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A LOCATIONAL ANALYSIS FOR THE PETROCHEMICAL INDUSTRY

WALTER ISARD AND LARRY PARCELS
University of Pennsylvania
Philadelphia, Pennsylvania

MASTER

December 1977

Prepared for the
BIOMEDICAL AND ENVIRONMENTAL ASSESSMENT DIVISION
NATIONAL CENTER FOR ANALYSIS OF ENERGY SYSTEMS
DEPARTMENT OF ENERGY AND ENVIRONMENT

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ABSTRACT

This report is one of a series of analyses which consider the current and future locational patterns of three of the more energy-intensive industries in the United States. Covered in the series are the iron and steel, the aluminum, and the petrochemicals industries. The analyses represent a comprehensive assessment of the economic, technological, political, and environmental factors which have lead to the current geographic distribution of economic activity and which may influence future locational decisions. While the primary emphasis is on the national and regional economic forces (product or input market orientation; technological change; transportation and energy, cost and availability differentials; etc.) affecting these decisions, the analytical conclusions are tempered by the recognized uncertainties and political and environmental realities under which such choices are made.

To be consistent with the level of detail implicit in Brookhaven National Laboratory's Multi-Regional Energy System Optimization Model (M-RESOM), regional analyses were conducted by state and U.S. Census Region. These locational analyses become important as the nonsubstitutable functional energy service requirements associated with the output of these industries form a portion of the demand structure of this model. Insights into the altered regional patterns of activity in these industries are, therefore, crucial for the detailed energy, economic, and environmental analyses required for energy policy formulation and evaluation.

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INTRODUCTION

Among the many factors complicating locational analysis of the petrochemical industry are (1) the infinite number of process combinations possible in a large petrochemical complex; (2) the difficulty of quantifying agglomeration economies which characterize the industry; (3) the large number of products defined as petrochemicals (some of which tend to be raw-material location oriented while others are market oriented).

In the following analysis, not all of these factors will be investigated in detail, however. Recent developments in the United States energy situation have impacted the industry in such a way as to make a locational analysis for future plant sites fairly straightforward, even though the pattern of petrochemical plant location may change significantly.

One of the most important changes the petrochemical industry is undergoing is the current shift in feedstocks. Over the years the industry has developed an increasing dependence on natural gas and its derivative fractions, and until recently it was possible to produce feedstocks quite inexpensively from cheap and plentiful supplies of domestic natural gas. The so-called "energy crisis" has completely altered this picture, however. Now that natural gas is becoming costly and scarce, new production facilities will no longer be based on the light feedstocks such as ethane, but will instead be based on heavier feedstocks such as gas-oil and naptha.

Since approximately half the future United States domestic oil demand will be met by foreign imports, and since the major consuming regions all have ports to which it is possible to ship oil at approximately the same cost, the raw material location for petrochemicals will in many cases coincide with the location of the market. Thus the locational analyst will no longer pit the market against the source of raw materials to find the minimum transport cost location. Instead, petrochemical manufacturers will compare the agglomerative economies associated with location at the present large petrochemical complex in the Gulf Coast area, with the transport cost advantage of locating at one of the regional markets. In the long run even this comparison may become irrelevant. Output will grow sufficiently to justify the existence of large petrochemical communities in several regions which possess most of the relevant agglomeration economies. To a large extent, then, the analysis becomes centered on nonquantifiable variables. One must decide how inertia will affect the spatial pattern of the industry. One or two producers must initiate the shift of the industry to a new producing region until a critical mass has been achieved at which agglomeration economies are forthcoming. Will any producer make the initial move? If so, when? Another important issue, perhaps the crucial one, is the effect that political and environmental pressures will have on the locational pattern of the industry. In the past they have exerted a powerful influence. It is no easy task to predict their influence in the future, however, whether it will be greater or less.

In the following analysis, we have attempted to outline the locational factors that will be most relevant to petrochemical producers of the future. The divergence of opinion over the effects and magnitude of the energy crisis or the future impact which enviornmental lobbying will have on petrochemical location makes it impossible to make projections with certainty. Consequently, we have tried to make explicit our assumptions and the uncertainty involved in some of these assumptions so that the reader can easily adjust our estimates in light of alternative hypotheses. Wherever possible we have relied on published predictions by industry experts.

THE IMPACT OF THE ENERGY CRISIS ON PETROCHEMICAL PLANT LOCATION

As mentioned previously, the most obvious effect of the domestic energy situation on the petrochemical industry will be the decreasing availability of natural gas as a feedstock. Figure 1 gives a prediction of future United States natural gas production which indicates that production has already peaked and has begun a period of decline. Figure 2 shows a similar prediction for U.S. crude oil production which may be compared with the world production estimate illustrated in Figure 3. The two obvious results having the most bearing on our locational analysis are an increasing dependence of the U.S. petrochemical industry on foreign oil imports (and perhaps domestic coal), and its declining reliance on natural gas and domestic oil production. (See Figures 4 and 5.)

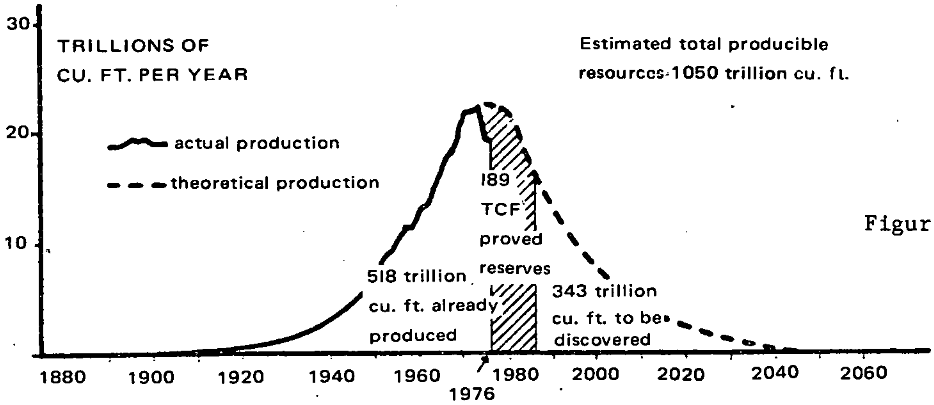

Figure 1. U.S. Natural Gas Production

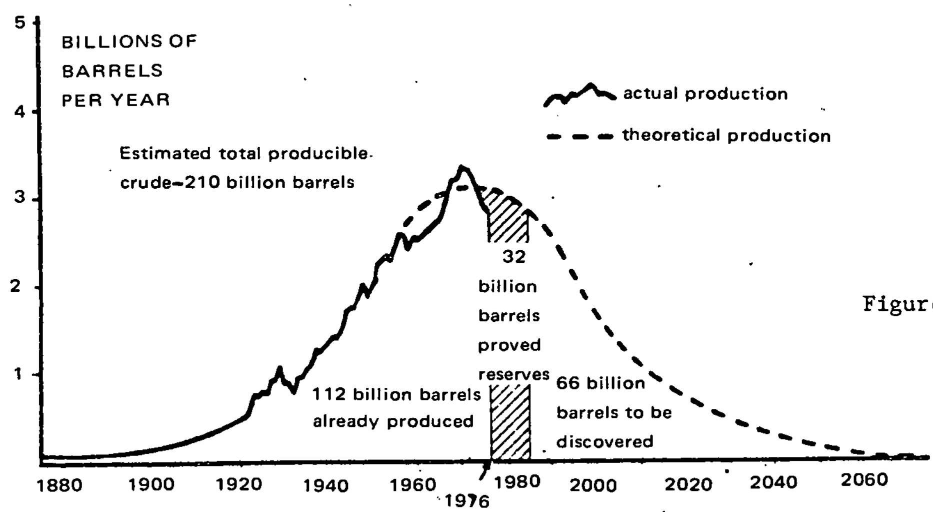

Figure 2. U.S. Crude Oil Production

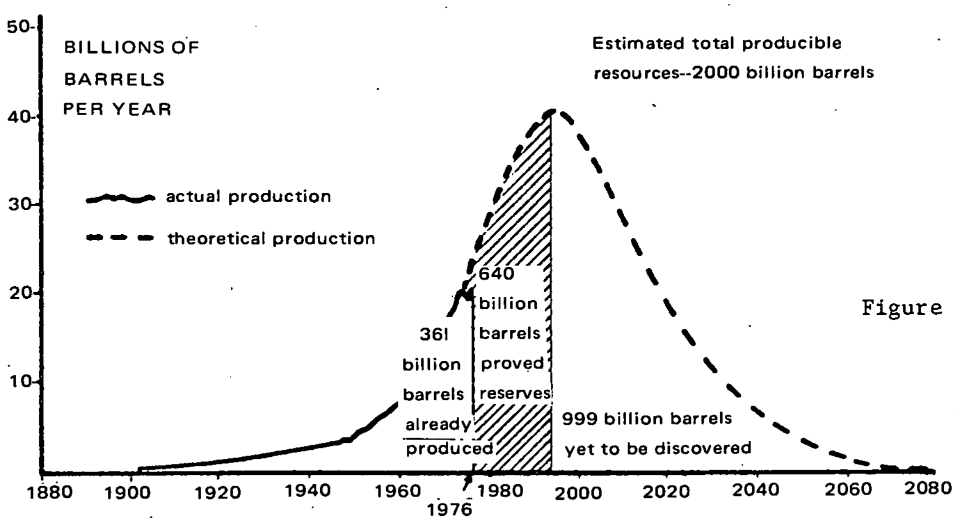

Figure 3. World Oil Production

Source: Du Pont Management Bulletin. Volume 6, No. 1, p. 2, January-February 1977.

