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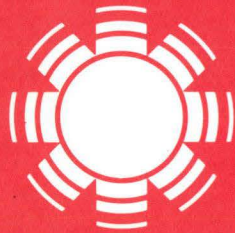
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Biomass Feedstocks for Petrochemical Markets: An Overview and Case Study

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1617 Cole Boulevard
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Operated for the
U. S. Department of Energy
under Contract No. EG-77-C-01-4042

SERI/TR-734-762

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Printed in the United States of America
Available from:
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price:
Microfiche \$3.00
Printed Copy \$ 6.50

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SERI/TR-734-762
UC CATEGORIES: UC-61,61a

BIOMASS FEEDSTOCKS FOR
PETROCHEMICAL MARKETS:
AN OVERVIEW AND CASE STUDY

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PREFACE

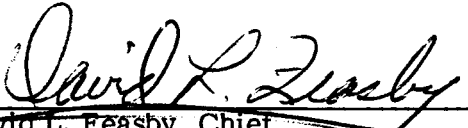
This report is one of a series about biomass substitution in petrochemical feedstock markets. This work was completed under Task No. 3346, Subtask 4, "New Markets for Biomass Feedstocks." The Agriculture Group of the Industrial Applications and Policy Branch, Solar Energy Research Institute, continues its systems engineering and economic studies of agricultural and forestry industry applications for biomass energy conversion. The Group acknowledges the support of the Biomass Energy Systems Branch of the U.S. Department of Energy in this work. The authors also acknowledge the helpful comments of Bert Mason, Marilyn Ripin, and Carl Wallace.



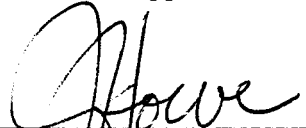
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SUMMARY

Most chemicals manufactured in the United States fifty years ago were made from lignocellulosic (e.g., biomass) materials. Then, the advent of cheap petroleum encouraged technological developments in chemical production. New feedstocks, processes, and products replaced biomass as the major chemical building block. However, recent increases in petroleum and natural-gas prices justify a reexamination of lignocellulosic materials as potential chemical feedstocks. This report represents a first step in evaluating biomass as a potential substitute in petrochemical feedstock markets.

Goldstein (1979; 1980) has identified three possible mechanisms for biomass substitution in petrochemical markets. The first of these alternatives involves the direct use of natural polymers and fibers rather than synthetic varieties. The second method of substitution involves the use of alternative feedstocks to produce the identical chemicals for their current final uses. The third method involves development of natural products to replace some of the intermediate products currently used in petrochemical markets. Intermediate products do not necessarily have to be identical to their potential substitutes. In addition, once the competitiveness of the intermediate product is determined, the relative competitiveness of its derivatives with petroleum products can also be ascertained.

Goldstein has also noted that "there is no technical barrier to the production of almost all petrochemicals, whether oxygenated aliphatics, aromatics, hydrocarbons, or chlorinated compounds, from biomass" (1980, p. 26). Given the technical feasibility of deriving most chemicals from biomass, the focus of petrochemical studies at the Solar Energy Research Institute (SERI) has been to identify high potential markets for biomass chemicals given current (albeit ancient for the chemical industry—50 years or more in some cases) technology and average prices for petroleum and natural gas feedstocks.

Even if all petrochemicals were obtained from biomass, the total reduction in U.S. energy would be small. Petrochemicals are much more important than their aggregate Btu content suggests, because:

- petrochemicals represent high-value markets that make biomass feedstocks economically feasible now;
- many biomass-to-petrochemical conversion processes are well-known and available for immediate application;
- some petrochemical uses may displace more than their "Btu equivalent" from petroleum;
- petrochemicals represent a "first market" for industry which involves them in biomass conversion; fuel production may then follow.

The case study contained here focuses on substitution possibilities for the production of methanol, an intermediate product. The case study for methanol reveals that its single largest use is in the production of formaldehyde, which, in turn, is used primarily in the production of thermoset resins and glues. These resins are used primarily by plywood and particleboard manufacturers who have substantial supplies of wood-waste materials. The demand for glues and resins closely follows the demand for wood products and the housing cycle. Thus, when plywood and particleboard supplies increase, so do supplies of wood-waste materials for manufacturing resins and glues. Costs of biomass methanol and derivatives are competitive with natural-gas-based products; market development activities are encouraged.

In addition to the case study, this report also includes petrochemical price forecasts provided by a consultant—the Pace Company of Houston, Texas. The price forecasts in Appendices A and B were prepared under subcontract to SERI to be used only as a baseline for future comparisons of biomass- and petroleum-derived chemicals. SERI neither endorses nor refutes any claims made by the Pace Company; rather, the report is designed to provide the insights and impressions of a chemical industry leader. In addition to the price forecasts, valuable material is presented which describes relationships of refiners and chemical firms and some impacts to be anticipated from their close ties.

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SECTION 1.0

INTRODUCTION

Fifty years ago, many chemicals manufactured in the United States were made from biomass (lignocellulosic) feedstocks, primarily wood. Products included silvichemicals, tanning agents, wood methanol, and latex rubber. Relatively cheap petroleum supplies, however, prompted an almost complete shift toward production of chemicals from petroleum. But recent increases in petroleum and natural gas prices warrant a re-examination of lignocellulosic materials as potential substitutes for petrochemical feedstocks. This paper proposes a first step in this process, by assessing the economic feasibility and market implications of alternative processes of producing one major chemical, methanol, from biomass. Methanol is chosen for our first case study because it is made from natural gas with a well-known and relatively uniform technology; no significant joint-product cost allocations are required. Today, methanol is made primarily from natural gas, but the general method of assessment that follows can apply to petroleum-derived chemicals as well. Natural gas is emphasized to simplify these comparisons. Cost summaries of methanol from coal and biomass are provided as alternatives to natural-gas feedstocks.

Goldstein (1979) has identified three possible mechanisms for biomass substitution in petrochemical markets. The first of these alternatives involves the direct use of natural polymers and fibers rather than synthetics. The second method of substitution involves the use of alternative feedstocks (e.g., biomass, coal) to produce identical chemicals. The third method proposes development of natural products to replace some intermediate products currently used in petrochemical markets. Intermediates do not necessarily have to be identical to their potential substitutes. This study examines substitution possibilities for the production of methanol, an intermediate product.

Intermediate products are examined here because natural polymers and fibers may require an adjustment in current consumption habits and marketing practices. Using biomass feedstocks in existing facilities may be quite expensive because the geographic location of existing plants does not usually coincide with the location of inexpensive biomass supplies. However, the production of basic chemical feedstocks (methane, butane, methanol, and other intermediates) could significantly reduce petroleum use.

Intermediate chemicals could be manufactured near low-cost biomass resources and transported to be remanufactured into higher-value chemicals. Cost savings can be substantial, since intermediates, rather than low-value raw feedstocks, are being transported. Also, examination of intermediate products broadens the market analysis relative to a narrow focus on one of the thousands of final petrochemical products. The entire petrochemical market can be summarized by looking at 10 or 20 intermediates.

To examine the feasibility of methanol uses, we compare costs of alternative feedstocks, the geographical distribution of production and consumption, and other market factors. New trends in refining and their impact on petrochemicals are examined. Since gasoline makes up the largest fraction of refinery output, supply and demand trends for vehicular fuels are also included. Every case study that follows will identify substitutability and complementarity with transportation fuels. These factors are discussed in detail in Appendix A.

This report is divided into five sections and three appendices. Following are a discussion of market factors and assumptions, an overview of the relationship between refining and petrochemical producers, methanol production costs, and conclusions. The report is a general petrochemical overview and case study of methanol. The appendices present general material for market assessments of several petrochemicals. Appendix A contains an overview of petrochemical supply and demand trends. Price and cost forecasts for major petrochemicals are presented in Appendix B. Appendix C contains a description of coal and biomass gasification technology.

This report was originally intended to be the first in a series of case studies. A substantial amount of time was devoted to developing a research method for assessment and gaining an understanding of the industry. This study's limited coverage could be extended, for a wider application of the method. In addition, an important criterion in examining petrochemicals is potential to replace imported oil. Because of the many chemicals and joint-product allocations of specific crude types, SERI subcontracted development of a substitution model, PETRONET, to estimate potentials for reducing oil imports through chemical production from biomass feedstocks. This model is unique and especially valuable to justify programs for producing chemicals from biomass. Because of 1981 funding problems, however, results of PETRONET simulations have not yet been published.

SECTION 2.0

MARKET FACTORS AND ASSUMPTIONS

2.1 METHANOL PRODUCTION AND CONSUMPTION

Almost all chemical-grade methanol now produced in the United States—about 500 million gallons—is made from natural gas and is used in the petrochemical, paint, and allied product industries. Conversion of natural gas occurs by reacting methane (natural gas) with steam to yield a syngas, which is reformed into methanol and carbon dioxide in the presence of a suitable catalyst. Approximately 95 ft³ of natural gas are required to make one gallon of methanol for feedstock and fuels (Chemical Engineering 1979). At this average rate, 1978 methanol production required 92.3 billion ft³ of natural gas, approximately 0.086 quad.*

The current installed capacity for methanol production is 1391 million gallons per year in 10 plants owned by 8 petrochemical firms. Effective capacity use among these plants is about 94% (Chemical and Engineering News 1979). Operational capacity, as defined in the industry, is currently higher than historical rates because two additional plants with a combined annual capacity of 137 million gallons are on standby.

Historically, the demand for methanol closely follows business cycles for housing starts (Chemical and Engineering News 1978). Presently, over 40% of total methanol sales goes to feedstocks for formaldehyde. Approximately 60% of formaldehyde production is used as a feedstock for the thermoset resins: urea-formaldehyde, melamine-formaldehyde, and phenol-formaldehyde. These thermoset adhesives are used in large quantities for plywood and particle board production. Other uses for formaldehyde include the manufacture of butanediol, acetal resins, and fertilizer.

Table 2-1 presents current uses of methanol. Formaldehyde manufacturing, our focus here, accounts for 42% of total use. Most uses of methanol are expected to grow at an annual rate of 5%–6% through the 1980s (Chemical Marketing Reporter 1980). Large growth in methanol demand is expected if producers and consumers accept methyltert-butyl ether (MTBE) on a large scale as an octane booster for gasoline. By 1985, the annual methanol demand for fuel blending may reach 180 million gallons per year, over twice the current levels of methanol consumed in this market (Oil and Gas Journal 1980).

2.2. AN APPROACH FOR MARKET ASSESSMENTS

The feasibility of producing substitutes in petrochemical markets depends on the perspective of the potential biomass chemical producer, product homogeneity, technology, feedstocks' costs, current capacity, conversion costs, and whether marginal cost or average cost comparisons are made. The potential producer's perspective depends in part on whether that producer is a buyer or seller in feedstock, intermediate, or final-product markets. Our perspective is that of the methanol buyer for purposes of manufacturing formaldehyde.

*One quad = 1.0×10^{15} Btu. The lower heating value of natural gas, 932 MBtu per million ft³, is assumed.

Table 2-1. Forecasted Percentage Uses of Methanol for 1980

| | % | Gallons (millions) |
|------------------------------------|-------------|-----------------------|
| Formaldehyde | 42.0 | 480.5 |
| General process solvents | 10.0 | 114.4 |
| Acetic acid | 7.0 | 80.0 |
| Methyl halides | 7.0 | 80.0 |
| Methyl amines | 5.0 | 57.2 |
| Methyl methacrylate | 5.0 | 57.2 |
| Dimethyl terephthalate (DMT) | 4.0 | 45.8 |
| Methyl tertiary butyl ether (MTBE) | 5.0 | 57.2 |
| Miscellaneous | 7.6 | 86.8 |
| Export Market ^a | 7.4 | 84.8 |
| Totals | 100% | 1144.0 |

