. Amarillo	Rail...	1.33	Amarillo source 0.78	1.03	....	....	0.55	0.30
	2. Monroe...	Rail...	1.04	Monroe source 0.50	0.65	....	....	0.54	0.39
		Barge..	0.18			0.32	0.47	....	....
Chicago.......	1. Amarillo	Rail...	1.22	Amarillo source 0.71	0.92	....	....	0.51	0.30
	2. Monroe...	Rail...	1.06	Monroe source 0.55	0.71	....	....	0.51	0.35
		Barge..	0.19			0.36	0.52	....	....
St. Louis.....	1. Amarillo	Rail...	1.19	Amarillo source 0.54	0.71	....	....	0.65	0.48
	2. Monroe...	Rail...	0.90	Monroe source 0.34	0.45	....	....	0.56	0.45
		Barge..	0.13			0.21	0.32	....	....

*All rail rates for acetic anhydride are based on quoted commodity rates.

ACETIC ANHYDRIDE FROM ETHANE (ACETYLENE): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York.....	1. Amarillo	Via— Rail...	$1.79	Amarillo source $0.72	$0.95	....	....	$1.07	$0.64
	2. Monroe...	Rail...	1.47	Monroe source 0.53	0.69	....	....	0.94	0.78
	3. Houston..	Rail... Ship...	1.68 0.45	Monroe source 0.53	0.69	.... 0.08	.... 0.24	1.15	0.99
Cincinnati....	1. Amarillo	Rail...	1.33	Amarillo source 0.46	0.60	....	....	0.87	0.73
	2. Monroe...	Rail... Barge..	1.04 0.18	Monroe source 0.29	0.39	.... 0.11	.... 0.20	0.75	0.66
Chicago.......	1. Amarillo	Rail...	1.22	Amarillo source 0.42	0.54	....	....	0.80	0.68
	2. Monroe...	Rail... Barge..	1.06 0.19	Monroe source 0.52	0.42	.... 0.13	.... 0.23	0.74	0.64
St. Louis.....	1. Amarillo	Rail...	1.19	Amarillo source 0.32	0.42	....	....	0.87	0.77
	2. Monroe...	Rail... Barge..	0.90 0.13	Monroe source 0.20	0.26	.... 0.07	.... 0.13	0.70	0.64

ACETIC ANHYDRIDE FROM ETHANE (VIA ETHANOL): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York.....	1. Amarillo	Via— Rail...	$1.79	Amarillo source $1.06	$1.38	....	....	$0.73	$0.41
	2. Monroe...	Rail...	1.47	Monroe source 0.78	1.02	....	....	0.69	0.45
	3. Houston..	Rail... Ship...	1.68 0.45	Monroe source 0.78	1.02	.... 0.33	.... 0.57	0.90	0.66
Cincinnati....	1. Amarillo	Rail...	1.33	Amarillo source 0.67	0.88	....	....	0.66	0.45
	2. Monroe...	Rail... Barge..	1.04 0.18	Monroe source 0.43	0.56	.... 0.25	.... 0.38	0.61	0.48
Chicago.......	1. Amarillo	Rail...	1.22	Amarillo source 0.61	0.79	....	....	0.61	0.43
	2. Monroe...	Rail... Barge..	1.06 0.19	Monroe source 0.47	0.62	.... 0.28	.... 0.43	0.59	0.44
St. Louis.....	1. Amarillo	Rail...	.19	Amarillo source 0.47	0.61	....	....	0.72	0.53
	2. Monroe...	Rail... Barge..	0.90 0.13	Monroe source 0.29	0.39	.... 0.14	.... 0.25	0.61	0.52

ACETIC ANHYDRIDE FROM ACETIC ACID: TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......	1. Amarillo	Via— Rail...	$1.79	Amarillo source [e]$2.39	[a]$2.42	$0.60	$0.63	....	....
	2. Monroe...	Rail...	1.47	Monroe source [a]1.96	[a]1.98	0.49	0.51	....	....
	3. Houston..	Rail...	1.68	Monroe source [b]2.23	[b]2.25	0.55	0.57	....	....
		Ship...	0.45	[c]0.66	[c]0.68	0.21	0.23	....	....
Cincinnati....	1. Amarillo	Rail...	1.33	Amarillo source [a]1.77	[a]1.79	0.44	0.46	....	....
	2. Monroe...	Rail...	1.04	Monroe source [a]1.37	[a]1.38	0.33	0.34	....	....
		Barge	0.18	[d]0.27	[d]0.28	0.09	0.10	....	....
Chicago.	1. Amarillo	Rail...	1.22	Amarillo source [a]1.62	[a]1.64	0.40	0.42	....	....
	2. Monroe...	Rail...	1.06	Monroe source [a]1.41	[a]1.42	0.35	0.36	....	....
		Barge..	0.19	[d]0.29	[d]0.30	0.10	0.11	....	....
St. Louis.....	1. Amarillo	Rail...	1.19	Amarillo source [a]1.57	[a]1.58	0.38	0.39	....	....
	2. Monroe...	Rail...	0.90	Monroe source [a]1.18	[a]1.19	0.28	0.29	....	....
		Barge..	0.13	[d]0.20	[d]0.21	0.07	0.08	....	....

[a] Acetic acid shipped by rail; fuel gas by pipeline.

[b] Acetic acid shipped by rail from Houston; fuel gas by pipeline from Monroe.

[c] Acetic acid shipped by tanker from Houston; fuel gas by pipeline from Monroe.

[d] Acetic acid shipped by barge; fuel gas by pipeline.

ACETIC ACID FROM NATURAL GAS ACETYLENE: TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......	1. Amarillo	Via— Rail...	*$1.79	Amarillo source $0.88	$1.15	....	....	$0.91	$0.64
	2. Monroe...	Rail...	1.47	Monroe source 0.65	0.84	....	....	0.82	0.63
	3. Houston..	Rail...	1.68	Monroe source 0.65	0.84			1.03	0.84
		Ship...	0.45			0.20	0.39	....	....
Cincinnati....	1. Amarillo	Rail...	1.33	Amarillo source 0.56	0.73	....	....	0.77	0.60
	2. Monroe...	Rail...	1.04	Monroe source 0.36	0.46	....	....	0.68	0.58
		Barge..	0.18			0.18	0.28	....	....
Chicago......	1. Amarillo	Rail...	1.22	Amarillo source 0.51	0.66	....	....	0.71	0.56
	2. Monroe...	Rail...	1.06	Monroe source 0.39	0.51	....	....	0.67	0.55
		Barge..	0.19			0.20	0.32	....	....
St. Louis.....	1. Amarillo	Rail...	1.19	Amarillo source 0.39	0.51	....	....	0.80	0.68
	2. Monroe...	Rail...	0.90	Monroe source 0.24	0.32	....	....	0.66	0.58
		Barge..	0.13			0.11	0.19	....	....

*All rail rates for acetic acid are based on quoted commodity rates.