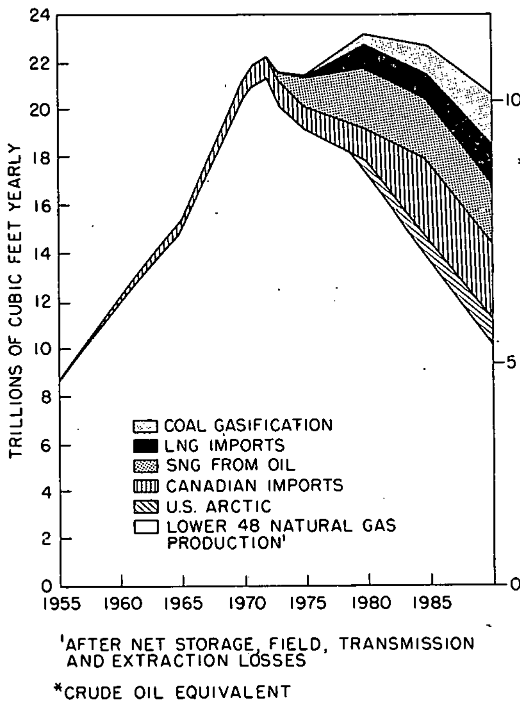

Figure 4. U.S. Gas Supply

Source: Shell Oil Company, National Energy Outlook, p. 18, May 1973.

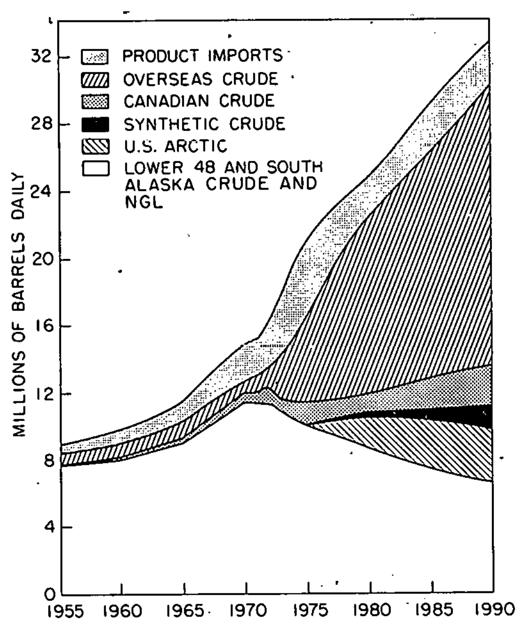

Figure 5. U.S. Petroleum Supply

Source: The Shell Oil Company, The National Energy Outlook, p. 16, May 1973.

The results of the natural gas shortage are discussed in the next section while the impact of foreign oil imports and the possible use of coal as a feedstock are discussed in the succeeding two sections of this report.

NATURAL GAS

The fact that U.S. natural gas production is in a long-run period of decline is certainly not an issue. The amount by which the decline will be slowed by price deregulation and other measures to encourage the oil industry is a matter in dispute, but basically on one in the petrochemical industry expects natural gas to play a dominant role as a feedstock in future years, even under the most optimistic assumptions. Though the physical quantity of gas used by the petrochemical industry may increase somewhat, we expect that in relative terms natural gas will play a greatly diminished role as petrochemical production increases. The increase in absolute quantity of natural gas used will result from the expected shift of natural gas to its most valuable end uses. Users with lower priority (where there is easy conversion and high substitutability with other fossil fuels) will turn rapidly to coal and oil as natural gas prices rise and the government takes actions to encourage conversion. At the same time residential and commercial users, as well as the petrochemical industry, will receive an increasing share of the natural gas which remains. (See Figures 6 and 7.)

In order to demonstrate the shift taking place in petrochemical feedstocks as a result of the natural gas shortage, we will use ethylene, by far the largest-volume petrochemical building block, as the prime illustration. Up until the present, ethane was the most important feedstock for producing ethylene. Declining natural gas production, drier gas (yielding less ethane), and rapidly rising natural gas prices have encouraged a shift away from this gas as a feedstock, however, even though new cryogenic ethane extraction technology has greatly improved ethane yields.[1] Table 1 shows a set of predictions made by the Pace Company for future feedstock usage in the production of ethylene.[2] The first column shows 1973 consumption; the second column shows an estimate made before the Arab oil embargo; and the third and fourth columns show recent estimates. Another prediction is illustrated in Figure 8. Many

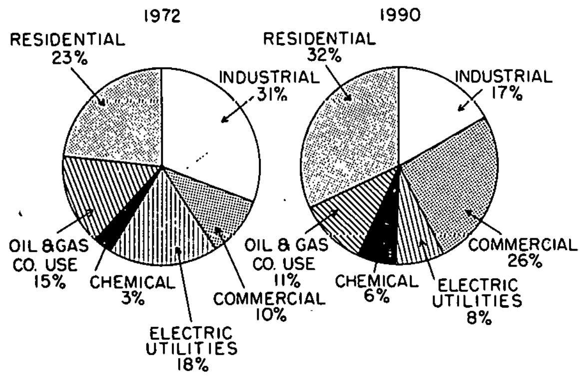

Figure 6. Gas Consumption by Market

Source: The Shell Oil Company, The National Energy Problem: Natural Gas, p. 18, August 1973.

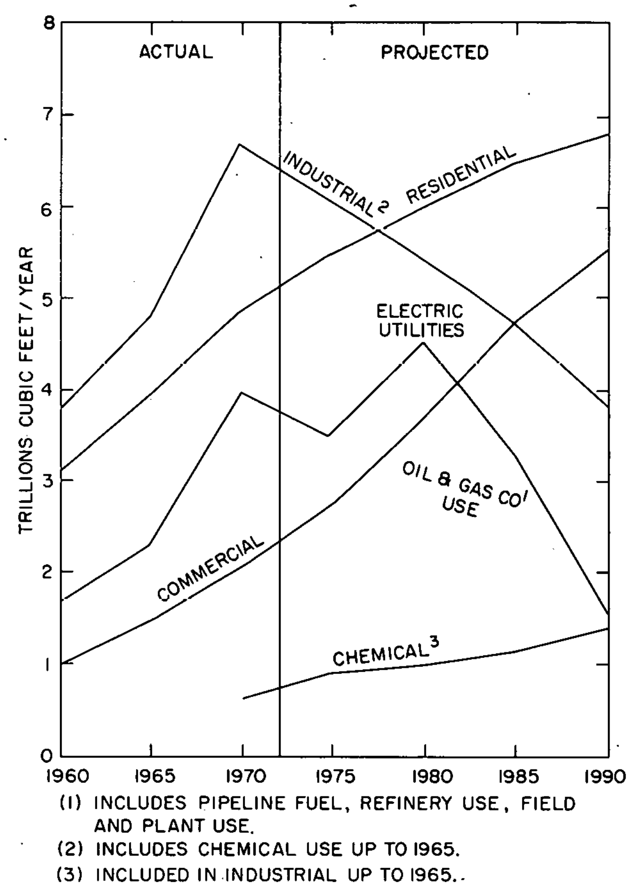

Figure 7. Use of Natural Gas Supplies

Source: The Shell Oil Company, The National Energy Problem: Natural Gas, p. 16, August 1973.

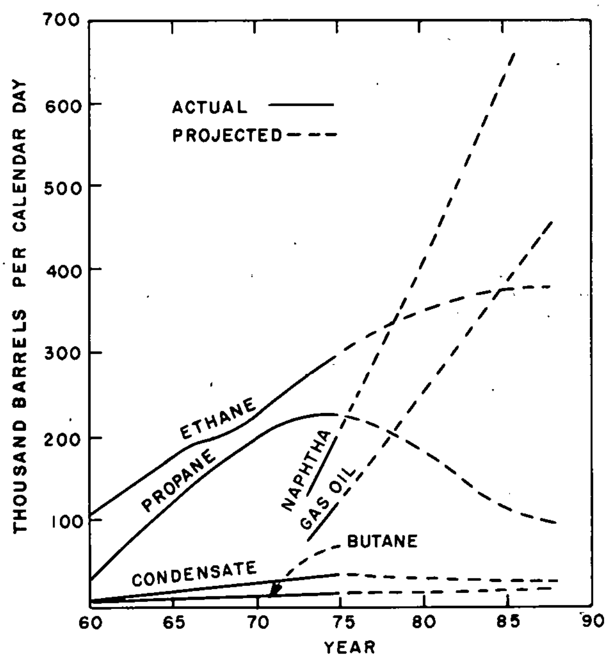

Figure 8. Feedstock Consumption for Ethylene Production, U.S. Supply

Source: J.B. O'Hara, E.D. Becker, N.E. Jentz, and T. Harding, Petrochemical feedstocks from coal, Chem. Eng. Prog., p. 64, June 1977.

predictions have been made regarding feedstock consumption for ethylene production[3], and all arrive at approximately the same conclusion. Ethane usage will increase gradually through the 80s, while propane usage declines markedly. The use of Naphtha and gas-oil as sources of feedstock will increase quite rapidly and will dominate by 1985. One estimate of the changing percentage of feedstock usage between the present and 1985 is given in Table 2.