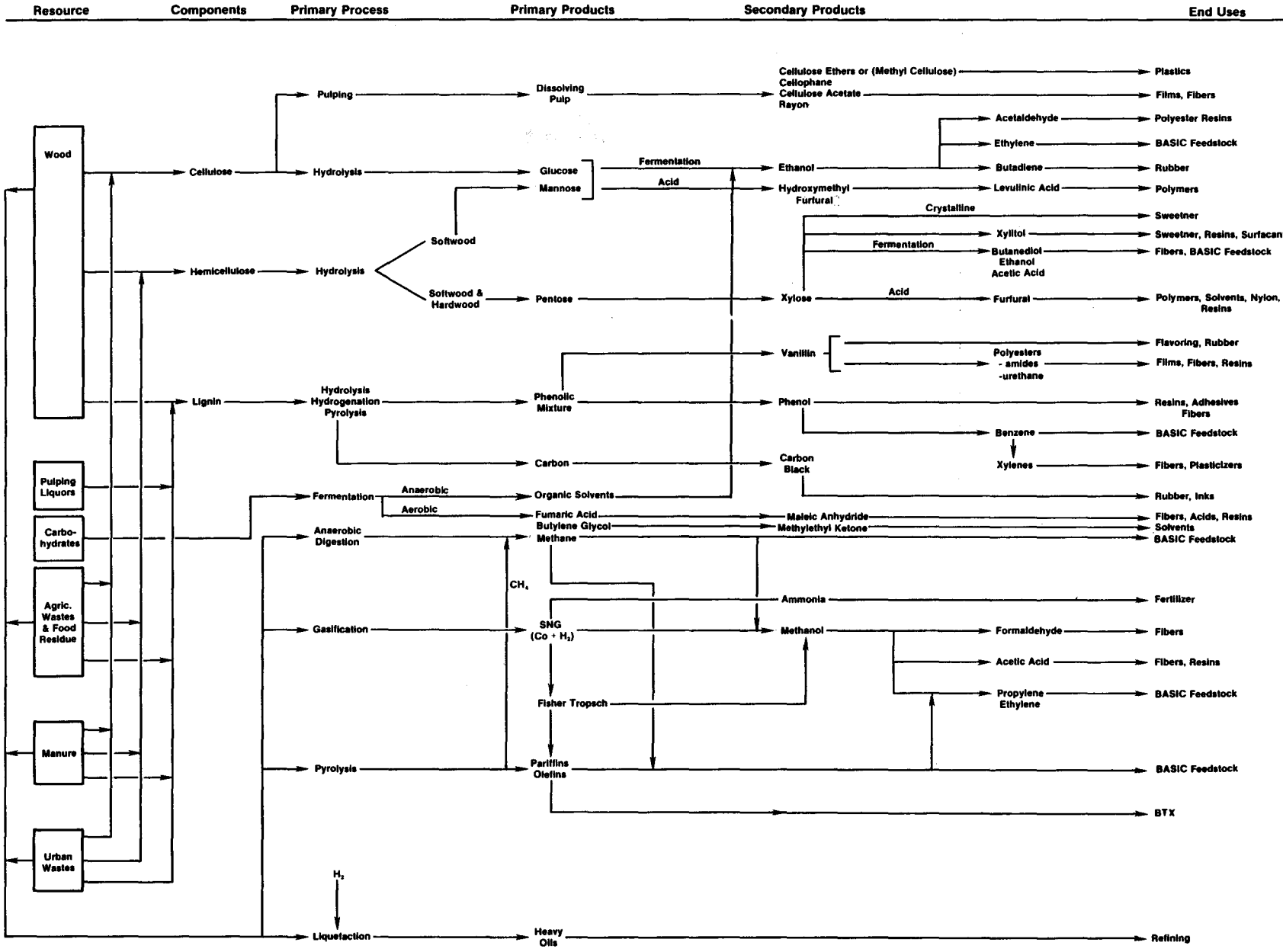
Source: Chemical Marketing Reporter 1980.

^a1976 export figure estimated from data in Kline Guide to the Chemical Industry, 3rd ed. (1977); p. 66.

Figure 2-1 illustrates several of the primary, intermediate, and final products from biomass conversion. To limit the number of intermediate products analyzed, we employed the following procedure. First, any secondary or final product in Fig. 2-1 can be selected for a starting point. Second, the precursors of this chemical are examined. If a precursor is bought and sold in active markets, the precursor and not the derivative product should be the focus of the analysis. The second step is repeated until the first precursor with a market (the principal marketed precursor, PMP) is identified. The rationale for this approach is that any derivative product that has a precursor with an established market can be produced with a known technology and costs similar to the same product manufactured from petroleum or natural gas. By identifying principal precursors of each intermediate product, the number of case studies for examination is limited to the first chemicals in a product stream (Fig. 2-1) for which costs and prices can be examined from a historical perspective. From Fig. 2-1, other principal marketed precursors that appear to be candidates for future examination are listed in Table 2-2. Long-term supply and demand trends for these PMPs from conventional feedstocks are presented in Appendix A. Cost and price forecasts for conventional feedstocks are presented in Appendix B.

2.3 ASSUMPTIONS

In 1978, the petrochemical industry's feedstock demand for oil and gas hydrocarbons was about 4.5% of total U.S. consumption, up from 3.5% in 1973. The chemical industry's reliance on petroleum feedstocks has created a highly competitive, yet symbiotic, relationship with the petroleum refining industry. This interrelationship is critical in determining the feasibility of producing chemicals from alternative feedstocks and is discussed in detail separately in Sec. 3.0.



Source: Adapted from National Academy of Sciences (1976)

Figure 2-1. Major Resources, Conversion Processes, Products and End Uses of Biomass Refining Processes

Table 2-2. Examples of Principal Marketed Precursors

Fatty acids (e.g. propionic, lactic, acetic, fumaric and citric acids)^a
Ammonia
Butanediol
Carbon Black
Ethanol
Furfural
Glycerol
Methane
Methanol
BTX (Benzene, Toluene, Xylene)
Phenols
Vanillin
Propylene and Ethylene

^aMany fatty acids are currently derived from biomass feedstocks.

In addition to their relationships with refiners, chemical companies are closely associated with crude or natural gas producers. In 1978, the top 15 petrochemical companies included 5 oil companies having chemical sales totaling \$10.6 billion (Chemical and Engineering News 1979). Chemical sales for 24 of the largest U.S. oil companies accounted for 16% of total petrochemical sales during 1978 (Lurie 1978). Long-term contracts predominate in the industry, with relatively few buyers and sellers. Acceptance of alternative feedstocks may be inhibited by existing agreements and the inherent difficulty in negotiating for biomass feedstocks from many suppliers. This paper examines feasibility in the absence of these barriers and assumes zero transactions and search costs.*

Another major assumption in the principal marketed precursor approach is product homogeneity. Although methanol from natural gas will have uniform qualities, methanol from coal and biomass feedstocks contains many different chemicals in varying proportions which may be removed only by special scrubbing equipment. Additional processing usually implies higher product cost. A multiproduct producer of intermediates is expected to maintain certain levels of quality and must be concerned with downstream effects on his own and his customer's products. The intermediate product consumer can keep costs down by ignoring impurities that do not affect the principal product or downstream processes. We assume here that no impurities must be removed from methanol.

In the cost comparisons that follow, there are substantial differences in scale among natural gas, coal, and biomass facilities; scale factors are not identified. In addition, the comparisons are based on 1980 technology; no extrapolations based on future technologies are made.

*At a minimum, feasibility analyses would require substantial efforts to sort out regional dependencies and their effects on feasibility.

2.4 PRICES, FEEDSTOCK COSTS, CAPACITY, AND EXPORTS

In general, the prices of petrochemicals follow the costs of their feedstocks. When higher demands create market growth, producers determine a minimum sale price to sustain production based on feedstock and processing costs. Contracts for feedstocks and products are made for varying periods of time, and firms either increase the use of existing production capacity or add new capacity to meet new commitments. Reductions in demand are often absorbed by lower operating capacities rather than capacity retirement.

Processing costs are relatively uniform within a subindustry because the technology is advanced and adopted rapidly in the production of petrochemicals. However, feedstock costs vary widely and may represent a large percentage of end-product cost. Feedstock cost differences can be illustrated by looking at methanol production from natural gas.

Natural gas is sold in regulated and unregulated interstate markets, but methanol's price is not regulated. Those firms with cheap, long-term contracts have an obvious cost advantage over firms that must pay unregulated gas prices. Firms that pay the highest feedstock costs, and still manage to sell their product, typically set a minimum acceptable price for the next chemical producer to renew his contract prices. Old contracts up for renewal follow the most recent price movements—usually upward, nominally.* If feedstock costs are rising faster than product prices, short-run losses can be absorbed. However, production cannot be sustained if average variable cost (AVC) is greater than product price.** Firms with the highest AVC are, in our example, those producers who must purchase unregulated natural gas.

The treatment of fixed cost is an important consideration for the production of methanol. Fixed costs are "sunk" costs and ignored when a firm minimizes short-run losses. Two methanol (from natural gas) plants are currently on standby for immediate production (Chemical Marketing Reporter 1980). Initially, alternative feedstock products must compete for contracts with these two plants, for which substantial fixed costs are sunk. Products from biomass and coal feedstocks cannot be marketed when their prices exceed the marginal cost of products from conventional feedstocks, unless demand for new supplies exceeds conventional capacity and a higher market equilibrium price is then established. If production from alternative feedstocks has the highest average variable costs, the alternatives will be most susceptible to slack demand and increasing feedstock costs.

Slack capacities and the sunk costs of existing natural gas plants may become increasingly important if U.S. petrochemical exports fall. U.S. industry exported about \$17 billion in chemical products in 1979, principally to Western Europe, Latin America, and Japan. This volume of exports is due largely to differences in petroleum feedstock costs between the U.S. and importers of U.S. chemical products (Chemical and Engineering News 1979). U.S. feedstock costs are based on the weighted average costs of regulated and deregulated domestic oil and natural gas and imported oil and gas. Foreign petrochemical concerns pay the higher import prices for all their feedstocks. This price advantage is expected to decline substantially as the U.S. industry is deregulated. This

*Nominal prices fluctuate, but the predominant direction has been upward in the last 10 years (Lowenheim and Moran 1975).

**Interpreting prices for feasibility is very difficult since most chemicals are joint products and no satisfactory method of allocating joint costs has been identified.

will make more domestic capacity available for domestic use. Exacerbating the idle capacity dilemma facing biomass entry into feedstock markets is higher idle capacity and production from lower marginal cost plants. New alternative feedstock plants must compete with the marginal cost of using existing idle capacity, which is probably lower than short-run or long-run average costs of new facilities using alternative sources.

Imports have not been a major factor in U.S. methanol production and consumption. However, Saudi Arabia and other major oil producers are building giant natural gas-to-methanol plants to develop markets for natural gas currently being flared. Methanol has several safety advantages relative to LNG; methanol consumption is expected to grow substantially, especially in transportation fuels markets.

SECTION 3.0

REFINING/PETROCHEMICAL OVERVIEW

3.1 INTRODUCTION

The refining and petrochemical industries in the United States developed independently until 1960. After that they drew much closer, following the major transitions in basic energy availability and costs that began to occur in the mid-1970s. Terms such as "chemical refinery" and "refinery-petrochemical synergism" have become common. As the following discussion of market structure suggests, interrelationships between the two industries are virtually certain to continue to grow because of feedstock supply dependencies.

The U.S. petrochemical industry was built mainly around natural gas and liquefied petroleum gases (LPGs)—ethane, propane, and butanes—extracted from gas. The availability and low costs of these materials, coupled with leading technology and economies of scale, were responsible for the United States' dominant world position in the petrochemical industry. Chemical companies concentrated their efforts on basic research, product development, manufacturing efficiency, and marketing. Raw materials, fuel availability, and costs were not major concerns.

Today, the situation is very different. Natural gas and LPGs for petrochemical manufacture are still available. Chemical companies must now compete for raw material supplies with the transportation fuels market, resulting predictably in much higher prices. Now, industrial planners must be concerned with the depressing influence of higher final-product prices on demand.

The changing natural gas/LPG situation has forced the petrochemical industry to look to other feedstock supplies. Crude-oil-derived products are perceived to be the only immediate alternative. Coal and biomass are receiving increasing attention, but construction lags and regulatory constraints appear to prohibit large-scale contributions before 1989. Thus, chemical companies must become involved, directly or indirectly, with the refining industry to ensure their feedstock supplies. The petrochemical industry no longer has the option of planning and operating independently of the oil industry.

Petrochemicals have become favorite products in oil company diversification, mainly because of the feedstock tie-in. However, current oil industry moves into petrochemicals are much different from rather ill-fated inroads into fertilizers and fibers that occurred in the fifties and sixties. Many of the large oil companies have demonstrated that the traditional chemical companies (DuPont, Dow, Union Carbide, Monsanto, etc.) no longer control chemical processing technology development. The oil industry has come to view chemicals as an integral part of their business rather than merely as an outlet for their products.

The enormous capital requirements of large-scale petrochemical facilities (costs approached \$1 billion for one ethylene plant in the 1980s) preclude all but the very largest chemical companies from undertaking major new projects. Oil companies make investments of this magnitude. In addition, when the overall benefits of refinery-olefins plant integration are taken into account, the economics are usually more attractive.

Refinery/petrochemical integration is accomplished by three broad means: (1) forward integration by oil companies, (2) backward integration by chemical companies, and (3) joint ventures. In recent years, some companies have used both joint ventures and forward or backward integration. Also, straight purchase/sales arrangements among chemical and oil companies are common. The following brief discussions summarize, with examples, the three principal forms of integration.

3.2 INDUSTRY INTEGRATION

3.2.1 Forward Integration by Oil Companies

Oil companies have been involved in petrochemical production in varying degrees for about fifty years. Their total share of the business was minor until the 1960s when they were attracted by growth rates higher than those for fuels and by new profit potential. Many initial large-scale ventures, especially in ammonia and fertilizers, were not successful. In fact, the oil companies were accused of destroying markets through overbuilding capacity and initiating price wars. The validity of these charges is still being debated. Nevertheless, the oil companies' early advances into petrochemicals were met with suspicion, animosity, and a degree of fear by some in the established chemical industry. A Chemical Week story published in 1962 noted that "most chemical men look on the refiners as a plague of wealthy locusts."