ACETIC ACID FROM ETHANE ACETYLENE: TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......	1. Amarillo	Via— Rail...	$1.79	Amarillo source $0.48	$0.63	....	....	$1.31	$1.16
	2. Monroe...	Rail...	1.47	Monroe source 0.35	0.46	....	....	1.12	1.01
	3. Houston..	Rail... Ship...	1.68 0.45	Monroe source 0.35	0.46	....	.... 0.01	1.33 0.10	1.22 ....
Cincinnati....	1. Amarillo	Rail...	1.33	Amarillo source 0.31	0.40	....	....	1.02	0.93
	2. Monroe...	Rail... Barge..	1.04 0.18	Monroe source 0.20	0.26	.... 0.02	.... 0.08	0.84	0.78 ....
Chicago.......	1. Amarillo	Rail...	1.22	Amarillo source 0.28	0.36	....	....	0.94	0.86
	2. Monroe...	Rail... Barge..	1.06 0.19	Monroe source 0.22	0.28	.... 0.03	.... 0.09	0.84	0.78 ....
St. Louis.....	1. Amarillo	Rail...	1.19	Amarillo source 0.21	0.28	....	....	0.98	0.91
	2. Monroe...	Rail... Barge..	0.90 0.13	Monroe source 0.13	0.18	.... 0.00	.... 0.05	0.77	0.72 ....

ACETIC ACID FROM ETHANE (VIA ETHANOL): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......	1. Amarillo	Via— Rail...	$1.79	Amarillo source $0.75	$0.98	....	....	$1.04	$0.81
	2. Monroe...	Rail...	1.47	Monroe source 0.55	0.72	....	....	0.92	0.75
	3. Houston..	Rail... Ship...	1.68 0.45	Monroe source 0.55	0.72	.... 0.10	.... 0.27	1.13	0.96 ....
Cincinnati....	1. Amarillo	Rail...	1.33	Amarillo source 0.48	0.62	....	....	0.85	0.71
	2. Monroe...	Rail... Barge..	1.04 0.18	Monroe source 0.30	0.39	.... 0.12	.... 0.21	0.74	0.65 ....
Chicago.......	1. Amarillo	Rail...	1.22	Amarillo source 0.43	0.62	....	....	0.79	0.60
	2. Monroe...	Rail... Barge..	1.06 0.19	Monroe source 0.33	0.43	.... 0.14	.... 0.24	0.73	0.63 ....
St. Louis.....	1. Amarillo	Rail...	1.19	Amarillo source 0.33	0.43	....	....	0.86	0.76
	2. Monroe...	Rail... Barge..	0.90 0.13	Monroe source 0.21	0.27	.... 0.08	.... 0.14	0.69	0.63 ....

ACETIC ACID FROM ETHANOL (VIA ACETALDEHYDE): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	$1.79	$^{a}\$1.99$	$^{a}\$2.12$	$0.20	$0.33	....	....
				Monroe source					
	2. Monroe...	Rail...	1.47	$^{a}1.60$	$^{a}1.69$	0.13	0.22	....	....
				Monroe source					
	3. Houston..	Rail...	1.68	$^{b}1.79$	$^{b}1.88$	0.11	0.20	....	....
		Ship...	0.45	$^{c}0.65$	$^{c}0.74$	0.20	0.29	....	....
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.33	$^{a}1.23$	$^{a}1.32$	....	....	$0.10	$0.01
				Monroe source					
	2. Monroe...	Rail...	1.04	$^{a}0.93$	$^{a}0.99$	....	....	0.11	0.05
		Barge..	0.18	$^{d}0.31$	$^{d}0.37$	0.13	0.19	....	....
				Amarillo source					
Chicago.......	1. Amarillo	Rail...	1.22	$^{a}1.17$	$^{a}1.24$	....	0.02	0.05	....
				Monroe source					
	2. Monroe...	Rail...	1.06	$^{a}0.99$	$^{a}1.05$	....	....	0.07	0.01
		Barge..	0.19	$^{d}0.33$	$^{d}0.39$	0.14	0.20	....	....
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	1.19	$^{a}0.90$	$^{a}0.96$	....	....	0.29	0.23
				Monroe source					
	2. Monroe...	Rail...	0.90	$^{a}0.65$	$^{a}0.69$	....	....	0.25	0.21
		Barge..	0.13	$^{d}0.21$	$^{d}0.25$	0.08	0.12	....	....

[a] Ethanol shipped by rail; fuel gas by pipeline. [b] Ethanol shipped by rail from Houston; fuel gas by pipeline from Monroe. [c] Ethanol shipped by tanker from Houston; fuel gas by pipeline from Monroe. [d] Ethanol shipped by barge; fuel gas by pipeline.

ACETIC ACID FROM ACETALDEHYDE: TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	$1.79	$^{a}\$1.68$	$^{a}\$1.71$	....	....	$0.11	$0.08
				Monroe source					
	2. Monroe...	Rail...	1.47	$^{a}1.37$	$^{a}1.39$	....	....	0.10	0.08
				Monroe source					
	3. Houston..	Rail...	1.68	$^{b}1.56$	$^{b}1.58$	....	....	0.12	0.10
		Ship...	0.45	$^{c}0.54$	$^{c}0.56$	0.09	0.11	....	....
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.33	$^{a}1.22$	$^{a}1.23$	....	....	0.11	0.10
				Monroe source					
	2. Monroe...	Rail...	1.04	$^{a}0.94$	$^{a}0.95$	....	....	0.10	0.09
		Barge..	0.18	$^{d}0.36$	$^{d}0.37$	0.18	0.19	....	....
				Amarillo source					
Chicago.......	1. Amarillo	Rail...	1.22	$^{a}1.10$	$^{a}1.12$	....	....	0.12	0.10
				Monroe source					
	2. Monroe...	Rail...	1.06	$^{a}0.95$	$^{a}0.96$	....	....	0.09	0.08
		Barge..	0.19	$^{d}0.38$	$^{d}0.39$	0.19	0.20	....	....
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	1.19	$^{a}0.99$	$^{a}1.00$	....	....	0.20	0.19
				Monroe source					
	2. Monroe...	Rail...	0.90	$^{a}0.74$	$^{a}0.75$	....	....	0.16	0.15
		Barge..	0.13	$^{d}0.24$	$^{d}0.25$	0.11	0.12	....	....

[a] Acetaldehyde shipped by rail; fuel gas by pipeline. [b] Acetaldehyde shipped by rail from Houston; fuel gas by pipeline from Monroe. [c] Acetaldehyde shipped by tanker from Houston; fuel gas by pipeline from Monroe. [d] Acetaldehyde shipped by barge; fuel gas by pipeline.

ACETALDEHYDE FROM NATURAL GAS ACETYLENE: TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......	1. Amarillo	Via— Rail...	*$2.06	Amarillo source $1.15	$1.51	....	....	$0.91	$0.55
	2. Monroe...	Rail...	1.69	Monroe source 0.65	1.11	....	....	0.84	0.58
	3. Houston..	Rail... Ship...	1.93 0.61	Monroe source 0.85	1.11	.... 0.24	.... 0.50	1.08	0.82 ....
Cincinnati....	1. Amarillo	Rail...	1.50	Amarillo source 0.74	0.96	....	....	0.76	0.54
	2. Monroe...	Rail... Barge..	1.17 0.41	Monroe source 0.47	0.61	.... 0.06	.... 0.20	0.70	0.56 ....
Chicago.......	1. Amarillo	Rail...	1.37	Amarillo source 0.66	0.87	....	....	0.71	0.50
	2. Monroe...	Rail... Barge..	1.18 0.44	Monroe source 0.51	0.67	.... 0.07	.... 0.23	0.67	0.51 ....
St. Louis.....	1. Amarillo	Rail...	1.23	Amarillo source 0.51	0.66	....	....	0.72	0.57
	2. Monroe...	Rail... Barge..	0.93 0.29	Monroe source 0.32	0.42	.... 0.03	.... 0.13	0.61	0.51 ....