Notice that European producers already depend largely on heavy liquid feedstocks. Thus it is very possible to shift feedstock consumption with today's technology, but the United States industry has lost a major cost advantage with the disappearance of available inexpensive domestic natural gas liquids.

The switchover in feedstocks from natural gas liquids to heavy liquids such as gas-oil and naptha will have another effect on the petrochemical industry in addition to changing its source of raw materials. In the future, petrochemical plants may be even more closely linked with refineries than they are presently. Whereas in the past, energy products made up only a very small percentage of the output of a petrochemical complex, they now make up about 40% of the output of a complex based on heavy liquids (see Figures 9 and 10). Much of the output stream which is returned to the energy sector requires further processing at a refinery, thus the locational ties between refinery and petrochemical complex are strengthened even further. In the light of these facts, it seems most economical for a petrochemical complex to build in close proximity to a refinery which produces a whole range of products, or in a region which has sufficient demand for energy products to support such a refinery.[4,5]

Table 1

Ethylene Feedstock Forecast
(millions bbl/yr)

		1985		
			Recent	
	1973	Pre-Embargo	High	Low
Off-gas....................	30	33	33	33
Ethane.....................	102	102	117	123
Propane....................	86	92	52	48
Butane.....................	7	10	43	51
Naphtha		75	226	219
Gas-Oil....................	56	434	137	73

Source: John R. Dosher, "Changing Petrochemical Feedstocks-Causes and Effects", Chemical Engineering Progress, September 1976, p. 18.

Table 2

Feedstocks for Production of Ethylene

Changing Feedstock Mix: 1975 vs 1985

Feedstock type	Feedstock usage-percentage			
	United States		Europe	
	1975	1985	1975	1985
Ethane....................	39	26	nil	nil
LPG/RG....................	36	14	1	4
Naphtha...................	25	20	95	71
Gas-oil...................		40	4	25
	100	100	100	100

Source: U.S. Industrial Outlook, p. 102, 1977.

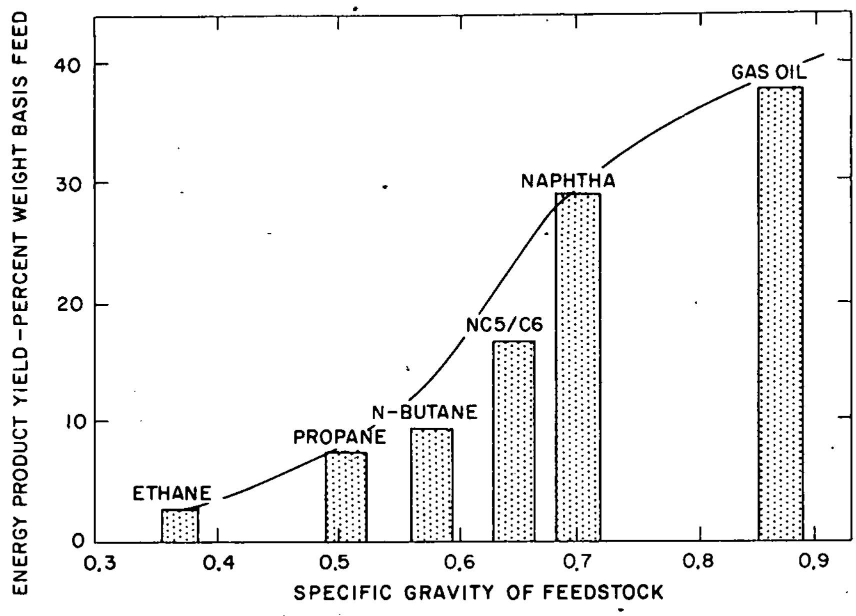

Figure 9. Yield of Energy Products as a Function of Olefin Plant Feedstock.

Source: Norman C. Whitehorn, Economic Analysis of the Petrochemical Industry in Texas, p. 52, May 1973.

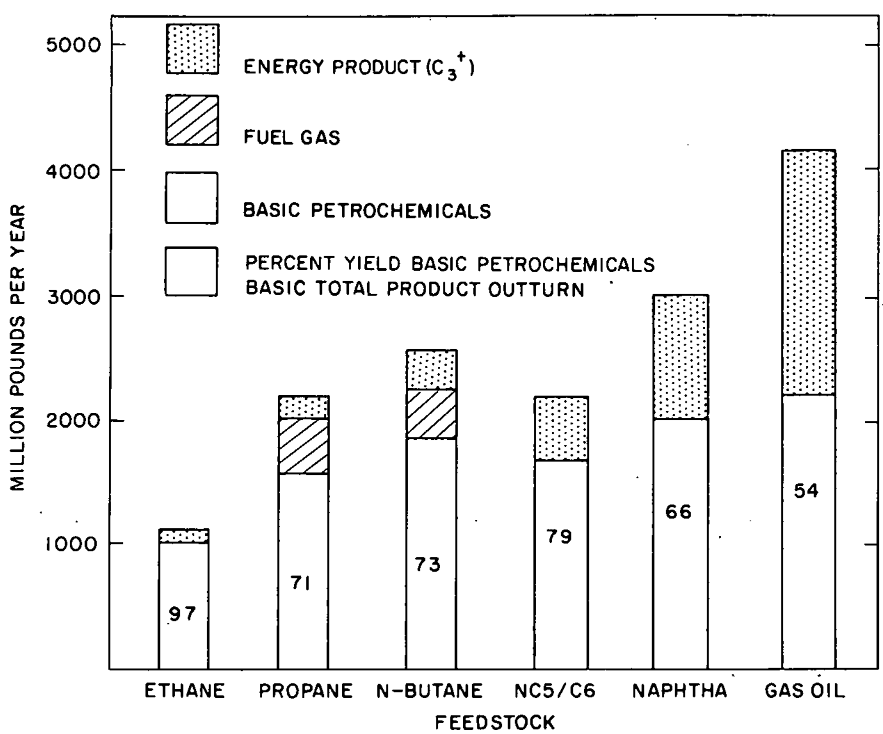

Figure 10. Olefins Plant Products Yields

Source: Norman C. Whitehorn, Economic Analysis of the Petrochemical Industry in Texas, p. 53, May 1973.

FOREIGN OIL IMPORTS

One issue which must be discussed is the role that oil imports will play in petrochemical plant location. If we hypothesize that foreign imports and domestic oil in Texas will be equal in price, then there is a definite transport cost advantage in shipping the oil to the East Coast, refining it there, and producing petrochemicals from the refinery output to meet the Eastern market's chemical demands. The transport cost advantage would equal the extra cost of shipping oil to Texas rather than to the East Coast (this is likely to be only a slight advantage, if any), plus the cost of shipping the petrochemical products from the Gulf Coast to the East Coast (this shipment would prove unnecessary if the petrochemical plant were already located at the East Coast).

Thus, given that oil imports will be meeting a major portion of the country's needs, refineries and petrochemical complexes based on heavy feedstocks could be located at coastal areas other than the Gulf Coast, with a substantial transport cost savings for petrochemical shipments.