Some still share this attitude, but in the last two decades chemical executives have developed a respect for oil companies as tough competitors, reliable suppliers, and, in some cases, customers or partners. Oil companies have gone beyond producing basic building blocks and intermediates and are now firmly geared to commodity plastics. Some have moved into fabricated products, though generally not to the extent of the chemical companies.

The summary shown in Table 3-1 illustrates the extent of oil companies' thrust in chemicals. Almost without exception, oil companies have increased their participation in markets for the products listed since 1974. We anticipate that this trend will continue because of little or no growth in traditional fuels markets and a logical tie-in through feedstocks and refinery/olefins plant synergism.

Other indications of oil company involvement in chemicals are sales and earnings, as shown in Table 3-2. Chemical sales were consistently higher in 1978 than in 1977, but earnings were very erratic. Some of this may be attributable to intracompany transfers or other practices. Chemical sales are generally a small part of an oil company's total sales, but they are large compared with chemical companies. DuPont, the largest chemical company, had 1978 sales of \$10.6 billion and only three others (Union Carbide, Dow, and Monsanto) had total sales in chemicals higher than Exxon's \$4.7 billion.

3.2.2 Backward Integration by Chemical Companies

There has been very little movement toward independent refining of basic raw materials by chemical companies. The enormous expense involved cannot be justified by smaller companies; securing a long-term supply of crude oil is difficult if not impossible.

Table 3-1. Oil Companies' Share of Petrochemical Capacity

| | 1974 | | | 1978 | | |
|---------------------------|---------------------|--------------------------------------|---------------------------------------|---------------------|-------------------------|---------------------------------------|
| | Number of Producers | Number of Oil Companies ^a | Percentage Share of Industry Capacity | Number of Producers | Number of Oil Companies | Percentage Share of Industry Capacity |
| Plastics | | | | | | |
| High-density polyethylene | 12 | 4.5 | 32.8 | 12 | 5.5 | 39 |
| Low-density polyethylene | 12 | 4.5 | 27.7 | 13 | 5.5 | 33 |
| Polypropylene | 9 | 4.0 | 51.6 | 12 | 6.0 | 56 |
| Polystyrene | 19 | 3.0 | 22.2 | 16 | 5.0 | 31 |
| Polyvinyl chloride | 23 | 2.0 | 10.6 | 22 | 2.0 | 10 |
| Organic Chemicals | | | | | | |
| Acetone | 13 | 5.5 | 35.2 | 13 | 5.5 | 43 |
| Acrylonitrile | 4 | 1.0 | 24.5 | 4 | 1.0 | 18 |
| Alkylbenzene, linear | 4 | 1.0 | 31.9 | 4 | 1.0 | 37 |
| Benzene | 32 | 24.0 | 79.8 | 33 | 26.5 | 85 |
| Cumene | 12 | 10.0 | 63.5 | 14 | 11.0 | 61 |
| Cyclohexane | 9 | 8.0 | 97.4 | 9 | 8.0 | 98 |
| Ethylene | 23 | 10.5 | 42.5 | 25 | 12.0 | 57 |
| Ethylene glycol | 11 | 2.5 | 10.7 | 11 | 2.5 | 12 |
| Isopropanol | 4 | 3.0 | 63.6 | 4 | 3.0 | 75 |
| Ortho-xylene | 12 | 9.0 | 86.3 | 12 | 9.0 | 87 |
| Para-xylene | 11 | 9.5 | 86.5 | 11 | 9.0 | 87 |
| Phenol | 11 | 3.0 | 9.0 | 12 | 4.0 | 21 |
| Phthalic anhydride | 9 | 3.0 | 21.5 | 9 | 3.0 | 18 |
| Propylene | 35 | 23.5 | 68.4 | 35 | 24.0 | 78 |
| Propylene glycol | 5 | 1.5 | 23.9 | 5 | 1.5 | 24 |
| Propylene oxide | 5 | 1.5 | 29.1 | 5 | 1.5 | 29 |
| Styrene | 11 | 4.5 | 27.4 | 10 | 4.5 | 27 |
| DMT | 5 | 1.0 | 10.2 | 3 | — | — |
| TPA | 2 | 1.0 | 80.4 | 2 | 1.0 | 93 |
| Total Terephthalates | 5 | 1.0 | 29.5 | 4 | 1.0 | 46 |
| Vinyl chloride | 10 | 2.0 | 31.7 | 11 | 25.0 | 22 |

^aIncludes joint ventures.

Table 3-1. Oil Companies' Share of Petrochemical Capacity (Concluded)

| | 1974 | | | 1978 | | |
|----------------------------|---------------------|--------------------------------------|---------------------------------------|---------------------|-------------------------|---------------------------------------|
| | Number of Producers | Number Of Oil Comapnies ^a | Percentage Share of Industry Capacity | Number of Producers | Number of Oil Companies | Percentage Share of Industry Capacity |
| <u>Inorganic Chemicals</u> | | | | | | |
| Caustic soda | 23 | 3.0 | 10.6 | 25 | 3.0 | 10 |
| Chlorine | 30 | 4.5 | 11.6 | 32 | 4.5 | 11 |
| Soda ash | 8 | 1.0 | 3.5 | 6 | 1.0 | 7 |
| Sodium tripolyphosphate | 6 | 2.0 | 18.2 | 6 | 2.0 | 15 |
| Titanium dioxide | 6 | 1.00 | 6.0 | 6 | 1.0 | 6 |
| <u>Fertilizers</u> | | | | | | |
| Ammonia | 58 | 12.5 | 31.9 | 65 | 21.5 | 28 |
| Ammonium phosphates | 28 | 4.3 | 9.8 | 31 | 3.3 | 10 |
| Phosphate rock | 17 | 4.3 | 15.9 | 19 | 2.3 | 17 |
| Phosphoric acid | 29 | 4.0 | 7.5 | 31 | 4.0 | 8 |
| Potash | 9 | 2.0 | 34.8 | 9 | 2.0 | 32 |
| Urea | 34 | 8.0 | 22.2 | 35 | 6.0 | 18 |

^aIncludes joint ventures.

Source: The Pace Company.

Table 3-2. Oil Companies' Chemical Sales and Earnings

(current million dollars)

| | Sales | | Earnings ^a | |
|---------------------------|----------------------|-------------------------|-----------------------|-------------------------|
| | Total in 1978 | Change from 1977 (%) | Total in 1978 | Change from 1977 (%) |
| Exxon Corporation | 4,653.0 ^b | +11.1 | 268.0 | +20.7 |
| Shell Oil | 2,710.1 ^b | +16.4 | 100.0 | -17.0 |
| Standard Oil (Indiana) | 1,831.6 | +12.6 | 45.5 ^c | +14.8 |
| Gulf Oil | 1,752.0 ^b | +38.8 | 81.0 | + 8.0 |
| Occidental Petroleum | 1,719.4 | + 6.0 | 38.5 ^c | -52.5 |
| Phillips Petroleum | 1,536.0 ^b | + 8.9 | 60.0 ^c | -20.0 |
| Atlantic Richfield | 1,512.0 | +22.4 | 91.0 | +18.2 |
| Mobil Corporation | 1,361.0 ^b | +13.1 | 153.0 | +16.8 |
| Texaco Inc. | 935.9 ^b | + 4.7 | 54.7 ^c | - 7.4 |
| Ashland Oil | 882.9 | +10.4 | 15.7 ^c | +97.4 |
| Standard Oil (California) | 831.0 | +12.0 | 25.0 ^c | -13.8 ^d |
| Tenneco Inc. | 808.0 | — ^d | 54.0 | — ^d |
| Conoco | 680.8 ^b | +35.0 | 61.3 ^c | +12.4 |
| Union Oil of California | 678.1 | +20.9 | 105.2 | +67.2 |
| Cities Service | 415.8 ^b | + 3.5 | 16.0 ^e | -50.2 |
| Kerr-McGee | 375.4 | +16.0 | 37.0 | NA |
| Standard Oil (Ohio) | 327.7 | + 4.1 | 19.7 | -36.7 |
| Northern Natural Gas | 235.3 | + 4.8 | 12.9 ^c | - 2.2 |
| El Paso Company | 206.4 | + 5.3 | 15.7 | -57.5 |
| Houston Natural Gas | 175.6 | + 8.1 | 29.6 ^e | +22.5 |
| American Petrofina | 167.9 | + 3.8 | 22.0 | +47.1 |
| Pennzoil Company | 151.5 | + 5.0 | 34.7 | + 5.7 |
| Getty Oil | 125.5 | - 3.9 | 18.0 | -31.0 |
| Clark Oil | 23.3 | + 2.0 | 6.1 | - 7.2 |
| Total | 24,906.6 | +13.7 | 1,013.2 | - 1.1 |

Sources: Chemical Week; the Pace Company.^aPretax operating income, unless otherwise noted.^bIncluding transfer to the company's other divisions.^cNet after-tax income.^dCompany made significant acquisitions in 1977, 1978; comparable 1977 data not reported.^eIncluding equity in earnings of chemical affiliates.

Dow Chemical, one exception, is nearing the start-up stage of a 200,000-bbl/day refinery (officially called a crude oil processing plant) at Oyster Creek, Texas, adjacent to its Freeport complex. The unit is unique in that it will produce no gasoline. Dow plans to supply full-range naphtha to its new ethylene facility at Plaquemine, Louisiana; use some of the fuels products internally; and market the rest. The project is on schedule and within its construction budget, but crude oil availability is a major problem. Unless Dow elects to buy on the erratic spot market, it will not have all the crude oil it needs. Dow's experience suggests that it is doubtful whether other chemical companies will attempt similar large-scale moves toward a raw material base.*

3.2.3 Joint Ventures

Large-scale joint ventures between oil and chemical companies have become common since the mid-1970s. They take many forms, but usually the oil company provides feedstocks and outlets for olefins plants by-product streams not readily usable for petrochemicals. The chemical company provides established marketing and distribution systems or utilization for existing facilities. Depending on the products, technology and manufacturing expertise can also be provided. Capital and plant operation are usually shared, but there are numerous variations. Examples of joint ventures involving oil and chemical companies are shown in Table 3-3.

Table 3-3. Oil/Chemical Companies' Joint Ventures

| Partners | Project Description |
|--|--|
| Conoco/Monsanto | Olefins/aromatics production |
| ICI/Champlin/Soltex | Olefins production |
| Texaco/USS Chemicals | High-density polyethylene |
| (letter of intent); ethylene under study | |
| DuPont/Shell | Long-term purchase agreement for olefins |
| DuPont/Conoco | Gas Exploration |

Source: The Pace Company.

In addition to these domestic joint ventures, there are many foreign joint ventures in various stages of planning. These are concentrated generally in less developed oil- or gas-rich areas, such as the Middle East, the Far East, and Latin America.

3.3 REFINING OPERATIONS AND PROCESSES

This section is intended to provide a basic understanding of refinery operations for those without background or experience in the industry. Those operations that have the greatest impact on petrochemicals are emphasized.

*Pace Co. observations.

There are nearly 300 refineries in the United States; each has a unique configuration. They process crude oils of diverse origin and properties and produce outputs to meet a multitude of marketing specifications. The information presented is therefore generalized, representing typical rather than actual units.

3.3.1 Crude Oil Distillation

Crude oil distillation, the first step in the manufacture of petroleum products, is the separation of the crude oil into individual streams. Each stream contains many compounds and reaches boiling points within a limited range. There are two broad types of crude oil distillation—atmospheric and vacuum. They usually are used in conjunction with each other.

In the atmospheric tower, the light fractions vaporize in a flash drum and the balance of the crude is raised to a temperature of about 750° F in a fired heater before entering the tower. Here, separation into the desired product boiling ranges takes place, controlled by temperature levels and reflux rates throughout the system.

Vacuum distillation of crude oil is used more frequently as a means to produce low-sulfur fuel oil in the refinery. Desulfurization of vacuum gas oils is less complex and expensive than desulfurization of residues. They are therefore desulfurized and blended with the vacuum bottoms to achieve a low-sulfur, heavy fuel oil pool.

Naphtha and gas oil streams, the major components of gasoline, jet fuel, and home heating oil, are also used as feedstocks to olefins plants. When used as feedstocks, these streams are referred to as "heavy liquids," as opposed to "light" feedstocks; e.g., ethane, propane, and butane. Some of these light petrochemical feedstocks also are produced in the refinery (in the gas stream), but most are extracted from natural gas.

3.3.2 Fluid Catalytic Cracking

This process converts gas oils to lower molecular weight products, such as high-octane gasoline, middle distillates (No. 2 fuel oil, kerosene), and olefins. Charge stock may be straight run, cracked, and extracted gas oils from a wide variety of sources, ranging from light distillates to vacuum distilled gas oils and deasphalted oils. The cracking process is extremely versatile. Product distribution can be varied to meet differing market requirements, and considerable desulfurization of liquid products occurs.

Iso-butane and light olefins (principally propylene and butylenes) are produced in substantial quantities in catalytic cracking. Both are used to produce gasoline alkylate and indirectly have impact on petrochemicals, since propylene and butylenes are also produced in olefins plants. Butylenes produce better alkylate, but propylene has many more petrochemical applications.