*All rail rates for acetaldehyde are uniform classification rates.

ACETALDEHYDE FROM ETHANE ACETYLENE: TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......	1. Amarillo	Via— Rail...	$2.06	Amarillo source $0.51	$0.67	....	....	$1.55	$1.39
	2. Monroe...	Rail...	1.69	Monroe source 0.38	0.49	....	....	1.31	1.20
	3. Houston..	Rail... Ship...	1.93 0.61	Monroe source 0.38	0.49	....	....	1.55 0.23	1.44 0.12
Cincinnati....	1. Amarillo	Rail...	1.50	Amarillo source 0.33	0.43	....	....	1.17	1.07
	2. Monroe...	Rail... Barge..	1.17 0.41	Monroe source 0.21	0.27	....	....	0.96 0.20	0.90 0.14
Chicago.......	1. Amarillo	Rail...	1.37	Amarillo source 0.29	0.38	....	....	1.03	0.99
	2. Monroe...	Rail... Barge..	1.18 0.44	Monroe source 0.23	0.30	....	....	0.95 0.21	0.88 0.14
St. Louis.....	1. Amarillo	Rail...	1.23	Amarillo source 0.23	0.29	....	....	1.00	0.94
	2. Monroe...	Rail... Barge..	0.93 0.29	Monroe source 0.14	0.19	....	....	0.79 0.15	0.74 0.10

ACETALDEHYDE FROM ETHANE (VIA ETHANOL): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	$2.06	$0.65	$1.11	....	....	$1.21	$0.95
				Monroe source					
	2. Monroe...	Rail...	1.69	0.62	0.82	....	....	1.07	0.87
				Monroe source					
	3. Houston..	Rail... Ship...	1.93 0.61	0.82	0.82	.... 0.01	.... 0.21	1.31	1.11 ....
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.50	0.54	0.71	....	....	0.96	0.79
				Monroe source					
	2. Monroe...	Rail... Barge..	1.17 0.41	0.34	0.45	....	.... 0.04	0.83 0.07	0.72 ....
				Amarillo source					
Chicago.......	1. Amarillo	Rail...	1.37	0.49	0.64	....	....	0.88	0.73
				Monroe source					
	2. Monroe...	Rail... Barge..	1.18 0.44	0.38	0.50	....	.... 0.06	0.80 0.06	0.68 ....
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	1.23	0.37	0.49	....	....	0.86	0.74
				Monroe source					
	2. Monroe...	Rail... Barge..	0.93 0.29	0.24	0.31	....	.... 0.02	0.69 0.05	0.62 ....

ACETALDEHYDE FROM ETHANOL: TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	$2.06	^{a}$2.46	^{a}$2.60	$0.40	$0.54	....	....
				Monroe source					
	2. Monroe...	Rail...	1.69	^{a}1.98	^{a}2.08	0.29	0.39	....	....
				Monroe source					
	3. Houston..	Rail... Ship...	1.93 0.61	^{b}2.44 ^{c}0.75	^{b}2.54 ^{c}0.75	0.51 0.14	0.61 0.24	....	....
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.50	^{a}1.52	^{a}1.61	0.02	0.11	....	....
				Monroe source					
	2. Monroe...	Rail... Barge..	1.17 0.41	^{a}1.16 ^{d}0.36	^{a}1.21 ^{d}0.41	....	0.04	$0.01 0.05	.... $0.00
				Amarillo source					
Chicago.......	1. Amarillo	Rail...	1.37	^{a}1.44	^{a}1.52	0.07	0.15	....	....
				Monroe source					
	2. Monroe...	Rail... Barge..	1.18 0.44	^{a}1.23 ^{d}0.38	^{a}1.29 ^{d}0.44	0.05	0.11	.... 0.06	.... 0.00
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	1.23	^{a}1.10	^{a}1.16	....	....	0.13	0.07
				Monroe source					
	2. Monroe...	Rail... Barge..	0.93 0.29	^{a}0.60 ^{c}0.24	^{a}0.84 ^{d}0.28	....	....	0.13 0.05	0.09 0.01

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[a] Ethanol shipped by rail; fuel gas by pipeline. [b] Ethanol shipped by rail from Houston; fuel gas by pipeline from Monroe. [c] Ethanol shipped by tanker from Houston; fuel gas by pipeline from Monroe. [d] Ethanol shipped by barge; fuel gas by pipeline.

ETHYL ALCOHOL (ETHANOL) FROM ETHANE: TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......	1. Amarillo	Via— Rail...	*$1.84	Amarillo source $0.37	$0.49	....	....	$1.47	$1.35
	2. Monroe...	Rail...	1.51	Monroe source 0.27	0.36	....	....	1.24	1.15
	3. Houston..	Rail...	1.73	Monroe source	....	....	....	1.46	1.37
		Ship...	0.39	0.27	0.36	....	....	0.12	0.03
Cincinnati....	1. Amarillo	Rail...	1.13	Amarillo source 0.24	0.31	....	....	0.89	0.82
	2. Monroe...	Rail...	0.89	Monroe source 0.15	0.20	....	....	0.74	0.69
		Barge..	0.16			....	0.04	0.01	....
Chicago.......	1. Amarillo	Rail...	1.08	Amarillo source 0.21	0.28	....	....	0.87	0.80
	2. Monroe...	Rail...	0.94	Monroe source 0.17	0.22	....	....	0.77	0.72
		Barge..	0.16			0.01	0.06	....	....
St. Louis.....	1. Amarillo	Rail...	0.83	Amarillo source 0.16	0.21	....	....	0.67	0.62
	2. Monroe...	Rail...	0.62	Monroe source 0.10	0.14	....	....	0.52	0.48
		Barge..	0.11			....	0.03	0.01	....

*All rail rates for ethyl alcohol are based on quoted commodity rates.

FORMALDEHYDE (37%) FROM METHANOL: TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......	1. Amarillo	Via— Rail...	*$2.06	Amarillo source [a] $0.82	[a] $0.82	....	....	$1.24	$1.24
	2. Monroe...	Rail...	1.69	Monroe source [a] 0.67	[a] 0.67	....	....	1.02	1.02
	3. Houston..	Rail...	1.93	Monroe source [b] 0.77	[b] 0.77	....	....	1.16	1.16
		Ship...	0.45	[c] 0.18	[c] 0.18	....	....	0.37	0.37
Cincinnati....	1. Amarillo	Rail...	1.50	Amarillo source [a] 0.51	[a] 0.51	....	....	0.89	0.89
	2. Monroe...	Rail...	1.17	Monroe source [a] 0.39	[a] 0.40	....	....	0.78	0.77
		Barge..	0.18	[d] 0.07	[d] 0.08	....	....	0.11	0.10
Chicago.......	1. Amarillo	Rail...	1.37	Amarillo source [a] 0.45	[a] 0.45	....	....	0.92	0.92
	2. Monroe...	Rail...	1.18	Monroe source [a] 0.38	[a] 0.38	....	....	0.80	0.80
		Barge..	0.19	[d] 0.08	[d] 0.08	....	....	0.11	0.11
St. Louis.....	1. Amarillo	Rail...	1.23	Amarillo source [a] 0.38	[a] 0.38	....	....	0.85	0.85
	2. Monroe...	Rail...	0.93	Monroe source [a] 0.27	[a] 0.27	....	....	0.66	0.66
		Barge..	0.13	[d] 0.05	[d] 0.05	....	....	0.08	0.08

*All rail rates for formaldehyde are uniform classification rates. [a] Methanol shipped by rail; fuel gas by pipeline.
[b] Methanol shipped by rail from Houston; fuel gas by pipeline from Monroe. [c] Methanol shipped by tanker from Houston; fuel gas by pipeline from Monroe. [d] Methanol shipped by barge, fuel gas by pipeline.