We need not assume that the price of domestic oil would equal the price of imported oil, however. One possible assumption is that domestic oil producers would peg the price of domestic oil equal to the price of imported oil delivered to the major East Coast markets. The price of oil in Texas, therefore, would be equal to the price of oil delivered at the Eastern market minus the shipment cost from Texas to the East Coast. The cost advantage would equal the cost differential between the cost of shipping crude oil from the Gulf Coast to the East Coast and the cost of shipping petrochemicals from the Gulf Coast to the East Coast. This differential is likely to be rather small. Since a large quantity of oil today is imported into the Gulf Coast, this suggests that the Gulf Coast in the long run may not be able to meet its own demand for oil, and thus the price of Gulf Coast oil is likely to approximate the New York-Philadelphia imported oil price.[6]

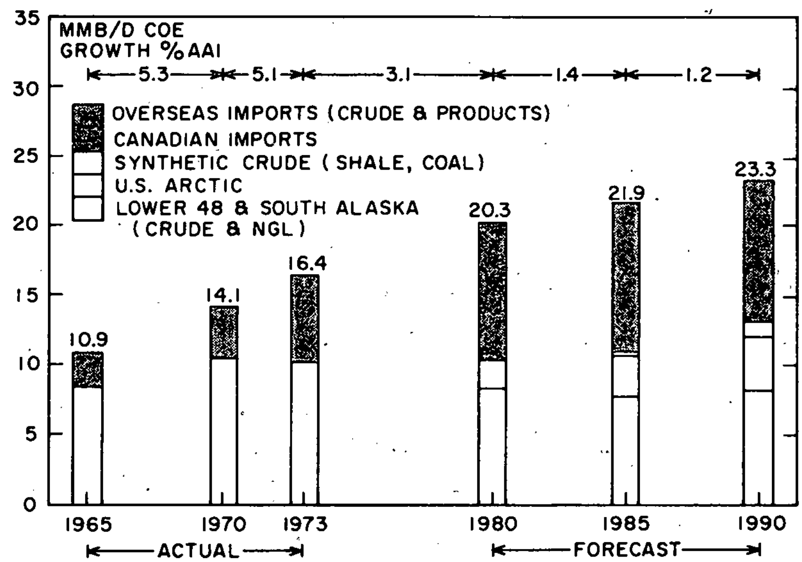

Figure 11. U.S. Oil Supply

Source: The Shell Oil Company, The National Energy Outlook 1980-1990, p. 15, September 1976.

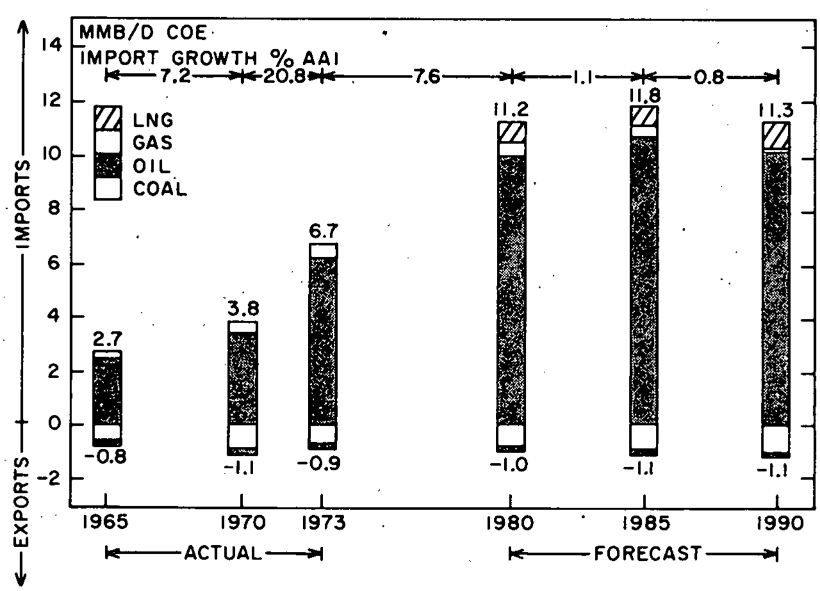

Figure 12. U.S. Energy Imports/Exports

Source: The Shell Oil Company, The National Energy Outlook 1980-1990, p. 18, September 1976.

THE FUTURE ROLE OF COAL AS A PETROCHEMICAL FEEDSTOCK

The use of coal, either directly or indirectly (through the process of liquefaction or gasification, for example), as a raw material for petrochemicals could have a significant impact on the location of the petrochemical industry at some future point in time. We feel that it will probably play a rather limited role from now until the end of the century, however. At present, coal is often used only incidentally as a source of raw materials for chemicals; for example, feedstocks are a by-product of certain coking operations. Although certain organic chemicals depend heavily on coal as a source of raw material, it does not currently play a major part as a feedstock source for the industry as a whole.[7] Petroleum sources now account for over 95% of the supply of benzene, toleune, xylene, and all olefin supplies.[8]

Although there has been a lot of research lately on methods of extracting feedstocks from coal, the technology for many processes has existed since the inception of the petrochemical industry when coal was the dominant source of raw material. Economic considerations made coal obsolete when processes (and, consequently, new chemical products) involving liquid natural gas feedstocks were developed to utilize the nation's abundance of olefin-rich gas streams which were a by-product of cracking operations. These same types of consideration are the driving force behind the current research to develop new conversion processes for coal, the cheapest and most abundant energy resource of today. ERDA has sponsored many pilot plants and smaller experimental units which test various types of coal conversion processes. One example of a possible coal-based complex which has been put forth by chemical engineers is shown in Table 3. Six to seven of these plants, each consuming 65,000 tons of coal per day, could meet 10% of the projected 1990 United States ethylene requirement.[9] Companion benzene production could meet 8% of domestic demand.

W.W. Reynolds and H.S. Klein of Shell Oil Company predict a rather limited role for coal as a source of feedstock for petrochemicals, even as far into the future as 1990. Forecasting a 3% energy growth rate and a 5 to 7% petrochemical growth rate to 1990, they suggest that long-term energy needs could be most

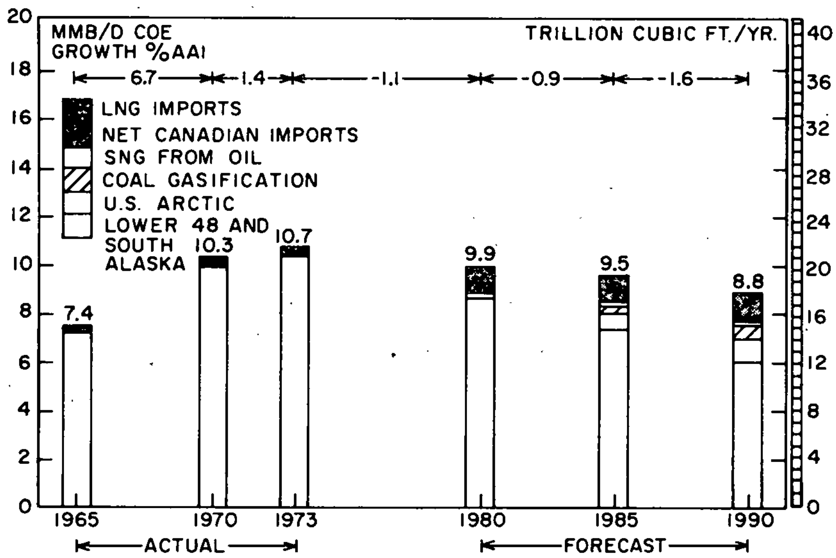

Figure 13. U.S. Gas Supply

Source: The Shell Oil Company, The National Energy Outlook 1980-1990, p. 17, September 1976.

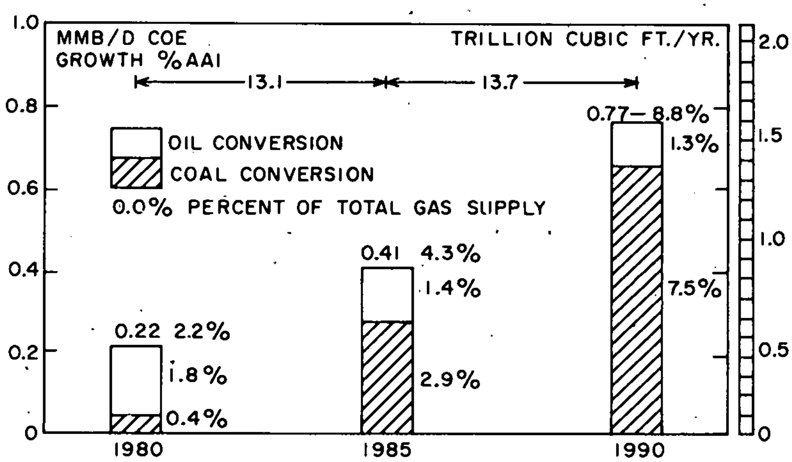

Figure 14. Synthetic Gas Supply

Source: The Shell Oil Company, The National Energy Outlook 1980-1990, p. 17, September 1976.