Two common designs are the Esso Model 4 "U bend" unit and the riser or transfer line cracker. The charge is mixed with the hot regenerated catalyst entering the single riser, in the simplified designs shown, where cracking occurs. Products are disengaged from the catalyst and pass to the main fractionator, where they are separated into the fractions desired. The required amount of heavy cycle oil is returned to the reactor. The unit may be designed, and older designs modified, to effectively increase the conversion to products lighter than the feed to as high as 95%.

3.3.3 Catalytic Reforming

This process is used primarily to upgrade low-octane naphtha to high-octane gasoline blending components containing significant quantities of aromatic hydrocarbons. Charge stocks may be straight-run or other naphthas boiling in the range of C6-400°F. The charge may be full-range naphtha or selected heart cuts.

A catalytic reforming unit is composed of reaction, separation, and fractionation sections. In the reaction section the charge is contacted with a tailored catalyst, containing platinum and possibly other metals, under the proper conditions for the desired reactions to occur. The principal chemical reactions involved are dehydrogenation of naphthenes to aromatics, dehydrocyclization of paraffins, hydrocracking of high molecular weight paraffins, isomerization of paraffins and naphthenes, and desulfurization of organic sulfur compounds to form hydrogen sulfide.

Catalytic reforming is the principal source of aromatics (benzene, toluene, xylene, or "BTX") in the refinery. They are essential to the petrochemical industry because they cannot be produced in sufficient quantities in olefins plants. The petrochemical industry must compete with gasoline for BTX supplies.

3.3.4 Hydrocracking

This process is used for the conversion of a wide range of hydrocarbon feedstocks to lighter products. Typical charge stocks are naphtha, light and heavy gas oils, vacuum gas oils, cracked and coker gas oils, deasphalted residuum, and topped crude. The refiner has the flexibility to make different product slates that can emphasize high-octane gasoline blendstocks, jet fuel, low pour point diesel, LPG, or low-sulfur fuel oil blendstocks. Hydrocracking has little direct impact on petrochemicals.

3.3.5 Alkylation

This process combines olefins (usually propylene and/or butylenes) with isobutane in the presence of a strong acid catalyst (sulfuric or hydrofluoric) to produce high-octane branched chain hydrocarbons (alkylate) for use in gasoline.

Alkylate production interfaces with petrochemicals as a consumer of propylene and/or butylenes. It has an indirect influence through its octane contribution to the gasoline pool, thus affecting requirements for other octane builders such as aromatics.

3.3.6 Polymerization

Polymerization is used to produce a high-octane gasoline blending component from olefins, typically propylene, butylenes, or mixtures of the two. Volume shrinkage of from 20% to 40% of the feed is the principal drawback. In general, olefins can be better utilized in alkylation units. Polymer gasoline is therefore not a major contributor to today's gasoline pool and does not have a significant impact on petrochemicals.

3.3.7 Other Processes

There are several other processes commonly used in refineries, but they are used to a limited extent or have little impact on petrochemical operations. These processes include:

- Visbreaking—produces fuel oils and a minimum of gasoline from a vacuum residual stream.
- Thermal cracking—produces gasoline from heavier-than-naphtha fractions without use of a catalyst. Extensive recycling is required, however.
- Coking—upgrades a wide range of low-value residual stocks to naphtha, middle distillates, catalytic cracking feedstock, and by-product gas and coke. Conversion of high-sulfur residual reduces sulfur level in the fuel oil pool and reduces the required volume of low-sulfur blendstocks.
- Distillate desulfurization—improves the qualities of a wide range of petroleum stocks by removal of sulfur, nitrogen, and heavy metal contaminants.
- Isomerization—improves the octane rating of pentane and hexane fractions, or both, from refinery naphthas. Butane isomerization converts normal butane to iso-butane.
- Dimerization—produces a gasoline blending component by combining two identical olefin molecules, usually propylene or butylene.

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SECTION 4.0

METHANOL PRODUCTION COSTS

In this section, we address a firm's fixed and variable costs for producing methanol from coal, biomass, and natural gas. Feedstock costs are variable costs but separated in this discussion, because we focus here on the production of intermediate products from biomass and coal. Feedstock cost estimates and their regional differences are discussed first.

4.1 FEEDSTOCK COSTS

A large determinant of the feasibility of supplying methanol from coal or biomass is feedstock costs. Both biomass and coal are expensive to transport, so regional availability will be a primary determinant of feasibility. Figure 4-1 presents a geographical distribution of methanol and formaldehyde production facilities in the United States. All methanol plants are in the Gulf Coast States near natural gas sources, but formaldehyde plants are located principally in the Pacific Northwest, in the Central States along the Mississippi and Ohio Rivers, and on the Eastern Seaboard.* The Pacific Northwest provides access to wood waste feedstocks and agricultural crop residue feedstocks. Formaldehyde plants along the river systems have access to substantial supplies of agricultural feedstocks and hardwood inventories with varying quality and quantities available. All formaldehyde plants along the Eastern Seaboard can obtain agricultural and forestry residues readily. In addition, other states have access to substantial supplies of municipal solid waste (MSW); but because of the diverse content of MSW and the lack of reliable cost data, MSW is not examined here.

Feedstock costs employed in this analysis are presented in Table 4-1. Costs are presented for two types of biomass—wood wastes and agricultural crop residues, and costs for natural gas and coal are also presented. Feedstock costs are developed for three primary formaldehyde-producing states: Oregon, Ohio, and North Carolina. Since agricultural crop residues are not bought and sold in sufficient quantities to report a market price, regionally independent engineering cost estimates are used as a substitute. Costs were lowest for wood waste feedstocks in Oregon (\$0.43/MBtu) and highest for natural gas in North Carolina (\$3.57/MBtu). Agricultural crop residues are more than twice as expensive as wood wastes and coal but cheaper than natural gas, except in Ohio.

Costs for coal and natural gas vary a great deal regionally. Oregon had the cheapest coal (\$0.83/MBtu) and the second least expensive natural gas. Ohio's coal costs were \$0.50/MBtu more expensive than Oregon's, but Ohio had the least expensive natural gas. North Carolina had the most expensive natural gas and coal.

*Conceivably, biomass feedstocks could be transported by barges on river systems to support existing methanol plants. The feasibility of the concept is not examined here. Deregulation of natural gas might result in the movement of plants closer to demand sources.



Figure 4-1. Geographic Distribution of Methanol and Formaldehyde Production Facilities in the United States



Table 4-1. Biomass, Coal, and Natural Gas Feedstock Costs for Chemical Plants—1979

| Resource | Unit | Total Delivered Cost | |
|-----------------------------|-----------------|----------------------|---------|
| | | \$/Unit | \$/MBtu |
| Agricultural ^{a,b} | Tons | | |
| 1) Corn stover | | 29.43 | 2.26 |
| Big round bales | | 27.87 | 2.14 |
| Stacks | | 29.02 | 2.23 |
| 2) Wheat Straw | | 28.49 | 2.19 |
| Wood waste | Unit | | |
| 1) Oregon ^c | | 8.50 | 0.43 |
| 2) Ohio | | 22.00 | 2.20 |
| 3) North Carolina | | 14.00 | 0.70 |
| Coal ^d | Tons | | |
| 1) Oregon | | 13.43 | 0.83 |
| 2) Ohio | | 29.87 | 1.38 |
| 3) North Carolina | | 35.10 | 1.45 |
| Natural gas ^d | ft ³ | | |
| 1) Oregon | | 2.63 | 2.52 |
| 2) Ohio | | 1.16 | 1.76 |
| 3) North Carolina | | 3.70 | 3.57 |

^aDauve and Flaim 1979.

^bBased on 13 MBtu (net) per ton. Costs are not regionally derived because no significant market for crop residues exists. Costs are derived on a regionally independent engineering approach and include harvesting costs (about \$16/ton), a \$10/ton fee to the farmer, and transportation and materials handling charges (\$2.50/ton for a 10-mile harvest radius). English et al. (1980) report costs that include \$7.50 for harvesting and \$0.09 per ton-mile for a hauling radius of 10 miles.

^cBased on an \$8.50 cost/unit. (1 unit = 200 ft³, at 53% moisture content wet basis and 20 MBtu/unit (net).)

^dFebruary 1979 average delivered prices that represent large-quantity, long-term contracts with steam electric power plants (DOE/EIA 1979).

Table 4-2. Comparison of Methanol Product Costs with Biomass, Coal, and Natural Gas Processes

| | Methanol Reforming | Koppers Totzek | Improved Gasification | Koppers Totzek & ICI | Wellman Glausha & ICI | Purox & ICI |
|---|--------------------|------------------|-----------------------|----------------------|-----------------------|----------------|
| <u>Feedstock</u> | <u>Natural gas</u> | <u>Coal</u> | <u>Coal</u> | <u>Biomass</u> | <u>Biomass</u> | <u>Biomass</u> |
| <u>Plant Capacity (tons/day output)</u> | 2000 | 2000 | 2000 | 535 | 450 | 386 |
| <u>Fixed Costs</u> | | | | | | |
| (1) Investment (in millions) ^a | | | | | | |
| (i) On-site | \$ 87.9 | \$ 206.1 | \$ 175.2 | \$ 100 | \$ 73.6 | \$ 86.4 |
| (ii) Off-site | 47.4 | 144.3 | 134.9 | 29.9 | 22.0 | 75.7 |
| Total | 135.3 | 350.4 | 310.1 | 130.1 | 95.6 | 112.1 |
| \$/ton of yearly capacity | (254) | (480) | (424) | (666) | (582) | (795) |
| (2) Annual maintenance and capital charges ^b (\$M) | 31.1 | 77.1 | 68.2 | 28.6 | 21.0 | 24.7 |
| \$/ton of yearly capacity | (43) | (105) | (93) | (146) | (127.0) | (175) |
| <u>Variable Costs</u> | | | | | | |
| (1) Feedstocks ^c (\$/MBtu) | \$2.00-3.57 | \$0.83-1.45 | \$0.83-1.45 | \$0.43-2.26 | \$0.43-2.26 | \$0.43-2.26 |
| (2) Operations and Labor (\$M) | 24.0 | 49.0 | 41.1 | 1.98 | 1.66 | 1.4 |
| \$ Per-unit capacity | (33.0) | (67.0) | (86.0) | (10.0) | (10.0) | (9.9) |
| (3) Working capital ^d (\$M) | (13.6) | (5.2) | (4.9) | (11.3) | (8.3) | (9.8) |
| (4) Sulfur credit (\$M) | | 1.9 ^e | 1.8 | | | |
| <u>Net Production Costs</u> | | | | | | |
| (\$/ton) | 146.8-211.3 | 221.8-246.2 | 194.3-217.1 | 205.2-277.9 | 171.7-250.8 | 227.1-319.4 |
| (\$/gal.) | .48-.69 | .73-.81 | .64-.71 | .68-.92 | .56-.82 | .75-1.05 |

^aInvestment costs were taken from Wan 1979.

^bMaintenance and capital charges were estimated at 22% of plant costs, except for natural gas, which was assessed to equal 23%.

^cRanges from Table 4-1.

^dCapital charges for working capital included in annual maintenance and capital charges.

^eInvestment costs include capital for scrubbers; credit is derived from sulfur sales at \$50 per ton.

4.2 FIXED AND VARIABLE COSTS OF METHANOL PRODUCTION

Fixed and variable costs for methanol production from natural gas, coal, and biomass processes are summarized in Table 4-2. Plant capacities vary widely; total investment ranges from \$95 million for biomass to \$350 million for coal. The investment per unit of capacity, measured in tons of methanol output per year, vary from \$254/t for natural gas to \$795/t for biomass. Maintenance and capital charges range from a low of \$21.0 million for biomass to \$77.1 million for coal. Maintenance and annual capital charges represent fixed or sunk costs for existing plants. Feedstock costs ranged from \$1.4 million for biomass to \$64.2 million for coal; operations and labor charges per unit of capacity (output) were lowest for natural gas and highest for biomass. Coal operations costs are higher than for biomass or natural gas.*

Cost data sources and assumptions are outlined in detail by Wan (July 1979, Vol. III). Equipment designs and costs are based on subcontractor reports to Science Applications, Inc., including equipment manufacturers and engineering design groups. A standard discounted cash flow approach was employed. The only assumption that differs considerably from today's market conditions is a 9% annual interest rate on debt assumed for 1979. We have chosen not to change this assumption but we realize the sensitivity of capital intensive projects to changes in interest rates. A comparison of cost estimates from several studies is provided in Table 4-3.

*See Wan (1979) for detailed explanations of costs and assumptions regarding their derivation.

Table 4-3. Comparison of Biomass to Methanol Costs

(1979\$)

| Source | Methanol; S. Tons/day | Biomass; ODT/day | Gasifier Type | Capital ^a Invest- ment; \$/gallon | Operat- ing Costs; \$/gallon | Product Cost (with- out feed- stock); \$/gallon |
|------------------|--------------------------|---------------------|------------------|---|------------------------------------|---|
| SAI | 1000 | 2860 | Purox | 0.49 | 0.08 | 0.57 |
| ICE ^b | 1000 | 2300 | Purox | 0.58 | 0.08 | 0.66 |
| MITRE | 670 | 1700 | Purox | 0.33 | 0.06 | 0.39 |
| MITRE | 1340 | 3400 | Purox | 0.25 | 0.05 | 0.30 |
| SRI ^c | 570 | 1000 | Purox | 0.35 | 0.14 | 0.40 |

Source: Wan 1979.