FORMALDEHYDE (37%) FROM NATURAL GAS (VIA METHANOL): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	$2.06	$0.22	$0.29	....	....	$1.84	$1.77
				Monroe source					
	2. Monroe...	Rail...	1.69	0.16	0.21	....	....	1.53	1.48
				Monroe source					
	3. Houston..	Rail...	1.93	0.16	0.21	....	....	1.77	1.72
		Ship...	0.45			....	....	0.29	0.24
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.50	0.14	0.19	....	....	1.36	1.31
				Monroe source					
	2. Monroe...	Rail...	1.17	0.09	0.12	....	....	1.08	1.05
		Barge..	0.18			....	....	0.09	0.06
				Amarillo source					
Chicago.......	1. Amarillo	Rail...	1.37	0.13	0.17	....	....	1.24	1.20
				Monroe source					
	2. Monroe...	Rail...	1.18	0.10	0.13	....	....	1.08	1.05
		Barge..	0.19			....	....	0.09	0.06
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	1.23	0.10	0.13	....	....	1.13	1.10
				Monroe source					
	2. Monroe...	Rail...	0.93	0.06	0.08	....	....	0.87	0.85
		Barge..	0.13			....	....	0.07	0.05

METHANOL FROM NATURAL GAS: TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	*$1.84	$0.46	$0.63	....	....	$1.36	$1.21
				Monroe source					
	2. Monroe...	Rail...	1.51	0.35	0.46	....	....	1.16	1.05
				Monroe source					
	3. Houston..	Rail...	1.73	0.35	0.46	....	....	1.38	1.27
		Ship...	0.39			....	0.07	0.04	....
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.13	0.31	0.40	....	....	0.82	0.73
				Monroe source					
	2. Monroe...	Rail...	0.89	0.19	0.25	....	....	0.70	0.64
		Barge..	0.16			0.03	0.09	....	....
				Amarillo source					
Chicago.......	1. Amarillo	Rail...	1.01	0.28	0.36	....	....	0.73	0.65
				Monroe source					
	2. Monroe...	Rail...	0.84	0.21	0.28	....	....	0.63	0.56
		Barge..	0.16			0.05	0.12	....	....
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	0.83	0.21	0.28	....	....	0.62	0.55
				Monroe source					
	2. Monroe...	Rail...	0.62	0.13	0.17	....	....	0.49	0.45
		Barge..	0.11			0.02	0.06	....	....

*All rail rates for methanol are based on quoted commodity rates.

PHTHALIC ANHYDRIDE FROM O-XYLENE: TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	*$2.20	[a]$1.87	[a]$1.83	....	....	$0.33	$0.37
				Monroe source					
	2. Monroe...	Rail...	1.82	[a]1.54	[a]1.51	....	....	0.28	0.31
				Monroe source					
	3. Houston..	Rail...	2.07	[b]1.78	[b]1.75	....	....	0.29	0.32
		Ship...	**0.39	[c]0.44	[c]0.41	0.05	0.02	....	....
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.60	[a]1.42	[a]1.39	....	....	0.18	0.21
				Monroe source					
	2. Monroe...	Rail...	1.25	[a]1.12	[a]1.10	....	....	0.13	0.15
		Barge..	**0.16	[d]0.17	[d]0.15	0.01	....	....	0.01
				Amarillo source					
Chicago.......	1. Amarillo	Rail...	1.47	[a]1.30	[a]1.27	....	....	0.17	0.20
				Monroe source					
	2. Monroe...	Rail...	1.28	[a]1.12	[a]1.10	....	....	0.16	0.18
		Barge..	0.16	[d]0.16	[d]0.14	....	....	0.00	0.02
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	1.31	[a]0.93	[a]0.91	....	....	0.38	0.40
				Monroe source					
	2. Monroe...	Rail...	1.00	[a]0.71	[a]0.70	....	....	0.29	0.30
		Barge..	0.11	[d]0.12	[d]0.11	0.01	0.00	....	....

*All rail rates for phthalic anhydride are uniform classification rates. **All ship and barge rates for phthalic anhydride are assumed to be the same as for ordinary non-corrosive liquid chemicals. [a]O-xylene shipped by rail; fuel gas by pipeline. [b]O-xylene shipped by rail from Houston; fuel gas by pipeline from Monroe. [c]O-xylene shipped by tanker from Houston; fuel gas by pipeline from Monroe. [d]O-xylene shipped by barge; fuel gas by pipeline.

POLYVINYL ACETATE FROM ETHANE (VIA ACETYLENE AND ACETYLENE—ACETIC ACID): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	*$2.20	$0.62	$0.81	....	....	$1.58	$1.39
				Monroe source					
	2. Monroe...	Rail...	1.82	0.45	0.59	....	....	1.37	1.23
				Monroe source					
	3. Houston..	Rail...	2.07	0.45	0.59	....	....	1.62	1.48
		Ship...	**0.39			0.06	0.20	....	....
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.60	0.39	0.51	....	....	1.21	1.09
				Monroe source					
	2. Monroe...	Rail...	1.25	0.25	0.33	....	....	1.00	0.92
		Barge..	**0.16			0.09	0.17	....	....
				Amarillo source					
Chicago.......	1. Amarillo	Rail...	1.47	0.35	0.46	....	....	1.12	1.01
				Monroe source					
	2. Monroe...	Rail...	1.28	0.27	0.36	....	....	1.01	0.92
		Barge..	0.16			0.11	0.20	....	....
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	1.31	0.27	0.35	....	....	1.04	0.96
				Monroe source					
	2. Monroe...	Rail...	1.00	0.17	0.22	....	....	0.83	0.78
		Barge..	0.11			0.06	0.11	....	....