Table 3
Petrochemical Feedstocks from a Solvent Refined Coal Complex

Component	Production rate, ton/day (basis: 10,000 ton/day process coal feed)	Product composition wt%
Methane	476	6.1
Ethane	329	4.2
Propane	19	0.2
Propane LPG	404	5.1
Isobutane	334	4.2
Normal butane	393	5.0
Light naphtha raffinate	492	6.3
Heavy naphtha raffinate	122	1.5
Sulfur	355	4.4
Ammonia	82	1.0
Benzene	144	1.7
Toluene	385	4.8
Xylene	285	4.2
Carbon black oil	1,891	24.1
Electrode binder	123	1.6
Calcined coke	1,870	23.8
Phenols	124	1.6
Amines	12	0.2
Totals	7,840	100.0

Source: J. B. O'Hara, E. D. Becker, N. E. Jentz, and T. Harding, Petrochemical Feedstocks from Coal, Chem. Eng. Prog., p. 69, June 1977.

efficiently met by adjusting the available energy mix rather than by unnecessarily wasting resources via coal gasification and liquefacation.[10] (These processes result in the loss of a substantial amount of thermal energy.). Reynolds and Klein predict that some gasification and liquefaction plants may be built to satisfy regional imbalances, but in general chemical by-products from coal conversion will have no significant impact on the petrochemical industry. In assessing the economic viability of particular coal chemicals, the two men estimated that coals would need to cost $9 per ton as compared to $11 per barrel of oil in order for acetylene from coal to be cost competitive. In other words, coal must be one-fifth the price of oil on a dollar per Btu basis. Methanol from coal was similarly found to have no advantage over ethylene chemistry on a cost per carbon content basis. Reynolds and Klein predict that by 1985 coal gasification by-products would meet only 3% of the total demand for most aromatics. This low estimate was recently confirmed by a 4% estimate made by another Shell Oil Company Official.[11] A more detailed breakdown is given in Table 4. Note that since naphthalene is currently coal derived anyway (from diverse processes), the predicted large amount coming from coal gasification plants would have little effect on the locational orientation of the industry.

Werner C. Brown, president of Hercules Corporation, also predicts that, with the exception of synthetic gas from methanol and ammonia production, hydrocarbon feedstocks will not be economically viable until at least the 1990's or perhaps not even until after the year 2000.[12]

A recent management bulletin put out by Du Pont has a somewhat more optimistic tone. It predicts that coal may become an important hydrocarbon feedstock toward the end of the century and that coal gasification may be economically practical for providing fuel by the mid-1980s.[13] An even more optimistic estimate made a few years ago by a group of engineers from Cameron Engineers Inc. predicts that with government aid, synthetic gas from coal could meet as much as 10% of the United States gas requirement by 1985.[14] Without some sort of government subsidy, however, the group predicted that such development would be unlikely.

It seems clear from the above discussion that the industry leaders cited have reached a rough consensus of opinion: coal will not play a crucial

Table 4
By-products from Coal Gasification as a Percentage of Demand

	%
Benzene	2.6
O-Xylene	5.6
Ethyl benzene	1.1
Phenol	7.8
Toluene	6.2
P-Xylene	3.1
Naphthalene	33.0
Ammonia	2.7

Source: W. W. Reynolds and H. S. Klein, Petrochemical and energy in perspective, Chem. Eng. Prog. 71, No. 3, p. 15 (1975).

Table 5
Natural Gas: Components of Supply
(trillions of cubic feet)

	1990
Domestic production	11.2
Imports	3.2
Liquid natural gas imports	1.6
Synthetic natural gas from oil	2.5
Coal gas	2.2
Total supply	20.7

Source: The Shell Oil Company, The National Energy Problem: Natural Gas, p. 9, August 1973.

role in petrochemical plant location in the coming couple of decades. Even if the most optimistic of the estimates was realized, syngas from coal would account for only a small percentage of petrochemical feedstocks. Moreover, existing plans for building inexpensive-to-operate coal slurry pipelines from mountain coal deposits to the West South Central States in the heart of the petrochemical-producing region indicate that the pattern of petrochemicals plants based on syngas might approximate the existing location of the industry anyway.[15]

FUTURE PETROCHEMICAL DEMAND

The Brookhaven estimates of petrochemical production for 1985 seem fairly consistent with several recently published predictions by the chemical industry itself. Using the element of the Brookhaven output vectors for 1967, 1985, and 2000 which corresponds to the petrochemical industry, we calculated the percentage growth in production from 1967 to 1985, and from 1967 to 2000. The total growth in output equaled 142% for the former period and 359% for the latter. Using an actual growth of 47.3% from 1967 to 1975, or approximately 82% from 1967 until the present (1977), and adding on various industry predictions of growth from either 1975 or 1977 to the future, we would arrive at an estimate of growth over the period from 1967 to 1985 of somewhere between 120 to 190%. Most estimates seem scattered near the lower end of that range, however. Thus we feel Brookhaven's estimate for 1985 is reasonable and we will use it in our analysis.

Klaus L. Mai, an executive of Shell Oil Company, predicts an increase of 21% in tonnage output of major petrochemicals (including butadiene, methanol, propylene, benzene, toluene, ethylene, ammonia, and xylenes) from 1976 to 1980, and a 98% increase between 1976 and 1990.[16] Linearly interpolating his estimate, we calculate a 60% increase from 1976 to 1985, or a 120% increase from 1967 to 1985. A slightly earlier estimate made in 1975[17] by W.W. Reynolds, also of Shell Oil, indicated that petrochemical production would increase by approximately 146% from 1967 to 1985.[18] Eugene J. Debreczeni, in a recent article in Chemical Engineering, made a prediction which implied that the combined tonnage of output of four major chemicals--ethylene, propylene, butadience, and xylene--would increase by 149% from 1967 to 1985.[19] In another article in the same periodical, an economist and industry specialist from Merrill Lynch predicted a growth in chemical output of 190% between 1967 and 1985.[20]

Though there are several sets of production estimates for 1990, few exist for the year 2000. One which we did encounter predicted a very optimistic 488% growth in output from 1967 to 2000.[21] The authors of that estimate were also at the extreme high end of the range of the 1985 estimates, however. Again, for the year 2000 we will use the Brookhaven estimate of growth which equals 359% over the 33-year period, or approximately a 4.7% average annual compound growth rate.[22]

RECENT LOCATIONAL TRENDS

Perhaps before the projections regarding the future distribution of the petrochemical industry are presented, a few words should be said about the recent locational trend of the industry. It would also be informative to discuss the opinions of the industry itself about future locational trends. The following quotation by J. M. Leathers, vice-president of Manufacturing and Engineering Technology, the Dow Chemical Company, seems to sum up fairly well the opinion of many industry leaders:

> As to how raw-material and energy sources will affect the location of future plants, units that are large producers of chemical intermediates (ethylene, propylene, ethylene oxide, chlorine, caustic, ethylene dichloride, vinyl chloride) will tend more to be located near deep-water transportation facilities, mainly so that raw materials - such as naphtha and crude oil - may be easily brought in, and to export finished goods or intermediates.
>
> Taking care of the environment, and at the same time continuing to run our businesses well, will continue to be a challenge.
>
> Dow does not intend to go into an area and build a plant when the local, state and other regulatory bodies are not receptive. We will not force ourselves on any state in the U.S., nor on any other country. And, we will build plants where the market exists, and where government and environmental factions will allow us to build. We expect to see other companies in the CPI adopting the same attitude.[23]

Similarly, a quote by Harry F. Mason of Turner, Mason, and Solomon indicates that the same types of considerations will be important:

> Utilization of imported feedstocks will have a great influence on plant site location. East Coast locations will actually have a slightly lower delivered feedstock cost than plants on the Gulf Coast. This could result in a major shift in plant location. However, resistance to further industrialization of this area and particularly resistance toward large-scale feedstock receiving and transhipment facilities may favor the Gulf Coast. Midwest locations via pipeline from the Gulf Coast may also become more attractive.[24]

The most recent article on plant location which is published annually by Chemical Week predicted that "increasing reliance on imported oil as a source of chemical feedstock will favor coastal location in coming years." How many plants will be located in the Eastern seaboard States as opposed to the Gulf Coast will depend on whether voters in the East can be persuaded of the desirability of refining and chemical plant investment.

Clearly, there is a tradeoff between the growing economic attractiveness of locating at the market and the political and environmental constraints of doing so. This is well illustrated by the example of the Dow Chemical Company. The West Coast is today one of the most attractive potential locations for a petrochemical plant. With the recent flow of Alaskan oil, it clearly makes sense to locate in an area where there is currently a large petrochemical deficit and it is necessary to import chemicals from a great distance. Two projects planned by Arco and Dow for the early 1980s would have met 90% of the West Coast's major chemical needs, only 10% of which are currently met by local production. Thus a ready market and source of feedstocks existed at one location, a situation very desirable from the point of view of a petrochemical manufacturer. Dow estimated that it could save $56 million dollars per year in transportation costs alone.[26] Stanford Research Institute estimated that by 1980, when West Coast refineries could supply Dow with Naphtha produced from Alaskan oil, Dow would pay a penalty of $160 million dollars per year by continuing to produce in the Gulf Coast and shipping to the West.[27] Powerful opposition from environmental groups and a very lengthy (and costly) bureaucratic regulatory tangle finally persuaded Dow to indefinitely postpone its plans to build in California, however. One company official said: "The project made a lot of sense when we started it, and it still does." But Dow will probably not make another attempt to build a complex in California until the conditions improve. Perhaps the most significant improvement would be in the regulatory procedure, which was criticized soundly by many West Coast newspapers and citizens who saw the complex as a welcome boom to the economy. Whether the procedure is streamlined and whether environmental consideration will hold as much sway in the future depend on the condition of both the environment and the regional economy in future years.