^aAll capital charges are reduced to the same basis—24% of total investment.

^bICE is Intergroup Consulting Economists.

^cSRI's methanol conversion efficiency is approximately 50% higher than other estimates.

SECTION 5.0

CONCLUSIONS

Cost comparisons of methanol from natural gas, coal, and biomass presented in this report are based on regional differences in feedstock costs and specific process costs for each feedstock. Biomass-derived chemicals appear economically feasible, but a strict determination of least-cost production alternatives cannot be made because of regional dependencies and details that are beyond the scope of this analysis. Biomass products are more capital intensive per unit of output, but coal and natural gas plants are far larger and are scaled for investment three times greater than biomass processes. Smaller plants allow siting near diverse biomass feedstock sources.

Marketing considerations are at least as important as feedstock and process costs in an evaluation of emerging petrochemical technologies. We have noted how long-term contracts with few buyers and sellers may act as a deterrent to accepting alternative feedstocks. In addition, product homogeneity, existing capacity, and net export capacity effects were identified as important parameters. Long-term contracts for inexpensive natural gas presents a substantial cost disadvantage for biomass feedstocks. As new contracts are renegotiated under deregulation, this disadvantage may decrease.

The future market for methanol is expected to grow quite rapidly despite rising prices for natural gas feedstocks. Growth in the market for fuel blending agents is expected to arise from legislated standards prohibiting the use of lead. The growth in market demand for methanol is expected to exceed current capacity even if new exports fall.

Two additional considerations should be mentioned. The first relates to comparing single-product alternative processes with joint products from conventional processes. The feasibility of any alternative depends on its own costs and the costs of existing processes. Cost allocations for joint products are often arbitrary because the firm maximizes revenues and minimizes costs over all products. Therefore, cost comparisons of conventional and alternative processes are based on cost allocations that are not well understood. We have avoided joint-product cost allocations in this study because methanol is a single product from natural gas reforming processes. Future studies of petroleum-derived products must attempt to make these joint-product cost allocations.

The second consideration is the effect of feedstock supply constraints. During 1972 and 1973, methanol consumption was growing at an annual rate of 6%. During 1974 and 1975, total marketed production shrank nearly 25% because of natural gas curtailments and a 16% increase in captive use. Supply constraints for methanol and its derivatives—used to manufacture thermoset resins, pharmaceuticals, paint, and allied products—were noted in several surveys (Chemicals Systems, Inc. 1976).

Biomass provides one alternative to imports of petroleum, natural gas, and their derivatives. Supply curtailments could become particularly important if the United States becomes a net importer of petrochemicals. Nonpetroleum companies will be particularly vulnerable, and this may lead to more industry concentration and higher vulnerability.

A principal precursor in the manufacture of formaldehyde, large biomass resource bases are already relatively near existing formaldehyde plants. Wood resources in particular represent large potential supplies of methanol feedstocks and the wood products industries consume large quantities of formaldehyde for glues and resins for plywood and particle board. This renewable biomass resource base appears well matched to the derivative products of methanol.

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APPENDIX A
SUPPLY AND DEMAND TRENDS
FOR PETROCHEMICALS

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APPENDIX A

SUPPLY AND DEMAND TRENDS FOR PETROCHEMICALS

A.1 INTRODUCTION

This appendix presents a summary of supply and demand trends for petrochemicals to 1990. The forecasts are based on the Pace Forecasting Model generally described in Appendix B. The chemicals selected for examination are the principal marketed precursors identified in Table 2-2. The extrapolations presented here are based on average growth rates in the U.S. economy, energy demand, and assumed petrochemical consumption. The annual rates for petrochemical growth are 4.3% for 1980-85, 4.1% for 1985-1990, and 3.9% for 1990-2000. Growth rates in the economy and energy demand are assumed to increase by 3.5% and 1.3% for 1980 to 1985, 2.9% and 1.9% for 1985 to 1990; and 2.5% and 1.8% for 1990 and 2000, respectively.

Economic activity is the basic driving force for petrochemical consumption. People buying homes, automobiles, furnishings, clothing, packaged goods, and other consumer items create demand for plastics, fibers, elastomers, and ultimately basic petrochemicals such as ethylene, propylene, and benzene. Consumer value judgments based on price and substitution relationships of competing products influence the demand for individual petrochemical products. As noted, refinery products—especially gasoline—drive the basic relationships of petrochemical production and consumption. All supply and demand trends listed are based on historical links between gasoline and petrochemical prices. Future developments in finding gasoline substitutes may alter the structure of the relationships assumed in these forecasts.

The Pace Co. developed forecasting techniques which quantitatively link these elements to petrochemical consumption. Other factors such as changing lifestyles (voluntary and forced), foreign trade (raw materials, intermediates, finished products), and political actions are also taken into account, subjectively. The petrochemicals of specific interest to Solar Energy Research Institute are addressed in some detail in this section. In-text tables contain forecast data for five-year intervals for conciseness.

Key trends assumed are:

- Long-term petrochemical growth of less than 4% per year is slightly lower than the recent rate and substantially below the high pre-1974 growth. Much of this slowdown can be attributed to maturing markets and specialty products becoming widely consumed commodities. Reduced economic growth resulting from an energy-constrained environment and higher energy/petrochemical prices are additional factors restraining growth.
- Petrochemicals will continue to exhibit stronger growth than the economy as a whole. Energy consumption lagging the economy is a reflection of conservation and improving efficiencies.
- Higher energy prices in the past have had a tendency to improve the cost-effectiveness of synthetics relative to "natural" products; i.e., metals wood, paper, glass, etc. Capacities of the natural products are limited, and they often face environmental and financial problems at least as severe as those encountered by petrochemicals. (If there were to be a trend away from synthetics because of higher costs, it would have been evident by now—six years after the first sharp increase in raw material and energy costs.)

A.2 NATURAL GAS/LPG FEEDSTOCKS

The U.S. petrochemical industry was built primarily on natural gas and liquids extracted from the gas (LPG). In 1970, nearly 90% of U.S. ethylene was produced from LPG feedstocks, principally ethane and propane. Methanol and ammonia production was based completely on natural gas. Aromatics were the only major petrochemicals derived predominantly from refineries.

Gas was used for two reasons: low cost and ready availability in large quantities. In the case of ethylene, LPG feedstocks (especially ethane) gave high ethylene yields with minimum amounts of heavy undesirable coproducts. An additional benefit was low capital investment for LPG-based plants compared with heavy liquids plants.

Declining natural gas production and the basic energy shortage forced ethylene producers to compete with fuels markets for ethane and propane. Pricing based on Btu content rather than volume diminished the attractiveness of LPGs as an olefins feedstock. Most new ethylene capacity built in the United States since the early 1970s has been based on heavy liquid feedstocks—naphtha and gas oil. Except for DuPont's new methanol plant based on residual fuel oil, all U.S. methanol and ammonia production is still based on natural gas. Securing natural gas supplies at prices that permit competition with imported ammonia and methanol is becoming increasingly difficult and coal and biomass feedstocks are serious competitors for domestic supplies.

The following review of natural gas/LPG trends for the United States is intended to provide a basis for the following petrochemical production and economic forecasts.

A.2.1 Natural Gas Supply

Total natural gas supply to the continental United States has been essentially constant for several years and is expected to remain so throughout the forecast period (Table A-1).

The key trends in natural gas supply implied in the table are:

- Mainland production, both associated and nonassociated natural gas, will continue to decline gradually but steadily.
- Pipeline gas from Alaska will become available in 1990, but supplies will be minimal.
- Imports of gas, including LNG, will peak in 1990 and then gradually decline. This is primarily a reflection of negative impacts of the Natural Gas Policy Act on future LNG projects. Also, pipeline imports from Canada and Mexico will decline as the economies of those countries use increasing amounts of their gas production internally.

The Natural Gas Policy Act (NGPA) of 1978 was one of the most controversial and strongly debated parts of the National Energy Act. The NGPA established, for the first time, federal price controls over intrastate gas and called for deregulation of a significant portion of the interstate market by 1985. The Act established first-sale price ceilings for major categories of natural gas production.

Table A-1. Historical and Forecasted U.S. Natural Gas Supplies
(trillion ft³ per year)

| | 1977 | 1980 | 1985 | 1990 |
|----------------------------------|--------------|--------------|--------------|--------------|
| Gross withdrawals (50 States) | 21.05 | 19.10 | 16.78 | 15.57 |
| Associated gas | 3.68 | 3.28 | 2.40 | 1.98 |
| Nonassociated gas | 17.37 | 15.82 | 14.38 | 13.59 |
| Alaska (pipeline) | - | - | - | 1.03 |
| SNG (net) | 0.35 | 0.40 | 0.54 | 0.73 |
| Imports (net) | 0.95 | 1.10 | 1.96 | 2.30 |
| LNG | 0.05 | 0.58 | 1.07 | 1.70 |
| Total | 22.40 | 21.18 | 20.35 | 21.33 |

Historical and Forecasted Natural Gas Liquids Consumption
(million standard ft³)

| | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1985 | 1990 |
|--------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Ethane | 516.2 | 549.7 | 621.8 | 654.1 | 530.2 | 543.1 | 500.0 | 493.0 |
| Propane | 1184.0 | 1259.2 | 1248.3 | 1192.9 | 1254.3 | 1239.8 | 1325.9 | 1501.3 |
| Butanes | 548.0 | 570.1 | 503.8 | 518.3 | 553.5 | 599.8 | 706.2 | 740.8 |
| Total | 2248.2 | 2379.0 | 2373.9 | 2365.3 | 2338.0 | 2382.7 | 2532.1 | 2735.1 |

The NGPA defines new onshore gas as that produced from a well spudded on or after 19 February 1977 and 2.5 miles away from or 1,000 ft deeper than an existing well, or from a reservoir that had not produced in commercial quantities before 20 April 1977. Also, any gas produced on the Outer Continental Shelf from a lease that took place after 20 April 1977, is classified as new gas. The initial ceiling price is \$1.75 per million Btu as of 20 April 1977. The price ceiling escalates at an annual rate equal to the BNP deflator plus 0.2 percentage point plus;

- 3.5 percentage points from 20 April 1977 to 20 April 1981; and
- 4.0 percentage points from 21 April 1981 until 1 January 1985.

As of 1 January 1985, new gas prices are scheduled to be deregulated under the law. The liquid fuels most likely to be considered by existing and potential gas users are No. 2 fuel oil and low-sulfur No. 6 fuel oil (0.5 weight percent sulfur or less). With the installation of a multifuel burner, consumers are able to "swing" between fuel oil and natural gas depending on price and availability. As a result of these considerations, we use the Btu cost of No. 2 fuel oil as the free market value for natural gas.

At the end of price controls on new gas in 1984, the ceiling price will still be significantly lower than our computed free market price. Consequently, we have assumed that price controls will be extended through 1990 to allow for phasing into price parity with competing fuels, avoiding a sudden sharp escalation. Our natural gas price forecasts are included in the consolidated price forecast tables in Appendix B.

A.2.2 Natural Gas Liquids

The term natural gas liquids (NGL) refers collectively to ethane, propane, the two butane isomers, and natural gasoline. The term liquefied petroleum gas (LPG) also refers to the same products (excluding natural gasoline) and the two are generally used interchangeably. When used as ethylene feedstock, LPGs are commonly referred to as "light" feedstocks as opposed to "heavy" liquids; i.e., naphtha, gas oil, raffinate, etc.

Our forecast of natural gas liquids prices (Table B-3) is based on:

- cost of production;
- pricing or value competing products; and
- supply/demand imbalances.

NGL prices came under controls along with other energy products in May 1973. On 30 December 1974, the Federal Energy Administration issued a mandatory allocation procedure that set the ceiling prices for propane, butanes, and natural gasoline. Ethane was not controlled. Controls have resulted in a wide disparity in the allowable prices for these products, depending upon the price of gas being processed and the age of the processing plant. However, there are three major trends which affect the entire industry:

- increasing natural gas prices;
- increasing international supplies of NGL; and
- increasing crude and refined product prices.

Prices of new gas supplies will increase rapidly over the next 10 years. More importantly, after 1985, natural gas prices will increase substantially faster than crude oil—assuming price parity with competing fuels is reached in 1990. During this period, new gas processing operations will have to contend with raw materials prices (natural gas) increasing faster than prices for products selling to markets in competition with crude oil-derived materials.

A large number of gas processing projects are now under way or planned in the Middle East, Africa, Southeast Asia, Mexico, and the North Sea. Even if these projects are discounted to reflect realistic schedules and plans, there will be a major increase in international NGL supplies by 1985. Most of the product from these NGL plants will be destined for Japan, Europe, and the United States.