*All rail rates for polyvinyl acetate are uniform classification rates. **All ship and barge rates for polyvinyl acetate are as-

POLYVINYL ACETATE FROM NATURAL GAS (VIA ACETYLENE AND ACETYLENE—ACETIC ACID): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......	1. Amarillo	Via— Rail...	$2.20	Amarillo source $1.23	$1.61	....	....	$0.97	$0.53
	2. Monroe...	Rail...	1.82	Monroe source 0.90	1.18	....	....	0.92	0.64
	3. Houston..	Rail... Ship...	2.07 0.39	Monroe source 0.90	1.18	.... 0.51	.... 0.79	1.17	0.89 ....
Cincinnati....	1. Amarillo	Rail...	1.60	Amarillo source 0.79	1.03	....	....	0.81	0.57
	2. Monroe...	Rail... Barge..	1.25 0.16	Monroe source 0.50	0.65	.... 0.34	.... 0.49	0.75	0.60 ....
Chicago......	1. Amarillo	Rail...	1.47	Amarillo source 0.71	0.92	....	....	0.76	0.55
	2. Monroe...	Rail... Barge..	1.28 0.16	Monroe source 0.55	0.72	.... 0.39	.... 0.56	0.73	0.56 ....
St. Louis.....	1. Amarillo	Rail...	1.31	Amarillo source 0.54	0.71	....	....	0.77	0.60
	2. Monroe...	Rail... Barge..	1.00 0.11	Monroe source 0.34	0.45	.... 0.23	.... 0.34	0.66	0.55 ....

POLYVINYL ACETATE FROM ETHANE (ETHYLENE—ACETIC ACID) AND NATURAL GAS (ACETYLENE): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......	1. Amarillo	Via— Rail...	$2.20	Amarillo source $1.13	$1.48	....	....	$1.07	$0.72
	2. Monroe...	Rail...	1.62	Monroe source 0.83	1.09	....	....	0.99	0.73
	3. Houston..	Rail... Ship...	2.07 0.39	Monroe source 0.83	1.09	.... 0.44	.... 0.70	1.24	0.98 ....
Cincinnati....	1. Amarillo	Rail...	1.60	Amarillo source 0.72	0.94	....	....	0.88	0.66
	2. Monroe...	Rail... Barge..	1.25 0.16	Monroe source 0.46	0.60	.... 0.30	.... 0.44	0.79	0.65 ....
Chicago......	1. Amarillo	Rail...	1.47	Amarillo source 0.65	0.85	....	....	0.82	0.62
	2. Monroe...	Rail... Barge..	1.28 0.16	Monroe source 0.50	0.65	.... 0.34	.... 0.50	0.78	0.62 ....
St. Louis.....	1. Amarillo	Rail...	1.31	Amarillo source 0.50	0.65	....	....	0.81	0.66
	2. Monroe...	Rail... Barge..	1.00 0.11	Monroe source 0.31	0.41	.... 0.20	.... 0.30	0.63	0.59 ....

POLYVINYL ACETATE FROM ETHANE (VIA ETHYLENE —ACETIC ACID, AND ACETYLENE): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	Natural gas site		Market site	
						34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......	1. Amarillo	Via— Rail...	$2.20	Amarillo source $0.80	$1.05	....	....	$1.40	$1.15
	2. Monroe...	Rail...	1.82	Monroe source 0.59	0.77	....	....	1.23	1.05
	3. Houston..	Rail... Ship...	2.07 0.39	Monroe source 0.59	0.77	.... 0.20	.... 0.38	1.48	1.30 ....
Cincinnati....	1. Amarillo	Rail...	1.60	Amarillo source 0.51	0.67	....	....	1.09	0.93
	2. Monroe...	Rail... Barge..	1.25 0.16	Monroe source 0.32	0.42	.... 0.16	.... 0.26	0.93	0.83 ....
Chicago.......	1. Amarillo	Rail...	1.47	Amarillo source 0.46	0.60	....	....	1.01	0.87
	2. Monroe...	Rail... Barge..	1.28 0.16	Monroe source 0.36	0.47	.... 0.20	.... 0.31	0.92	0.81 ....
St. Louis.....	1. Amarillo	Rail...	1.31	Amarillo source 0.35	0.46	....	....	0.96	0.85
	2. Monroe...	Rail... Barge..	1.00 0.11	Monroe source 0.22	0.29	.... 0.11	.... 0.18	0.78	0.71 ....

POLYVINYL ACETATE FROM VINYL ACETATE: TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	Natural gas site		Market site	
						34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......	1. Amarillo	Via— Rail...	$2.20	Amarillo source [a]$1.90	[a]$1.91	....	....	$0.30	$0.29
	2. Monroe...	Rail...	1.82	Monroe source [a]1.56	[a]1.56	....	....	0.26	0.25
	3. Houston..	Rail... Ship...	2.07 0.39	Monroe source [b]1.78 [c]0.42	[b]1.78 [c]0.42	.... 0.03	.... 0.03	0.29	0.29 ....
Cincinnati....	1. Amarillo	Rail...	1.60	Amarillo source [a]1.16	[a]1.17	....	....	0.44	0.43
	2. Monroe...	Rail... Barge..	1.25 0.16	Monroe source [a]0.92 [d]0.17	[a]0.92 [d]0.17	.... 0.01	.... 0.01	0.33	0.33 ....
Chicago.......	1. Amarillo	Rail...	1.47	Amarillo source [a]1.11	[a]1.12	....	....	0.36	0.35
	2. Monroe...	Rail... Barge..	1.28 0.16	Monroe source [a]0.97 [d]0.17	[a]0.97 [d]0.17	.... 0.01	.... 0.01	0.31	0.31 ....
St. Louis.....	1. Amarillo	Rail...	1.31	Amarillo source [a]0.86	[a]0.86	....	....	0.45	0.45
	2. Monroe...	Rail... Barge..	1.00 0.11	Monroe source [a]0.64 [d]0.12	[a]0.64 [d]0.12	.... 0.01	.... 0.01	0.36	0.36 ....

[a] Vinyl acetate shipped by rail; fuel gas by pipeline. [b] Vinyl acetate shipped by rail from Houston; fuel gas by pipeline from Monroe. [c] Vinyl acetate shipped by tanker from Houston; fuel gas by pipeline from Monroe. [d] Vinyl acetate shipped by barge; fuel gas by pipeline.

POLYVINYL CHLORIDE FROM ETHANE (VIA ETHYLENE DICHLORIDE): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	*$2.20	$0.41	$0.54	....	....	$1.79	$1.66
				Monroe source					
	2. Monroe...	Rail...	1.82	0.30	0.40	....	....	1.52	1.42
				Monroe source					
	3. Houston..	Rail...	2.07	0.30	0.40	....	....	1.77	1.67
		Ship...	**0.39			....	....	0.09	0.01
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.60	0.26	0.34	....	....	1.34	1.26
				Monroe source					
	2. Monroe...	Rail...	1.25	0.17	0.22	....	....	1.08	1.03
		Barge..	**0.16			0.01	0.05	....	....
				Amarillo source					
Chicago.......	1. Amarillo	Rail...	1.47	0.24	0.31	....	....	1.23	1.16
				Monroe source					
	2. Monroe...	Rail...	1.28	0.18	0.24	....	....	1.10	1.04
		Barge..	0.16			0.02	0.08	....	....
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	1.31	0.18	0.24	....	....	1.13	1.07
				Monroe source					
	2. Monroe...	Rail...	1.00	0.11	0.15	....	....	0.89	0.85
		Barge..	0.11			0.00	0.04	....	....

*All rail rates for polyvinyl chloride are uniform classification rates.

**All ship and barge rates for polyvinyl chloride are assumed to be the same as for ordinary non-corrosive liquid chemicals.