PROJECTION OF PETROCHEMICAL PLANT LOCATION FOR 1985 AND 2000

In order to project a regional distribution of the demand for petrochemicals, we have partially relied on regional population projections prepared by the U.S. Department of Commerce. Population seems to be fairly well correlated with consumption in most areas of the country. A different consumption pattern does seem to hold in the West, however, and using population as a proxy would probably overstate petrochemical consumption there significantly. For our projection of 1985 petrochemical production in each region, we have slightly modified an estimate made by an industry expert on plant location, W.W. Reynolds of Shell Oil Company. For his 1985 estimate of regional petrochemical demand, Mr. Reynolds used 1974 statistics of regional thermoplastics consumption published by the Society of the Plastics Industry. We have modified Mr. Reynold's estimate, which was done for five regions, by breaking the petrochemical demand estimate down further into the nine census regions. We have roughly based the breakdown of the larger regions into the smaller regions on the 1985 distribution of population. For the year 2000, we took Reynolds's regional consumption projections (based on the 1974 distribution of thermoplastics consumption adjusted by the national growth rate for petrochemical consumption to 1985) and adjusted them to reflect the regional shift in population from 1974 to 2000.[28] The demand distribution for each year can be seen in Tables 8 and 9.

Table 6 gives the 1985 projections made by W.W. Reynolds for petrochemical demand and production in each of the five regions shown in Figure 16. Since

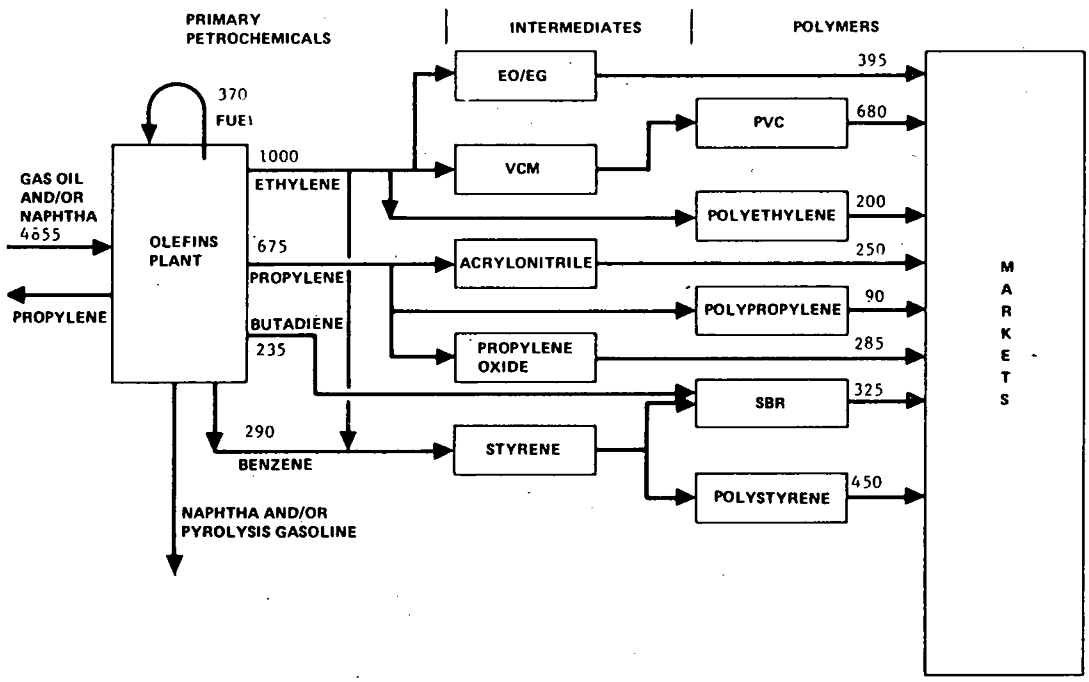

Figure 15. Illustrative Refinery-intergrated Core Petrochemical Complex

Source: W.W. Reynolds, "Investing in Primary Petrochemicals," Chemical Engineering Progress, Vol. 68, No. 9 (September 1972), p. 33; and Elliot M. Mager, "Aromatics Production," in Arthur M. Brownstein, ed., U.S. Petrochemicals (Tulsa: Petroleum Publishing Company, 1972), pp. 96-131.

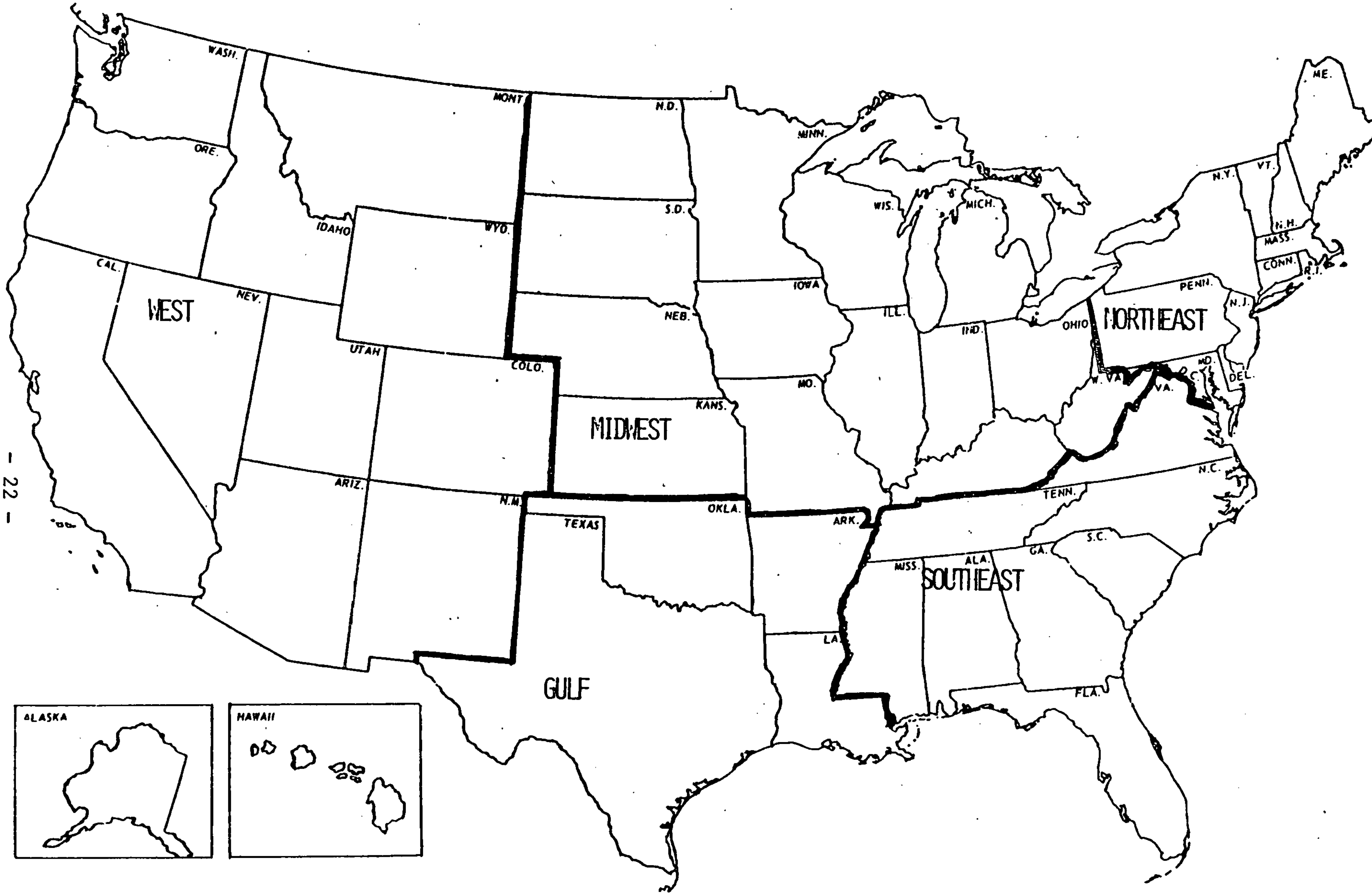

Figure 16. U.S. Map Showing Production and Demand Regions

Source: W. W. Reynolds, Shell Oil Company

Table 6
Estimated Demand for Core Petrochemical Complexes, 1985
(W.W. Reynolds estimate)

Location	1974 Regional demand**	1974 Effective complexes*	1974 Net regional demand	1985 Regional demand**	1974-1985 Projected new complexes*	1985 Net regional demand
Northeast	6.5	0.5	6.0	11.0	2.5	8.0
Southeast	2.5	-	2.5	6.0	1.0	5.0
Midwest	9.0	2.0	7.0	15.0	2.0	11.0
Gulf	2.5	20.0	(17.5)	4.0	12.0	(28.0)
West Coast	2.0	0.5	1.5	3.0	1.0	1.5
Puerto Rico	-	1.5	(1.5)	-	0.5	(2.0)
Total	22.5	24.5	(2.0)	39.0	19.0	(4.5)

* Core petrochemical complex consists of an olefins plant having a 12-billion-pound per year ethylene capacity and associated derivative units (see Figure 16).