A.2.2.1 Ethane

Two primary forces in ethane pricing are the value of ethane in competition with propane in a light feedstock olefins plant and incremental extraction costs from natural gas. Ethylene feedstock is essentially the only outlet for ethane. Most ethylene plants designed for light feedstocks have the capability to substitute significant amounts of ethane for propane, or vice-versa. Thus, the value of ethane to an ethylene producer is the price that will give the plant a profit margin equivalent to propane. The value of ethane in an ethylene plant represents a ceiling for future prices.

From the gas processors' perspective, the price received for ethane must at least cover the cost of shrinkage plus incremental processing cost or the processor will choose to leave ethane in the gas. Most processors will look to average gas prices rather than new gas prices in determining whether ethane recovery is attractive. Thus, the incremental cost of recovering ethane from average-priced natural gas will set the minimum price for ethane.

A.2.2.2 Propane

In contrast to ethane, propane serves a broad spectrum of uses. Some of these uses, such as residential/commercial space heating and crop drying, will support a substantial premium over alternate fuels—principally No. 2 fuel oil. The demand for propane in other applications, such as standby fuel for industrial facilities, is very strongly related to relative pricing. It is important to note that whereas the economics associated with the decision to use propane, No. 2 fuel oil, gas, etc., are generally made at the point of use, the prices represented in this report reflect the costs of extraction and shrinkage from average natural gas. The influence of competition with No. 2 fuel oil will also have an impact on prices at the downstream level.

Until the international surplus of LPGs develops (1983 to 1985), propane prices will continue to track No. 2 fuel oil. On a Btu basis, propane will sell for about 25% less than No. 2 fuel oil at the United States Gulf Coast distribution point. When the surplus occurs, the discount will increase but not below the point that extraction and shrinkage costs can be recovered. However, after 1985, the price of average natural gas will be increasing so fast that propane prices will have to rise to maintain the margin above average gas prices necessary to recover the extraction and shrinkage costs.

A.2.2.3 Normal Butane

The major use of normal butane is for gasoline blending, although it is also used as a feedstock for ethylene and to a very limited extent in the manufacture of butadiene via dehydrogenation. Normal butane can be expected to continue to reflect its value as a gasoline blending component for the next several years. However, the demand for gasoline has started a slow decline as automobile efficiencies continue improvement and diesels become a larger factor.

By 1985, refiners' needs for purchased normal butane will decline somewhat as a result of lower gasoline production and increased internal refinery production of butanes. With demand for butane in gasoline blending declining, the value as an industrial boiler fuel is expected to set normal butane prices. In these applications, butane is valued at Btu equivalency with competitive fuels.

A.2.2.4 Iso-Butane

Iso-butane's principal use is in the manufacture of gasoline alkylate, but a significant volume is now used by Oxirane to make propylene oxide. Under equilibrium conditions, the differential between iso- and normal butane is the cost of separation—about 1.4 cents per gallon of feed. Since the separation is usually performed to secure iso-butane, this product carries the entire cost—about 4.0 cents per gallon. However, during periods when demands for iso- and normal butane are out of balance, the differential can widen substantially. This situation existed in 1978 and 1979 when the differential often ranged from 10 to over 20 cents per gallon. In the longer term, the differential between iso- and normal butane prices will narrow as demand for iso-butane in alkylation stagnates.

A.2.3 Natural Gas Derivatives

A.2.3.1 Acetic Acid

Acetic acid is produced via butane oxidation, via acetaldehyde oxidation, and via methanol carbonylation. Before 1970, most acetic acid was produced via butane oxidation, but Monsanto's development of methanol carbonylation and the industry's acceptance of this process has resulted in each process accounting for about one-third of total acetic acid capacity. New acetic acid capacity is forecast to use the methanol carbonylation process which will then be the manufacturing cost basis for acetic acid pricing.

Acetic acid is a mature commodity chemical with two principal end uses. Its largest market is as a feedstock for vinyl acetate monomer production. Vinyl acetate is polymerized alone or as a comonomer with vinyl chloride. Most vinyl acetate is used as a single monomer and vinyl acetate polymers are used in the housing and construction industry, in paint formulations, and as adhesives. Acetic acid is also used as a feedstock for cellulose acetate. During the 1960s, cellulose acetate was the primary outlet for acetic acid. It was replaced in the fibers industry by other synthetics and in its other applications by plastics such as polypropylene and polyethylene. Its decline has been the dampener for consumption growth of acetic acid. We expect consumption growth to average about 4% per year. The supply/demand balance is presented in the Table A-2.

**Table A-2. Historical and Forecasted Acetic Acid Supply/
Demand Balances**
(million pounds)

| Year | Consumption | Actual Capacity | % Utilization |
|------|-------------|---------------------|-------------------|
| 1975 | 2,193 | 2,645 | 83 |
| 1976 | 2,455 | 2,725 | 90 |
| 1977 | 2,570 | 2,880 | 89 |
| 1978 | 2,698 | 3,480 | 78 |
| 1979 | 3,329 | 3,570 | 93 |
| 1980 | 2,894 | 4,140 | 1,246 |
| 1981 | 3,472 | 4,140 | 668 |
| | | Forecasted Capacity | Surplus/(Deficit) |
| 1982 | 3,611 | 4,140 | 529 |
| 1983 | 3,755 | 4,140 | 385 |
| 1984 | 3,906 | 4,140 | 234 |
| 1985 | 4,062 | 4,140 | 78 |
| 1990 | 4,942 | 4,140 | (802) |

A.2.3.2 1,4 Butanediol

Butanediol is produced in the Reppe process from acetylene and formaldehyde. It is classified a natural gas derivative because of its formaldehyde requirements. Butanediol is produced in the United States by only three companies—DuPont, GAF Corporation, and BASF Corporation. DuPont and GAF produce 1,4 butanediol primarily for captive consumption.

DuPont uses its 1,4 butanediol production as a tetrahydrofuran (THF) feedstock. THF is used as a solvent in production of polyvinyl chloride. It also serves as a feedstock for polytetra-methylene glycol and a Grignard reaction solvent. THF is the largest end use for 1,4 butanediol. GAF uses its 1,4 butanediol captively as a feedstock for gamma-butyrolactone, which also serves as a feedstock for chemicals such as 2-pyrrolidone and n-methyl-2-pyrrolidone. Gamma-butyrolactone is also used directly as a solvent. Gamma-butyrolactone is the second largest end use for 1,4 butanediol. BASF does not have any known captive uses for 1,4 butanediol and probably sells most of its output to polybutylene terephthalate producers as a feedstock.

Other smaller markets for 1,4 butanediol include its use as a feedstock for polyurethanes, plasticizers, and pharmaceuticals. These markets account for an estimated 10 to 15% of total 1,4 butanediol consumption. The total consumption of 1,4 butanediol can only be estimated since production data are not published by the U.S. International Trade Commission. The supply/demand balance presented (Table A-3) is Pace's estimate based on analysis of captive requirements and polybutylene terephthalate market needs.

A.3 METHANOL

Methanol is experiencing rapid growth. This change in emphasis is caused partly by new applications, partly by the energy, gasoline, and octane shortages, and partly by the desire to develop remote natural gas fields. Besides the conventional uses of methanol in formaldehyde and solvents, uses of methanol in fuels, production of acetic acid, and single-cell proteins have caused most industry analysts to believe that methanol could show the strongest growth rate of any petrochemical in the 1980s and will grow significantly faster than the economy and faster than the total petrochemical industry. Methanol is the subject case study of this report.

A.3.1 Cost/Price Structure

The recent increased demand for methanol has caused significant price increases. During 1976, 1977, and 1978, prices for methanol oscillated between 38 and 44 cents per pound. By the first quarter of 1980, the prices had risen above 60 cents per pound and now they are above 70 cents per pound. Although feedstock costs have also risen during this period, the profitability of methanol has increased significantly. This increase in profits has brought a flurry of announcements for new capacity and expansions, both domestic and foreign.

These wide swings in demand and prices illustrate the commodity nature of methanol. Accordingly, new methanol plants will be large and adjacent to cheap sources of raw materials in order to reduce overall costs. Such a philosophy will safeguard profits even if demand softens or overbuilding occurs.

**Table A-3. Historical and Forecasted 1,4 Butanediol Supply/
Demand Balances**
(million pounds)

| Year | Consumption | Actual Capacity | % Utilization |
|------|-------------|------------------------|-------------------|
| 1975 | 170 | 245 | 69 |
| 1976 | 185 | 245 | 76 |
| 1977 | 202 | 305 | 66 |
| 1978 | 220 | 365 | 60 |
| 1979 | 253 | 365 | 69 |
| 1980 | 225 | 365 | 140 |
| 1981 | 244 | 365 | 121 |
| | | Forecasted Capacity | Surplus/(Deficit) |
| 1982 | 263 | 365 | 102 |
| 1983 | 284 | 365 | 81 |
| 1984 | 307 | 365 | 58 |
| 1985 | 330 | 365 | 35 |
| 1990 | 463 | 365 | (98) |

Methanol is made from synthesis gas—a combination of carbon monoxide and hydrogen. This syn-gas can be made from natural gas, naphtha, residual fuel, coal, and cellulose and hemicellulose materials. Most methanol plants in the United States are based on a natural gas feedstock.

Natural gas is playing a dominant role in the current increases in worldwide methanol capacity. It is well known that large reserves of natural gas are located in remote world areas (i.e., Alaska, Canada, Saudi Arabia, Indonesia, etc.) where pipeline costs and local consumption cannot provide a sufficient market for the gas. Thus, these reserves must be flared, left unused, or converted to a liquid product for oceanic shipment to other world areas. Liquefied natural gas (LNG) is one means of this liquefaction, but it is a costly, complex process and shipment requires special vessels. Methanol, on the other hand, provides a cheaper, safer means of transporting natural gas to world markets. By producing methanol, which can be shipped in normal ocean tankers, these remote reserves can be more easily tapped.

A.3.2 Demand

The traditional uses of methanol are in the production of formaldehyde and in various solvent applications. The new uses for methanol include the production of acetic acid, in various fuels applications, and making single-cell protein. Traditional uses are expected to continue to grow at 5% per year through 1990, while other uses should grow at a combined rate of about 14% per year.

A.3.2.1 Formaldehyde

Formaldehyde is now and will continue to be the largest consumer of methanol. Historically, most methanol plants also included formaldehyde facilities with a portion of the methanol going to the merchant market. However, some new plants will have supply production facilities which include no formaldehyde. Still, most methanol producers will remain active in the formaldehyde market.

Uses of formaldehyde are primarily based on adhesives. Most formaldehyde is used in making urea resins and phenolic resins, both of which are consumed in construction industry products—plywood and insulation. Even though the construction industry is currently in a slump, formaldehyde demand is still stable due to formaldehyde use in energy saving insulation, mobile homes, and home repair items. In addition, the export demand has been strong.

A.3.2.2 Solvents

The other traditional use for methanol is in various solvent applications. Although growth in this market will continue, it cannot expect to be greater than overall U.S. economic growth. No new industrial solvent applications are expected to increase growth. Losses in antifreeze applications to glycols will cease, as most changes have already been made.

A.3.2.3 Fuels Applications

The crude shortage, gasoline shortages, and octane crunch have combined to increase significantly the applications of methanol and methanol-based derivatives in the fuels market. Thus, the fuels applications are the newest, most dynamic feature of the methanol market.

Methyl Tertiary Butyl Ether. The regulations to decrease the use of lead octane additives combined with the increased use of unleaded gasoline and the demand for higher octane unleaded gasoline have caused a great need for nonlead additives. This need has caused a temporary shortage of benzene and other aromatics, resulting in sharper increases in prices for those products. Methyl tertiary butyl ether (MTBE) has proven to be a high-quality nonlead octane booster. The Environmental Protection Agency (EPA) has approved the use of MTBE as an octane additive, and consumption of MTBE is expected to increase at 14% per year through 1990. This growth will be evident despite the overall decrease in U.S. gasoline consumption.

Gasoline Blending. In addition to octane additives, methanol is being considered as a straight blending material for gasoline. Methanol/gasoline fuels have successfully been used in Europe and are being seriously considered in New Zealand. However, methanol blending does increase the volatility of the gasoline and so limits the amount of C₄ alkylates that can be contained in the gasoline pool.

Gasoline Extender. Sun Petroleum Company and Oxirane Corporation have proposed a gasoline extender composed of methanol, MTBE, and tertiary butyl alcohol (TBA). This mixture, called Oxinol, could be blended with gasoline to increase octane as well as the total gasoline supply.

Gasoline Substitute. Methanol has also been studied as a straight automotive fuel. Although there is no mechanical problem in using methanol in the engines currently used in normal passenger cars, the engines and cars would require minor modifications. Because of the solvent properties of methanol, different gaskets would be required. Since the energy per volume of methanol is less than gasoline, larger fuel tanks would be required to obtain the same distance range.