POLYVINYL CHLORIDE FROM NATURAL GAS ACETYLENE: TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	$2.20	$1.11	$1.46	....	....	$1.09	$0.74
				Monroe source					
	2. Monroe...	Rail...	1.82	0.82	1.07	....	....	1.00	0.75
				Monroe source					
	3. Houston..	Rail...	2.07	0.82	1.07	....	....	1.25	1.00
		Ship...	0.39			0.43	0.68	....	....
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.60	0.71	0.93	....	....	0.89	0.67
				Monroe source					
	2. Monroe...	Rail...	1.25	0.45	0.59	....	....	0.80	0.66
		Barge..	0.16			0.29	0.43	....	....
				Amarillo source					
Chicago.......	1. Amarillo	Rail...	1.47	0.64	0.84	....	....	0.83	0.63
				Monroe source					
	2. Monroe...	Rail...	1.28	0.49	0.65	....	....	0.79	0.63
		Barge..	0.16			0.33	0.49	....	....
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	1.31	0.49	0.64	....	....	0.82	0.67
				Monroe source					
	2. Monroe...	Rail...	1.00	0.31	0.40	....	....	0.69	0.60
		Barge..	0.11			0.20	0.29	....	....

POLYVINYL CHLORIDE FROM ETHANE ACETYLENE: TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	Natural gas site		Market site	
						34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York.....	1. Amarillo	Via— Rail...	$2.20	Amarillo source $0.64	$0.83	....	....	$1.56	$1.37
	2. Monroe...	Rail...	1.82	Monroe source 0.47	0.61	....	....	1.35	1.21
	3. Houston..	Rail... Ship...	2.07 0.39	Monroe source 0.47	0.61	.... 0.08	.... 0.22	1.60	1.46 ....
Cincinnati....	1. Amarillo	Rail...	1.60	Amarillo source 0.41	0.53	....	....	1.19	1.07
	2. Monroe...	Rail... Barge..	1.25 0.16	Monroe source 0.26	0.34	.... 0.10	.... 0.18	0.99	0.91 ....
Chicago.......	1. Amarillo	Rail...	1.47	Amarillo source 0.37	0.48	....	....	1.10	0.99
	2. Monroe...	Rail... Barge..	1.28 0.16	Monroe source 0.28	0.37	.... 0.12	.... 0.21	1.00	0.91 ....
St. Louis.....	1. Amarillo	Rail...	1.31	Amarillo source 0.28	0.37	....	....	1.03	0.94
	2. Monroe...	Rail... Barge..	1.09 0.11	Monroe source 0.18	0.23	.... 0.07	.... 0.12	0.82	0.77 ....

VINYL ACETATE FROM NATURAL GAS (VIA ACETYLENE AND ACETYLENE—ACETIC ACID): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	Natural gas site		Market site	
						34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York.....	1. Amarillo	Via— Rail...	*$1.84	Amarillo source $1.19	$1.55	....	....	$0.65	$0.29
	2. Monroe...	Rail...	1.51	Monroe source 0.87	1.14	....	....	0.64	0.37
	3. Houston..	Rail... Ship...	1.73 0.39	Monroe source 0.87	1.14	.... 0.48	.... 0.75	0.86	0.59 ....
Cincinnati....	1. Amarillo	Rail...	1.13	Amarillo source 0.76	0.99	....	....	0.37	0.14
	2. Monroe...	Rail... Barge..	0.89 0.16	Monroe source 0.48	0.63	.... 0.32	.... 0.47	0.41	0.26 ....
Chicago.......	1. Amarillo	Rail...	1.08	Amarillo source 0.68	0.89	....	....	0.40	0.19
	2. Monroe...	Rail... Barge..	0.94 0.16	Monroe source 0.53	0.69	.... 0.37	.... 0.53	0.41	0.25 ....
St. Louis.....	1. Amarillo	Rail...	0.83	Amarillo source 0.52	0.68	....	....	0.31	0.15
	2. Monroe...	Rail... Barge..	0.62 0.11	Monroe source 0.33	0.43	.... 0.22	.... 0.32	0.20	0.19 ....

*All rail rates for vinyl acetate are based on quoted commodity rates.

VINYL ACETATE FROM ETHANE (VIA ACETYLENE AND ACETYLENE—ACETIC ACID): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......		Via—		Amarillo source					
	1. Amarillo	Rail...	$1.84	$0.58	$0.76	....	....	$1.26	$1.08
				Monroe source					
	2. Monroe...	Rail...	1.51	0.43	0.56	....	....	1.08	0.95
				Monroe source					
	3. Houston..	Rail... Ship...	1.73 0.39	0.43	0.56	.... 0.04	.... 0.17	1.30	1.17
Cincinnati....				Amarillo source					
	1. Amarillo	Rail...	1.13	0.37	0.49	....	....	0.86	0.64
				Monroe source					
	2. Monroe...	Rail... Barge..	0.89 0.16	0.24	0.31	.... 0.08	.... 0.15	0.65	0.58
Chicago.......				Amarillo source					
	1. Amarillo	Rail...	1.08	0.33	0.44	....	....	0.75	0.64
				Monroe source					
	2. Monroe...	Rail... Barge..	0.94 0.16	0.26	0.34	.... 0.10	.... 0.18	0.68	0.60
St. Louis.....				Amarillo source					
	1. Amarillo	Rail...	0.83	0.26	0.34	....	....	0.57	0.49
				Monroe source					
	2. Monroe...	Rail... Barge..	0.62 0.11	0.16	0.21	.... 0.05	.... 0.10	0.46	0.41

VINYL ACETATE FROM ETHANE (ETHYLENE—ACETIC ACID) AND NATURAL GAS (ACETYLENE): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......		Via—		Amarillo source					
	1. Amarillo	Rail...	$1.84	$1.09	$1.43	....	....	$0.75	$0.41
				Monroe source					
	2. Monroe...	Rail...	1.51	0.80	1.05	....	....	0.71	0.46
				Monroe source					
	3. Houston..	Rail... Ship...	1.73 0.39	0.80	1.05	.... 0.41	.... 0.66	0.93	0.68
Cincinnati....				Amarillo source					
	1. Amarillo	Rail...	1.13	0.70	0.91	....	....	0.43	0.22
				Monroe source					
	2. Monroe...	Rail... Barge..	0.89 0.16	0.44	0.58	.... 0.28	.... 0.42	0.45	0.31
Chicago.......				Amarillo source					
	1. Amarillo	Rail...	1.08	0.63	0.82	....	....	0.45	0.26
				Monroe source					
	2. Monroe...	Rail... Barge..	0.94 0.16	0.48	0.63	.... 0.32	.... 0.47	0.46	0.31
St. Louis.....				Amarillo source					
	1. Amarillo	Rail...	0.83	0.48	0.63	....	....	0.35	0.20
				Monroe source					
	2. Monroe...	Rail... Barge..	0.62 0.11	0.30	0.40	.... 0.19	.... 0.29	0.32	0.22

VINYL ACETATE FROM ETHANE (VIA ETHYLENE—ACETIC ACID; AND ACETYLENE): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	$1.84	$0.77	$1.01	....	....	$1.07	$0.83
				Monroe source					
	2. Monroe...	Rail...	1.51	0.56	0.74	....	....	0.95	0.77
				Monroe source					
	3. Houston..	Rail... Ship...	1.73 0.39	0.56	0.74	.... 0.17	.... 0.35	1.17	0.99 ....
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.13	0.49	0.64	....	....	0.64	0.49
				Monroe source					
	2. Monroe...	Rail... Barge..	0.89 0.16	0.31	0.41	.... 0.15	.... 0.25	0.58	0.48 ....
				Amarillo source					
Chicago.......	1. Amarillo	Rail...	1.08	0.44	0.58	....	....	0.64	0.50
				Monroe source					
	2. Monroe...	Rail... Barge..	0.94 0.16	0.34	0.45	.... 0.18	.... 0.29	0.60	0.49 ....
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	0.83	0.34	0.44	....	....	0.49	0.39
				Monroe source					
	2. Monroe...	Rail... Barge..	0.62 0.11	0.21	0.28	.... 0.10	.... 0.17	0.41	0.34 ....