** Regional demand for petrochemical complexes based on thermoplastics consumption estimates.

Source: W. W. Reynolds, Shell Oil Company.

Table 7
Estimated Demand for Core Petrochemical Complexes,*,** 1985
(author's estimate)

Location	1974 Regional demand	Effective complexes in 1974	1974 Net regional demand	Projected 1985 regional demand	Projected new complexes built 1974-1985	Projected 1985 net regional demand
New England	1.0	-	1.0	2.0	-	2.0
Middle Atlantic	5.0	0.5	4.5	8.0	2.5	5.0
East North Central	7.5	2.0	5.5	11.0	2.0	7.0
West North Central	1.5	-	1.5	3.0	-	3.0
South Atlantic	2.0	-	2.0	5.5	-	5.5
East South Central	1.0	-	1.0	2.5	1.0	1.5
West South Central	2.5	20.0	(17.5)	4.0	12.0	(28.0)
Mountain	0.5	-	0.5	0.5	-	0.5
Pacific	1.5	0.5	1.0	2.5	1.0	1.0
Puerto Rico	-	1.5	(1.5)	-	0.5	(2.0)
Total	22.5	24.5	(2.0)	39.0	19.0	(4.5)

* A core petrochemical complex consists of an olefins plant having a 12-billion-pound per year ethylene capacity and associated derivative units (see Figure 15).

** The authors have attempted to make this estimate consistent with the W. W. Reynolds estimate in Table 6.

Table 8
Estimated Demand for Core Petrochemical Complexes,*,** 1985
(author's alternative estimate)

Location	1974 Regional demand	Effective complexes in 1974	1974 Net regional demand	Projected 1985 regional demand	Projected new complexes built 1974-1985	Projected 1985 net regional demand
New England	1.0	--	1.0	2.0	-	2.0
Middle Atlantic	5.0	0.5	4.5	8.0	2.5	5.0
East North Central	7.5	2.0	5.5	11.0	3.0	6.0
West North Central	1.5	-	1.5	3.0	-	3.0
South Atlantic	2.0	-	2.0	5.5	1.0	4.5
East South Central	1.0	-	1.0	2.5	1.0	1.5
West South Central	2.5	20.0	(17.5)	4.0	8.5	(24.5)
Mountain	0.5	-	0.5	0.5	-	0.5
Pacific	1.5	0.5	1.0	2.5	2.0	-
Puerto Rico	-	1.5	(1.5)	-	1.0	(2.5)
Total	22.5	24.5	(2.0)	39.0	19.0	(4.5)

* A core petrochemical complex consists of an olefins plant having a 12-billion-pound per year ethylene capacity and associated derivative units (see Figure 15).

** This estimate is based on the assumption of greater market orientation (see text for explanation).

Table 9
Estimated Demand for Core Petrochemical Complexes,* 2000

Location	2000 Projected regional demand	1985 Projected effective complexes (alternative estimate)**	Projected new complexes 1985-2000	Total complexes in 2000	Projected 2000 net regional demand
New England	3.5	-	-	-	3.5
Middle Atlantic	16.0	3.0	2.0	5.0	11.0
East North Central	19.0	5.0	5.0	10.0	9.0
West North Central	5.5	-	1.0	1.0	4.5
South Atlantic	11.0	1.0	3.0	4.0	7.0
East South Central	4.5	1.0	5.0	6.0	(1.5)
West South Central	7.0	28.5	17.0	45.5	(38.5)
Mountain	1.0	-	-	-	1.0
Pacific	6.5	2.5	3.5	6.0	0.5
Puerto Rico	-	2.5	1.0	3.5	(3.5)
Total	74.0	43.5	37.5	81.0	(7.0)

* A core petrochemical complex consists of an olefins plant having a 12-billion-pound per year ethylene capacity and associated derivative units.

** Based on our alternative 1985 estimate.

Reynolds's overall demand projection was consistent with the estimate we derived from Brookhaven's 1985 output vector, we were able to follow his scenario closely, breaking the statistics down into nine census regions rather than five. His West corresponds to the Mountain and Pacific Census regions; his Gulf to the Census West South Central; his Midwest to the Census West North Central plus the Census East North Central plus West Virginia and Kentucky and the South Atlantic less West Virginia, Maryland and Delaware; and his Northeast corresponds to the Middle Atlantic, plus New England plus Maryland and Delaware. Our initial breakdown, which parallels that of Reynolds, is shown in Table 7. We have subsequently modified these figures to derive an alternative estimate which is not quite as conservative. The modified figures assume less spatial inertia and fewer constraints on the locational choice. See Table 8.

Our reasons for locating petrochemical plants where we did are varied. As mentioned before, the West Coast seems to be a very attractive location, and we feel that certain portions of the Pacific region would be acceptable plant locations to environmentalists if effective pollution controls were incorporated into the design of the plant. Some may argue that the proposed Dow plant which was recently halted met these criteria. The failure of the plant may be partially attributable to its projected location astride two political jurisdictions, however. Other contributing factors may have been the particular state government administrators in office at the time, and also the state's rather cumbersome licensing procedure. In the long run, we feel that growing economic, political, and environmental pressures in other regions, and a reasonable assessment by West Coast residents of the costs and benefits of having some limited petrochemical activity in their own area will enable some petrochemical expansion to take place.

On the basis of a feasibility study done by the Coastal Plains Regional Commission, we have hypothesized that one complex will be built in the South Atlantic region by 1985. In contrast to California, this region has actually sought out petrochemical investments. In fact, the governors of three coastal states, Georgia, North Carolina, and South Carolina, met with oil and chemical company executives in May 1975 to encourage them to locate refineries and chemical plants within the coastal areas of the three states.[29] The plan which was discussed envisioned an offshore deepwater oil terminal which would pump oil to refineries onshore. The refinery complex could then meet the feedstock requirements of a heavy-liquids-based petrochemical complex. The Commission's report estimated that there would be sufficient demand within the three-state area alone to support one more complex by 1985 and still another by 1992.[30] The concentrated textile industry within the region would make an ideal customer for many of the petrochemical products, and the energy emdand of the region, currently unmet by local production, could be served by the energy by-products of the core complex. Considerable transport cost savings would accrue from locating a petrochemical complex within the region rather than continuing to import raw materials from the Gulf Coast and the Midwest.

Needless to say, not all states are actively seeking petrochemical development. At the same time that the governors of North Carolina, Georgia, and South Carolina were wooing petrochemical industry officials, Maryland's governor was signing a bill that would restrict the location of refineries and related chemical plants along the coast of that state.[31] Likewise, we predict that it is very unlikely that the citizens of New England would welcome such development, even if suitable locations could be found there. Thus we have projected no complexes for New England for either 1985 or 2000.

Though the Middle Atlantic states have recently taken measures to encourage industrial development, it is doubtful that too much expansion would be permitted to take place there because of the high population density and lack of available plant sites. We have therefore limited expansion to 2.5 units for 1985 and 2 more by the year 2000.

In Alabama, Mississippi, and Tennessee, the completion of the Tennessee-Tombigbee waterway by 1981 will help spur development in that area.[32] The waterway will connect the Tombigbee River with the Tennessee, thus linking the Gulf of Mexico and the Midwest. The project could stimulate investment as far north as Pennsylvania and Ohio.[33] The East South Central region may also gain from the lack of available sites farther west along the Gulf Coast. Available land and resources in the Houston area are already becoming scarce, and the gradual shift of activity from Texas to Louisiana may continue eastward to Alabama and Mississippi.[34] For 1985 we have projected one core chemical complex for the East South Central region and an additional five by the year 2000.

We expect that several petrochemical complexes will be located in the East North Central regions which will use refinery capacity located there as a source fo petrochemical feedstocks. In the Midwest, there is a large demand for petrochemicals, and environmental constraints are not so pressing as to restrict the development of production facilities to serve the regional market. We expect three new complexes in the East North Central States by 1985, and an additional five by the year 2000, as well as a complex in the neighboring West North Central region.

Although we have projected the addition of one petrochemical complex to Puerto Rico's productive capacity in each of the two time periods, this forecast hinges partially on political considerations. The Puerto Rican government's current $2.00 per barrel oil import fee may put companies located there at a disadvantage if it is not renegotiated. Also, because of the Jones Act of 1920, petrochemical producers in Puerto Rico must ship their products to the United States in U.S. vessels, thus adding 42¢ to the shipment costs on a barrel of petrochemical products.[35] In view of the scarcity of suitable mainland sites, we will tentatively hold to our prediction despite these factors, however.