Methyl Fuel (Mega-Methanol). Saudi Arabia's tremendous supply of natural gas, currently being flared, has caused them to consider building huge methanol plants to produce non-chemical grade material. These mega-methanol plants could supply methyl fuel to utilities throughout the world and reduce the amount of fuel oil required. This methyl fuel could be supplied at a lower price than LNG, would be safer, and could be burned directly without revaporizing. In addition, the clean burning qualities of methanol could have significant environmental advantages. For such fuel to be competitive in the United States, a tariff exemption differentiating methyl fuel from chemical-grade methanol might be required. Methyl fuel probably will have only limited applications in utilities where the environmental situation requires the use of a clean fuel.

A.3.2.4 Acetic Acid

Traditionally, acetic acid has been made from butane and ethylene. However, a Monsanto process for acetic acid from methanol was found to be much more energy efficient. The overall energy savings in operating costs and raw material yields can even outweigh the recent large increases in the price of methanol. Thus, methanol use in acetic acid production will grow at more than 10% per year.

A.3.2.5 Exports

Supplies of methanol in Japan are extremely tight, since most of the Japanese capacity for methanol is based on naphtha or butane. As crude prices and LPG prices have increased, Japan could not make methanol economically from these feedstocks. A similar situation exists in Europe where methanol production is also based on naphtha. Thus, in the United States, where methanol is produced from relatively cheap natural gas, U.S. producers can compete in both the European and Japanese markets. However, as supplies in the United States become tight and world production of methanol in Canada, Saudi Arabia, Indonesia, and Mexico increases, U.S. exports of methanol will decrease.

A.3.2.6 Single-Cell Protein

A new use for methanol has been established in the production of single-cell protein, which can be used in animal feed. Growth of methanol consumption for this use is expected to be 8% per year through 1990.

A.3.3 Supply

The present high demand for methanol has caused a marked increase in capacity utilization to the 90%-95% range. At the same time, higher prices have caused a significant increase in methanol plant profitability. These changes have generated interest in methanol by many companies, and numerous announcements for new plants and expansions have been made. A comparison of total capacity versus consumption is shown in Table A-4. New plants affecting domestic capacity include DuPont's new partial oxidation plant, ARCO's 200 million-gallons-per-year plant at Channelview, Texas (which will feed ARCO's MTBE plant), and Celanese's proposed coal-based methanol facility. In addition to grass-roots facilities, Borden, Allemania, and Texaco have all announced plans for significant expansions of existing facilities.

Beyond the domestic capacity, several methanol facilities are planned outside the United States. Both Celanese and Alberta Natural Gas plan grass-roots complexes in Canada. Texas Eastern and Celanese are joint-venturing a methanol complex in Saudi Arabia. New Zealand has approved plans for a methanol plant by a joint venture of Petro Corporation and Alberta Natural Gas. Pemex is also considering a methanol complex for Mexico.

**Table A-4. Historical and Forecasted Synthetic Methanol Supply/
Demand Balances**
(million pounds)

| Year | Consumption | Actual Capacity | % Utilization |
|------|-------------|---------------------|-------------------------------------|
| 1975 | 4,654 | 8,387 | 55 |
| 1976 | 4,828 | 8,732 | 55 |
| 1977 | 6,475 | 9,063 | 71 |
| 1978 | 6,675 | 9,063 | 74 |
| 1979 | 7,427 | 9,063 | 82 |
| 1980 | 8,321 | 9,481 | 1,160 |
| 1981 | 8,487 | 10,217 | 1,730 |
| | | Forecasted Capacity | Domestic Capacity Surplus/(Deficit) |
| 1982 | 8,657 | 10,217 | 1,560 |
| 1983 | 8,830 | 10,217 | 1,387 |
| 1984 | 9,007 | 10,217 | 1,210 |
| 1985 | 9,187 | 10,217 | 1,030 |
| 1990 | 11,177 | 10,217 | (960) |

A.4 AMMONIA

Ammonia is the backbone of the huge nitrogen-based chemical industry. In addition, ammonia is the basic building block of the complex and volatile fertilizer market. Because of ammonia's strong ties to the agriculture industry, the demand for it fluctuates with the demand for commodity products that ammonia helps produce (e.g. wheat, corn, etc.). This relationship to the fertilizer market dictates that the demand for ammonia will be both seasonal and cyclical. The long-term growth potential in the United States for ammonia will be pushed gradually by the increased consumption of fertilizer.

A.4.1 Cost/Price Relationship

The raw materials for ammonia are synthesis gas and air. Synthesis gas is a combination of carbon monoxide and hydrogen. It can be made from natural gas, naphtha, residual fuel oil, coal, and biomass. Most of the ammonia produced in the United States is made from synthesis gas derived from natural gas. This process is preferred because of the high ratio of hydrogen to carbon in the synthesis gas produced from natural gas. This hydrogen-rich stream can be reacted with nitrogen from the air to produce ammonia.

The commodity nature of ammonia dictates the manufacturing economics for specialty markets and manufacturers, who emphasize low-cost production. Consequently, plants in the United States are normally located close to the raw material source or close to the end user to reduce transportation costs. Most new plants built today both in the United States and abroad are large, to take advantage of economies of scale. Thus, most manufacturers operate on low margin and depend on high volumes to make their profit. However, the large swings in demand and prices for ammonia can cause equally large changes in profitability. Currently, U.S. producers have an advantage over European producers because of regulated natural gas prices. On the other hand, the future development of the U.S. ammonia industry is being clouded by potential imports from low-cost natural gas sources.

A.4.2 Demand

As mentioned, ammonia demand is strongly dependent on the demand for fertilizer. Seventy percent of all ammonia consumed in the United States is used in some form of fertilizers. The remaining ammonia is used as a building block for plastics, fibers, elastomers, and resins, and as a component in the manufacture of explosives, animal feeds, and other chemicals.

Of all the ammonia used in fertilizers, about 40% is consumed in direct application of ammonia mixtures on various vegetation. Ammonia is also used in producing urea, which has both fertilizer and animal feed applications. In addition, ammonium sulfate, ammonium nitrate, and ammonium phosphate all have fertilizer uses and require ammonia for production. A significant volume of ammonia is exported. Since the demand for fertilizer is higher in spring and summer, prices usually will rise at that time, and local short-term shortages are common. The weather and annual U.S. agricultural production cycles result in cyclical demand for ammonia and ammonia products.

Ammonia is also used in producing various types of petrochemicals. It is consumed in the production of acrylics (e.g., acrylonitrile), amino chemicals (e.g., mono ethyl amine), poly amides (e.g., nylon), and urethanes. In addition, certain explosives with both industrial and military applications are produced using ammonia (e.g., nitroglycerine). However, these chemicals have a small overall impact on the seasonal or cyclical nature of the ammonia market.

A.4.3 Supply

The domestic supply of ammonia has been based on supplies of natural gas, historically located on the U.S. Gulf Coast. Plants were either built adjacent to these natural gas reservoirs or at remote sites where ammonia demand was high and cheap natural gas was available via pipeline. In order to satisfy the seasonal demand for ammonia, multiple storage facilities have been required both at the plant site and close to end users. Ammonia is shipped by truck, rail, or barge to agricultural areas. Swings in demand can cause problems both in storage and transportation capabilities of the industry.

U.S. ammonia producers have an advantage over manufacturers in Europe and Japan, where most production is based on naphtha or imported LNG. As gas prices are deregulated in the United States, this advantage will erode. In addition, as world communities use natural gas supplies in remote areas by making ammonia, the available export markets will diminish. In fact, to the extent countries (i.e., Canada, Indonesia, Saudi Arabia, Russia) value this remote natural gas at prices less than U.S. Btu equivalents, U.S. producers will have to compete with foreign ammonia imports. This situation is exemplified in the Soviet Union/Occidental trade of ammonia for superphosphate.

Occidental Petroleum had planned as of last summer to import about 1.5 million tons of ammonia from Russia in 1980. A group of thirteen domestic producers appealed to the International Trade Commission (ITC) for protection from low-priced imports, which they said would drive them out of business. The ITC found in favor of the charge and recommended that the President limit Russian imports to 1.0, 1.1, and 1.3 million tons in 1980, 1981, and 1982, respectively. (In 1979, net ammonia imports into the United States were 977 thousand tons, including 777 thousand tons from the Soviet Union.) President Carter at first refused to impose a limit, but later reversed his decision and set a 1980 quota of one million tons. (U.S. producers wanted imports held to the 1979 level for five years.)

Coincident with the embargo on exports of certain products to the Soviet Union, superphosphoric acid exports planned by Occidental to the Soviet Union were banned. There was concern that the Russians would reciprocate by reducing or eliminating ammonia shipments to the United States. This has not occurred, but shipments to date have been below the one-million-ton annual rate. Ammonia's supply/demand balance is summarized in Table A-5.

Several oxygen gasifiers for ammonia production in agricultural areas appear promising but currently are too expensive for commercial applications. Development of low-cost gasifiers on a scale suitable for agriculture is an ongoing effort in SERI research programs.

A.5 ETHYLENE

Ethylene is the largest volume petrochemical produced in the United States. Its manufacture and consumption directly and indirectly influence the entire petrochemical industry. Of the major building blocks, ethylene is unique in two respects:

- It is almost totally produced by cracking various hydrocarbons. Except for minor amounts produced in refining off-gas, ethylene does not occur as a by-product or coproduct. Although ethylene plants yield a wide variety of coproducts, they are operated primarily to produce ethylene.
- Ethylene's only use is in petrochemical synthesis. Unlike the other olefins and aromatics, ethylene has no significant application in gasoline or as a direct fuel.

Ethylene growth is expected to average slightly over 4% per year through 1990. Consumption by major derivatives is summarized in Table A-6.

Another perspective on ethylene is presented in Table A-7. The data are generally self-explanatory; the key point is that there is adequate capacity in place or under construction to meet anticipated demand through 1985. Therefore, no short-term ethylene shortages are expected.

A.5.1 Feedstock Trends

The most significant trends in the ethylene industry occur in the feedstock area. The broad long-term shift has been and will continue to be toward heavy (naphtha/gas oil) feeds, and away from light (LPH) feedstocks. Although ethylene plants used to be built to operate on a single feedstock or on a narrow range (e.g., ethane/propane mixtures), new facilities are being designed with increasing flexibility. Although this increases the capital costs, it is necessary because of the growing complexities and uncertainties of future feedstock availability and cost. Complete flexibility (i.e., from ethane through gas oil) is costly, but some degree of feedstock substitution is almost mandatory.

Anticipated trends in ethylene feedstocks, along with historical data, are shown in Table A-8. The top portion of the table reveals the widely varying ethylene yields among individual feedstocks. A better indication of the trend is seen in the lower chart, where the approximate percentage of ethylene based on each of the major feedstocks is shown.

The key points of significance derived from Table A-8 are:

- Incremental supplies of ethane and propane feedstocks will be initiated during the early to mid-1980s.
- Heavy liquid feedstocks will be dominated by paraffinic naphthas displaced from the gasoline pool beginning in the period 1981-1982 and continuing into the late 1980s.
- Gas oil feedstocks will constitute the major incremental feedstock supply beyond 1985, based on availability and costs.
- Normal butane will become an increasingly attractive feedstock beginning in the mid- to late-1980s.

The following discussions detail the outlook for individual feedstocks.

**Table A-5. Historical and Forecasted Ammonia Supply/
Demand Balances**
(thousand tons)

| Year | Consumption | Actual Capacity | %Utilization |
|------|-------------|---------------------|-------------------------------------|
| 1975 | 16,925 | 18,573 | 91 |
| 1976 | 17,021 | 18,872 | 90 |
| 1977 | 18,055 | 20,787 | 87 |
| 1978 | 17,944 | 22,334 | 80 |
| 1979 | 19,284 | 22,074 | 87 |
| 1980 | 19,050 | 22,804 | 3,254 |
| 1981 | 19,431 | 22,829 | 3,398 |
| | | Forecasted Capacity | Domestic Capacity Surplus/(Deficit) |
| 1980 | 19,050 | 22,804 | 3,254 |
| 1981 | 19,431 | 22,829 | 3,398 |
| 1982 | 19,820 | 22,829 | 3,009 |
| 1983 | 20,216 | 22,829 | 2,613 |
| 1984 | 20,620 | 22,829 | 2,209 |
| 1985 | 21,033 | 22,829 | 1,796 |
| 1990 | 23,797 | 22,829 | (968) |

Table A-6. Historical and Forecasted U.S. Ethylene Consumption
(billion pounds)

| | 1977 | 1978 | 1979 | 1980 | 1985 | 1990 |
|---------------------|--------------|--------------|--------------|--------------|--------------|--------------|
| Polyethylene: | | | | | | |
| Low density | 6.8 | 7.47 | 8.18 | 7.94 | 9.41 | 11.40 |
| High density | 3.83 | 4.41 | 5.26 | 5.07 | 6.89 | 9.58 |
| Ethylene oxide | 4.35 | 4.60 | 5.13 | 4.94 | 5.78 | 6.96 |
| Ethylene dichloride | 3.45 | 4.10 | 4.57 | 4.03 | 5.04 | 5.70 |
| Ethylbenzene | 2.18 | 2.30 | 2.36 | 2.27 | 2.41 | 2.74 |
| Ethyl alcohol | 0.84 | 0.84 | 0.91 | 0.97 | 1.09 | 1.23 |
| Other | 3.45 | 3.60 | 3.91 | 3.90 | 4.65 | 5.73 |
| Total | 24.90 | 27.32 | 30.32 | 29.12 | 35.27 | 43.34 |

**Table A-7. Historical and Forecasted U.S. Ethylene Supply/
Demand Balances**
(billion pounds)

| Year | Domestic Consumption | Actual Production | Inventory ^a Change |
|------|-------------------------|----------------------|--|
| 1960 | 5.4 | 5.5 | 0.1 |
| 1965 | 9.6 | 9.0 | — |
| 1970 | 17.5 | 18.1 | 0.6 |
| 1973 | 22.3 | 22.2 | (0.1) |
| 1974 | 22.8 | 23.7 | 0.9 |
| 1976 | 23.1 | 22.7 | (0.4) |
| 1977 | 24.9 | 25.4 | 0.5 |
| 1978 | 27.3 | 26.0 | (1.3) |
| 1979 | 30.3 | 29.2 | (1.1) |
| 1980 | 29.1 | 35.9 | 6.8 |
| | | Potential Supply | Capacity Surplus ^b (Shortage) |
| 1985 | 35.3 | 38.0 | 2.7 |
| 1990 | 43.3 | 38.0 | (5.3) |

^aIncludes minor exports/imports.