VINYL ACETATE FROM ACETIC ACID AND NATURAL GAS (ACETYLENE): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	$1.84	[a]$1.83	[a]$2.00	....	$0.16	$0.01	....
				Monroe source					
	2. Monroe...	Rail...	1.51	[a]1.45	[a]1.58	....	0.07	0.06	....
				Monroe source					
	3. Houston..	Rail... Ship...	1.73 0.39	[b]1.60 [c]0.73	[b]1.73 [c]0.86	.... $0.34	0.00 0.47	0.13	$0.00 ....
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.13	[a]1.30	[a]1.41	0.17	0.28	....	....
				Monroe source					
	2. Monroe...	Rail... Barge..	0.69 0.16	[a]0.97 [d]0.36	[a]1.04 [d]0.43	0.08 0.20	0.15 0.27	....	....
				Amarillo source					
Chicago.......	1. Amarillo	Rail...	1.08	[a]1.19	[a]1.29	0.11	0.21	....	....
				Monroe source					
	2. Monroe...	Rail... Barge..	0.94 0.16	[a]1.00 [d]0.38	[a]1.07 [d]0.45	0.06 0.22	0.13 0.29	....	....
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	0.83	[a]1.03	[a]1.16	0.26	0.33	....	....
				Monroe source					
	2. Monroe...	Rail... Barge..	0.62 0.11	[a]0.80 [d]0.25	[a]0.84 [d]0.29	0.18 0.14	0.22 0.18	....	....

[a] Acetic acid shipped by rail; fuel and feedstock gas by pipeline. [b] Acetic acid shipped by rail from Houston; fuel and feedstock gas by pipeline from Monroe. [c] Acetic acid shipped by tanker from Houston; fuel and feedstock gas by pipeline from Monroe. [d] Acetic acid shipped by barge; fuel and feedstock gas by pipeline.

VINYL ACETATE FROM ACETIC ACID AND ETHANE (ACETYLENE): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	$1.84	[a]$1.51	[a]$1.53	....	....	$0.33	$0.26
				Monroe source					
	2. Monroe...	Rail...	1.51	[a]1.22	[a]1.27	....	....	0.29	0.24
				Monroe source					
	3. Houston..	Rail...	1.73	[b]1.37	[b]1.42	....	....	0.36	0.31
		Ship...	0.39	[c]0.50	[c]0.55	0.11	0.16	....	....
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.13	[a]1.09	[a]1.14	....	0.01	0.04	....
				Monroe source					
	2. Monroe...	Rail...	0.89	[a]0.84	[a]0.87	....	....	0.05	0.02
		Barge..	0.16	[d]0.23	[d]0.26	0.07	0.10	....	....
				Amarillo source					
Chicago.......	1. Amarillo	Rail...	1.08	[a]1.01	[a]1.05	....	....	0.07	0.03
				Monroe source					
	2. Monroe...	Rail...	0.94	[a]0.86	[a]0.89	....	....	0.08	0.05
		Barge..	0.16	[d]0.24	[d]0.27	0.08	0.11	....	....
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	0.83	[a]0.95	[a]0.98	0.12	0.15	....	....
				Monroe source					
	2. Monroe...	Rail...	0.62	[a]0.71	[a]0.73	0.09	0.11	....	....
		Barge..	0.11	[d]0.16	[d]0.18	0.05	0.07	....	....

[a] Acetic acid shipped by rail; fuel and feedstock gas by pipeline. [b] Acetic acid shipped by rail from Houston; fuel and feedstock gas by pipeline from Monroe. [c] Acetic acid shipped by tanker from Houston; fuel and feedstock gas by pipeline from Monroe. [d] Acetic acid shipped by barge; fuel and feedstock gas by pipeline.

VINYL CHLORIDE FROM ETHANE—ACETYLENE: TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	[*]$2.56	$0.41	$0.54	....	....	$2.15	$2.02
				Monroe source					
	2. Monroe...	Rail...	2.10	0.30	0.39	....	....	1.80	1.71
				Monroe source					
	3. Houston..	Rail...	2.40	0.30	0.39	....	....	2.10	2.01
		Ship...	0.61			....	....	0.22	0.31
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.81	0.25	0.34	....	....	1.55	1.47
				Monroe source					
	2. Monroe...	Rail...	1.42	0.17	0.22	....	....	1.25	1.20
		Barge..	0.41			....	....	0.24	0.19
				Amarillo source					
Chicago.......	1. Amarillo	Rail...	1.66	0.24	0.31	....	....	1.42	1.35
				Monroe source					
	2. Monroe...	Rail...	1.44	0.18	0.24	....	....	1.26	1.20
		Barge..	0.44			....	....	0.26	0.20
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	1.50	0.18	0.24	....	....	1.32	1.26
				Monroe source					
	2. Monroe...	Rail...	1.13	0.11	0.15	....	....	1.02	0.98
		Barge..	0.29			....	....	0.18	0.14

[*] All rail rates for vinyl chloride are based on quoted commodity rates.

VINYL CHLORIDE FROM ACETYLENE (NATURAL GAS): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......		Via—		Amarillo source					
	1. Amarillo	Rail...	$2.56	$0.65	$1.11	....	....	$1.71	$1.45
				Monroe source					
	2. Monroe...	Rail...	2.10	0.62	0.81	....	....	1.48	1.29
				Monroe source					
	3. Houston..	Rail... Ship...	2.40 0.61	0.62	0.81	.... 0.01	.... 0.20	1.78	1.59 ....
Cincinnati....				Amarillo source					
	1. Amarillo	Rail...	1.81	0.54	0.70	....	....	1.27	1.11
				Monroe source					
	2. Monroe...	Rail... Barge..	1.42 0.41	0.34	0.45	....	.... 0.04	1.08 0.07	0.97 ....
Chicago.......				Amarillo source					
	1. Amarillo	Rail...	1.66	0.49	0.63	....	....	1.17	1.03
				Monroe source					
	2. Monroe...	Rail... Barge..	1.44 0.44	0.38	0.49	....	.... 0.05	1.06 0.06	0.95 ....
St. Louis.....				Amarillo source					
	1. Amarillo	Rail...	1.50	0.37	0.49	....	....	1.13	1.01
				Monroe source					
	2. Monroe...	Rail... Barge..	1.13 0.29	0.23	0.31	....	.... 0.02	0.90 0.06	0.82 ....