With its declining petroleum and natural gas production and the resultant scarcity of petrochemical feedstocks, its remoteness from major consuming areas, and the growing shortage of prime site locations there, we would expect the Gulf Coast to lose some of its attractiveness as a location for petrochemical complexes. In a 1972 poll taken of 68 petrochemical firms currently located in Texas, the "shortage of feedstocks," and "remoteness from main market area," were rated as the two largest deterrents to future growth in that area. We are forced to project a large amount of petrochemical expansion in the Gulf Coast region in the future, however, because of the constraints on expansion in other regions of the country. There are several factors also contributing to the East South Central region's future attractiveness. As mentioned previously, agglomeration economies play an important role in petrochemical production, and the huge production complex existing in the Gulf Coast provides a ready market and source of raw material for even the most specialized petrochemical intermediates. The accessibility of the region with

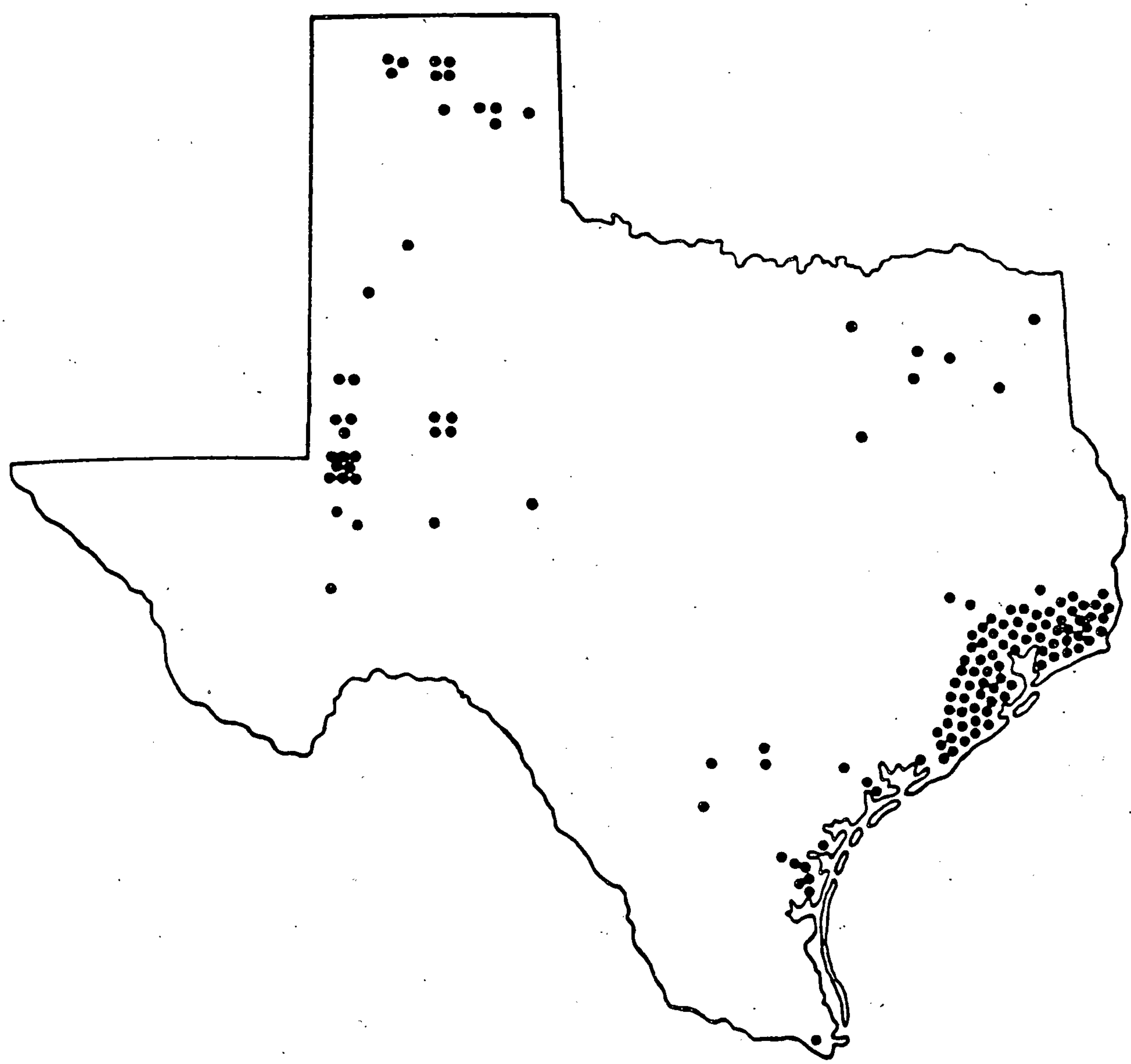

Figure 17. Location of Petrochemical Plants in Texas

Source: Norman C. Whitehorn, <u>Economic Analysis of the Petrochemical Industry in Texas</u>, p. 6, May 1973.

respect to water transport is another factor in its favor. The projected development in the less developed coastal areas (such as Corpus Christi[36]) of deepwater ports to handle oil imports will ensure a source of feedstocks for the future as would the natural gas pipeline tentatively planned to be constructed from Mexico to the Gulf Coast, if it is indeed built.

Thus we find that the strictly economic locational factors influencing the orientation of the petrochemical industry are often outweighed by political, social, and environmental constraints. The uncertainty associated with the latter considerations must necessarily limit the accuracy of any locational projections.

INTERREGIONAL PETROCHEMICAL SHIPMENTS

Theoretically, in a perfectly competitive system, we would expect shipments to be made only from surplus regions (e.g., Puerto Rico and the West South Central by 1985 and also the East South Central by 2000), and not from deficit regions. In actual practice, though, one can expect some cross shipment of petrochemical products between regions. However, since environmental hazards are associated with the shipment of petrochemicals, we forecast that public pressure as well as economic factors will discourage cross hauling to a large extent. On the other hand, because of specialization in petrochemical production we can expect cross hauling to appear in data on aggregate petrochemical shipments, but we are unable to forecast the extent of such specialization. For these reasons, and also for the sake of simplicity, we will adopt the theoretical pattern of shipments. We further assume that Puerto Rican shipments to New England, the Middle Atlantic, and the South Atlantic are in the ratio of 2.0 to 5.0 to 4.5, respectively, for the year 1985, and of 3.5 to 11.0 to 7.0 for the year 2000. For the East South Central region, we assume that approximately one-half its surplus in 2000 goes to the East North Central and one-half to the South Atlantic. Accordingly, Tables 10 and 11 indicate the projected pattern of shipments for 1985 and 2000, respectively.

Table 10
Interregional Petrochemical Shipments, 1985
(interregional shipments are measured in core petrochemical complex* units)

	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific	Puerto Rico	Total regional production
New England	-	-	-	-	-	-	-	-	-	-	-
Middle Atlantic	-	2.7	-	-	-	-	-	-	-	-	2.7
East North Central	-	-	4.5	-	-	-	-	-	-	-	4.5
West North Central	-	-	-	-	-	-	-	-	-	-	-
South Atlantic	-	-	-	-	0.9	-	-	-	-	-	0.9
East South Central	-	-	-	-	-	0.9	-	-	-	-	0.9
West South Central	1.6	4.3	5.6	3.0	4.6	1.6	4.0	0.5	0.2	-	25.4
Mountain	-	-	-	-	-	-	-	-	-	-	-
Pacific	-	-	-	-	-	-	-	-	2.3	-	2.3
Puerto Rico	0.4	1.0	0.9	-	-	-	-	-	-	-	2.3
Total regional demand	2.0	8.0	11.0	3.0	5.5	2.5	4.0	0.5	2.5	-	39.0

* A core petrochemical complex consists of an olefins plant having a 12-billion-pound per year ethylene capacity and associated derivative units.

Table 11
Interregional Petrochemical Shipments, 2000
(interregional shipments are measured in core petrochemical complex* units)

	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific	Puerto Rico	Total regional production
New England	-	-	-	-	-	-	-	-	-	-	-
Middle Atlantic	-	4.6	-	-	-	-	-	-	-	-	4.6
East North Central	-	-	9.1	-	-	-	-	-	-	-	9.1
West North Central	-	-	-	0.9	-	-	-	-	-	-	0.9
South Atlantic	-	-	-	-	3.7	-	-	-	-	-	3.7
East South Central	-	-	0.5	-	0.5	4.5	-	-	-	-	5.5
West South Central	3.0	9.8	9.4	4.6	5.7	-	7.0	1.0	1.0	-	41.5
Mountain	-	-	-	-	-	-	-	-	-	-	-
Pacific	-	-	-	-	-	-	-	-	5.5	-	5.5
Puerto Rico	0.5	1.6	-	-	1.1	-	-	-	-	-	3.2
Total regional demand	3.5	16.0	19.0	5.5	11.0	4.5	7.0	1.0	6.5	-	74.0

* A core petrochemical complex consists of an olefins plant having a 12-billion-pound per year ethylene capacity and associated derivative units.

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