VINYL CHLORIDE FROM ETHANE (VIA ETHYLENE DICHLORIDE): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......		Via—		Amarillo source					
	1. Amarillo	Rail...	$2.56	$0.21	$0.27	....	....	$2.35	$2.29
				Monroe source					
	2. Monroe...	Rail...	2.10	0.15	0.20	....	....	1.95	1.90
				Monroe source					
	3. Houston..	Rail... Ship...	2.40 0.61	0.15	0.20	....	....	2.25 0.46	2.20 0.41
Cincinnati....				Amarillo source					
	1. Amarillo	Rail...	1.81	0.13	0.17	....	....	1.68	1.64
				Monroe source					
	2. Monroe...	Rail... Barge..	1.42 0.41	0.08	0.11	....	....	1.34 0.33	1.31 0.30
Chicago.......				Amarillo source					
	1. Amarillo	Rail...	1.66	0.12	0.16	....	....	1.54	1.50
				Monroe source					
	2. Monroe...	Rail... Barge..	1.44 0.44	0.09	0.12	....	....	1.35 0.35	1.32 0.32
St. Louis.....				Amarillo source					
	1. Amarillo	Rail...	1.50	0.09	0.12	....	....	1.41	1.38
				Monroe source					
	2. Monroe...	Rail... Barge..	1.13 0.29	0.06	0.08	....	....	1.07 0.23	1.05 0.21

UREA FROM NATURAL GAS (VIA AMMONIA): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a— Natural gas site		Transport advantage of a— Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	*$1.91	$0.39	$0.51	....	....	$1.52	$1.40
				Monroe source					
	2. Monroe...	Rail...	1.58	0.28	0.37	....	....	1.30	1.21
				Monroe source					
	3. Houston..	Rail...	1.73	0.28	0.37	....	....	1.51	1.42
		Ship...	**0.39			....	....	0.11	0.02
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.38	0.25	0.32	....	....	1.13	1.06
				Monroe source					
	2. Monroe...	Rail...	1.06	0.16	0.20	....	....	0.92	0.88
		Barge..	**0.16			0.00	0.04	....	....
				Amarillo source					
Chicago.......	1. Amarillo	Rail...	1.28	0.22	0.29	....	....	1.06	0.99
				Monroe source					
	2. Monroe...	Rail...	1.10	0.17	0.23	....	....	0.93	0.87
		Barge..	0.16			0.01	0.07	....	....
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	1.14	0.17	0.22	....	....	0.97	0.88
				Monroe source					
	2. Monroe...	Rail...	0.86	0.11	0.14	....	....	0.75	0.72
		Barge..	0.11			0.00	0.03	....	....

*All rail rates for urea are uniform classification rates. **All ship and barge rates for urea are assumed to be the same as for ordinary non-corrosive liquid chemicals.

POLYETHYLENE FROM ETHANE: TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a— Natural gas site		Transport advantage of a— Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		Via—		Amarillo source					
New York......	1. Amarillo	Rail...	*$2.20	$0.54	$0.70	....	....	$1.66	$1.50
				Monroe source					
	2. Monroe...	Rail...	1.82	0.30	0.51	....	....	1.43	1.31
				Monroe source					
	3. Houston..	Rail...	2.07	0.39	0.51	....	....	1.68	1.56
		Ship...	**0.39			0.00	0.12	....	....
				Amarillo source					
Cincinnati....	1. Amarillo	Rail...	1.60	0.34	0.45	....	....	1.26	1.15
				Monroe source					
	2. Monroe...	Rail...	1.25	0.22	0.28	....	....	1.03	0.97
		Barge..	**0.16			0.06	0.12	....	....
				Amarillo source					
Chicago.......	1. Amarillo	Rail...	1.47	0.31	0.40	....	....	1.16	1.07
				Monroe source					
	2. Monroe...	Rail...	1.28	0.24	0.31	....	....	1.04	0.97
		Barge..	0.16			0.08	0.15	....	....
				Amarillo source					
St. Louis.....	1. Amarillo	Rail...	1.31	0.24	0.31	....	....	1.07	1.00
				Monroe source					
	2. Monroe...	Rail...	1.00	0.15	0.19	....	....	0.85	0.81
		Barge..	0.11			0.04	0.08	....	....

*All rail rates for polyethylene are uniform classification rates. **All ship and barge rates for polyethylene are assumed to be the same as for ordinary non-corrosive liquid chemicals.

ETHYLENE DICHLORIDE FROM ETHANE: TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......	1. Amarillo	Via— Rail...	*[illegible]	Amarillo source $0.14	$0.16	....	....	[illegible]	[illegible]
	2. Monroe...	Rail...	[illegible]	Monroe source 0.10	0.13	....	....	[illegible]	1.56
	3. Houston...	Rail... Ship...	[illegible] [illegible]	Monroe source 0.10	0.13	....	....	[illegible] [illegible]	[illegible] 0.26
Cincinnati....	1. Amarillo	Rail...	1.50	Amarillo source 0.09	0.11	....	....	1.41	1.39
	2. Monroe...	Rail... Barge...	1.17 0.16	Monroe source 0.05	0.07	....	....	1.12 0.11	1.10 0.09
Chicago......	1. Amarillo	Rail...	1.37	Amarillo source 0.08	0.10	....	....	1.29	1.27
	2. Monroe...	Rail... Barge...	1.18 0.16	Monroe source 0.06	0.08	....	....	1.12 0.10	1.10 0.08
St. Louis.....	1. Amarillo	Rail...	1.23	Amarillo source 0.06	0.08	....	....	1.17	1.15
	2. Monroe...	Rail... Barge...	0.93 0.11	Monroe source 0.04	0.05	....	....	[illegible] 0.07	[illegible] 0.06

*All rail rates for ethylene dichloride are uniform classification rates.

ETHYL CHLORIDE (CHLORINATION OF ETHANE): TRANSPORT COST DIFFERENTIALS PER 100 POUNDS

Market served	Total transport cost (= transport cost on finished product) when plant location at—			Total transport cost (= transport cost on fuel and feedstock gas) when location at market		Transport advantage of a—			
						Natural gas site		Market site	
				34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	25"-30" pipe 60-65% L.F.	34" pipe 90-95% L.F.	26"-30" pipe 60-65% L.F.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
New York......	1. Amarillo	Via— Rail...	*$2.35	Amarillo source $0.22	$0.29	....	....	$2.13	$2.06
	2. Monroe...	Rail...	1.93	Monroe source 0.16	0.21	....	....	1.77	1.72
	3. Houston..	Rail... Ship...	2.21 0.61	Monroe source 0.16	0.21	....	....	2.05 0.45	2.00 0.40
Cincinnati....	1. Amarillo	Rail...	1.70	Amarillo source 0.14	0.18	....	....	1.56	1.52
	2. Monroe...	Rail... Barge..	1.33 0.41	Monroe source 0.09	0.12	....	....	1.24 0.32	1.21 0.29
Chicago......	1. Amarillo	Rail...	1.56	Amarillo source 0.13	0.17	....	....	1.43	1.39
	2. Monroe...	Rail... Barge..	1.36 0.44	Monroe source 0.10	0.13	....	....	1.26 0.34	1.23 0.31
St. Louis.....	1. Amarillo	Rail...	1.40	Amarillo source 0.10	0.13	....	....	1.30	1.27
	2. Monroe...	Rail... Barge..	1.06 0.29	Monroe source 0.06	0.08	....	....	1.00 0.23	0.98 0.21

*All rail rates for ethyl chloride are uniform classification rates.