^bSupply is based on firm, announced capacity expected onstream through 1985. The average effective capacity (year-end nameplate capacity adjusted for partial operation of new plants) is assumed to operate at an overall rate of 90%. This rate has been demonstrated to be a practical, sustainable maximum.

Table A-8. Historical and Forecasted U.S. Olefin Plant Feedstocks
(million barrels per year)

| | 1976 | 1977 | 1980 | 1985 | 1990 |
|-----------------|------------|------------|------------|------------|------------|
| Virgin ethylene | 3 | 4 | 5 | 5 | 4 |
| Ethane | 132 | 141 | 173 | 174 | 133 |
| Propane | 59 | 58 | 56 | 116 | 95 |
| Butane | 8 | 8 | 8 | 19 | 29 |
| Naphtha | | | 45 | 46 | 90 |
| Gas oil | 53 | 76 | 47 | 56 | 185 |
| Total | 255 | 287 | 334 | 416 | 536 |

Estimated Ethylene Production by Feedstock
(percentage of total)

| | 1976 | 1977 | 1980 | 1985 | 1990 |
|-----------------|------------|------------|------------|------------|------------|
| Virgin ethylene | 2 | 2 | 2 | 2 | 1 |
| Ethane | 58 | 56 | 58 | 48 | 30 |
| Propane | 20 | 18 | 14 | 24 | 16 |
| Butane | 3 | 2 | 2 | 4 | 5 |
| Naphtha | | | 12 | 10 | 16 |
| Gas oil | 17 | 22 | 12 | 12 | 32 |
| Total | 100 | 100 | 100 | 100 | 100 |

A.5.2 Ethane/Propane

The substantial increase in world crude prices that occurred in 1979, coupled with suppressed natural gas under price controls, has resulted in ethane and propane being more economical feedstocks (on a full-cost basis) than both full-range naphtha and gas oil heavy liquid feedstocks. This has occurred despite the substantial increase in heavy liquid coproduct prices, particularly aromatics. Decontrol of domestic crude oil will further increase the disparity between petroleum-based feedstocks and gas liquids through late 1981. We expect the economic advantage to continue through the early 1980s.

By 1985, domestic ethane/propane availability will become the limiting factor as mainland gas production declines in both total volume and contained liquid content. Substantial quantities of imported propane will be required to balance 1985 total propane demand in the United States beginning in the mid-1980s. By 1990, we expect the price of imported propane to carry a 5%-10% premium over No. 2 fuel oil on a delivered basis.

Ethane will tighten in the early mid-1980s as ethylene producers compete for limited supplies. This market demand will cause ethane prices to rise above floor value (equal to its natural gas Btu value plus extraction costs from an existing gas processing plant), ultimately increasing to a ceiling price which equates ethane to propane (or the next lowest cost feedstock) on a cash-cost ethylene feedstock basis. In fact, ethane already has moved above its Btu floor value. During 1979, ethane prices nearly doubled from \$0.13 to \$0.22 per gallon, while natural gas moved from \$2.10 to about \$2.30 per million Btu, an increase of only 10%. This increase results from the significantly higher crude oil and naphtha prices that occurred during the period. Ethylene producers can pay more for ethane because naphtha has moved up sharply, relative to natural gas. The result has been increased short-term profitability for both the ethylene producer and the gas processor. However, new ethane crackers or extraction capacity might not be economically justified because the disparity between ethane and naphtha prices is a short-term situation. By the time construction could be completed, the cost advantage might disappear.

Beyond 1985, natural gas prices will rise rapidly because of decontrol. We have assumed that new natural gas prices will rise to those for No. 2 fuel oil by 1990 on a delivered Btu basis. Correspondingly, the Btu floor value of ethane plus extraction costs will reflect these higher gas prices. Ethane feedstock costs will give way to heavy liquids, similar to propane, and ethane use will be limited to existing LPH crackers. Additional gas processing investments cannot be justified at the resulting ceiling prices for ethane.

A.5.3 Butane/Naphtha/Gas Oil

The changing demand pattern for gasoline will play a major role in determining future optimum olefin plant feedstocks. Values for full-range virgin naphtha feedstocks will continue to track gasoline price and will reflect the increasing demand for high-octane unleaded gasoline. Naphtha feedstocks will be at a disadvantage to ethane and propane through the early to mid-1980s because of recent crude oil price increases, coupled with natural gas and natural gas products under price controls. Virgin naphtha supplies will be tight throughout the 1980s and 1990s. While adequate supplies will be available to meet petrochemical demands, prices will reflect this market tightness. Naphtha will show a slight disadvantage relative to gas oil feedstocks through the forecast time period. As a result, we expect little growth in full-range naphtha as an olefin feedstock at least through 1990.

Significant volumes of light, straight-run (paraffinic) refinery naphtha, thermal naphthas, BTX raffinate, and natural gasoline streams will become increasingly available in the early 1980s. These low-octane naphthas are used primarily in leaded regular gasoline. As the volume of leaded regular-grade gasoline declines, the only alternate disposition for many of these streams will be refinery fuel or olefin feedstock.

The combination of yield patterns, capacity configuration, and price will assure the absorption of these paraffinic naphthas by ethylene producers. Incremental supplies will be used fully during the early years of the forecast period. When fully utilized, these low-octane naphthas are expected to be priced on a cash-cost parity basis with gas oil olefins feedstock. We have estimated the volume of these low-octane naphtha streams at about 300 thousand barrels per day by the early 1980s. This volume will provide most of the heavy-liquids ethylene feedstock requirements through 1990. After this source is fully depleted, additional virgin naphtha will have to be bought away from the gasoline pool at higher prices, and gas oil thus becomes more attractive.

As the total volume of gasoline declines through the 1980s, a surplus of normal butane will develop. Less gasoline volume means fewer butanes can be blended at a given gasoline RVP specification. In addition, higher reformer severities required to satisfy increasing octane demand will produce more by-product gas, including more butanes. Furthermore, increased quantities of imported butane (in conjunction with propane) will aggravate the surplus situation. As a result, we expect the price of normal butane, which has been determined historically by its blending value in gasoline, to decrease to approximately the same as No. 2 fuel oil.

The combination of increased availability and lower prices for butane should promote its use as an ethylene feedstock. This is reflected in Table A-8. We do not expect, however, that ethylene plants designed to crack only butane will be built. Most of the butane will be used in heavy liquids plants designed with light feedstock flexibility. Uncertainty about future supplies and prices will be responsible for this restriction.

After 1985, butane costs will improve relative to gas oil and naphtha. During this period, butylene dehydrogenation facilities will no longer be required—since all butadiene requirements can be met through coproduct (ethylene plant) material. When this occurs, the value of butadiene will be set by extraction economics rather than dehydrogenation economics, resulting in a value/price decline of about 10–15 cents per pound. This will adversely affect the attractiveness of naphtha/gas oil cracking because substantially more butadiene is produced than from butane; thus, the overall coproduct credit is lowered. (There are, however, offsetting factors; e.g., higher aromatics output from naphtha/gas oil.) The key point is that the source of incremental butadiene—dehydrogenation or coproduct—will play a key role in selecting an optimum olefins feedstock mix.

Any factor that improves the economic attractiveness of ethane and propane as light feedstocks (such as delayed decontrol of natural gas) also delays the economic attractiveness of butane as a light feedstock (ethane/propane produce less butadiene, which delays the shutdown of dehydrogenation manufacture of butadiene).

Through the mid-1980s, there will be little economic incentive to crack more gas oil than necessary for intra-company product balances at the individual producer level because of the availability of low-octane naphtha. Refiners who have completely integrated olefin plants with the refinery may have to crack heavier feedstocks simply to support their gasoline marketing programs.

Beyond 1985, gas oil will constitute the major incremental feedstock. Gas oil holds a small cost advantage relative to full-range naphtha throughout the forecast period. This advantage reflects a large amount of by-product credits versus naphtha cracking. While supplies should be adequate to satisfy petrochemical demand, the rapid growth in distillate and diesel fuel requirements for transportation will cause competition for supplies. From a crude-constrained standpoint, gas oil feedstocks will be vulnerable to future shortages, similar to all other petroleum-based petrochemical feedstocks.

A.6 ETHYLENE DERIVATIVES

A.6 Ethanol

Synthetic ethanol, a primary ethylene derivative, is one of the most regulated industrial chemicals. Produced by the direct hydration of ethylene, synthetic ethanol is used in a variety of applications. Since ethanol can be consumed as a beverage, it must be rendered unfit for human consumption to be exempt from federal tax regulations on alcoholic beverages. The tax regulations, reporting requirements, and mandated additives required to render alcohol unfit for human consumption are an important determinant of the markets in which synthetic ethanol competes with other chemicals not subject to ethanol's extensive regulations.

Ethanol serves a variety of markets primarily as a chemical feedstock and as a solvent. It is used as a feedstock in production of ethyl amines, ethyl acetate, ethyl acrylate, and glycol ethers. Ethanol is used as a solvent in cosmetic and personal care products, proprietary industrial formulations, cleaning and detergent formulations, and various other industrial applications.

Until the early 1970s, synthetic ethanol was widely used as a raw material in the production of acetaldehyde. The demand for acetaldehyde was one of the keys to the strong growth that synthetic ethanol experienced during the 1960s. However, acetaldehyde's demand was derived from its use as a raw material for such chemicals as acetic acids, butyraldehyde, butanol, and 2-ethylhexanol. Processes for these chemicals which use ethylene or propylene directly were developed, and these new processes began displacing those based on acetaldehyde. Ethanol markets declined, as a result. The replacement of acetaldehyde in these areas is essentially complete, and ethanol's decline is expected to reverse.

Another significant market pressure that will affect consumption of domestically produced synthetic ethanol is the availability of low-priced imports. These imports represent, to a significant degree, ethanol produced in foreign countries where government subsidies result in below-market prices in the United States. This factor is partially responsible for the relatively low operating rate of the domestic synthetic ethanol industry.

The federally encouraged development of biomass-based ethanol industry is a significant factor in the assessment of its supply/demand balance and pricing for synthetic ethanol. Although an ethanol-for-gasohol producer who receives federally backed financing for his plant construction will probably be restricted to selling his output as gasohol, all fermentation plants are not being built with government financing. Those producers who acquire private financing will be eligible for federal entitlements and state gasoline tax exemptions and will not be restricted in the markets they serve. Such a producer could compete in markets that have been served traditionally by synthetic ethanol. The net

**Table A-9. Historical and Forecasted Synthetic Ethanol Supply/
Demand Balances^a**
(million pounds)

| Year | Consumption | Actual Capacity | % Utilization |
|------|-------------|------------------------|--|
| 1975 | 1,429 | 2,110 | 68 |
| 1976 | 1,496 | 2,110 | 71 |
| 1977 | 1,339 | 2,110 | 63 |
| 1978 | 1,285 | 2,110 | 61 |
| 1979 | 1,308 | 2,110 | 62 |
| 1980 | 1,211 | 2,110 | 899 |
| 1981 | 1,320 | 2,110 | 790 |
| | | Forecasted Capacity | Domestic Capacity Surplus/(Deficit) |
| 1982 | 1,350 | 2,110 | 760 |
| 1983 | 1,370 | 2,110 | 740 |
| 1984 | 1,391 | 2,110 | 719 |
| 1985 | 1,412 | 2,110 | 698 |
| 1990 | 1,521 | 2,110 | 589 |

^aExcludes grain ethanol for beverages and gasohol programs.

result will be a dampening of the synthetic ethanol price. Our forecast for synthetic ethanol consumption and pricing is based on our analysis of the relative competitive positions of fermentation-based ethanol and synthetic ethanol. The synthetic ethanol supply/demand balance is summarized in Table A-9. In terms of overall volume, biomass-based ethanol is expected to exceed synthetic production by 600 million pounds by 1981.

A.6.2 Propionic Acid

Propionic acid, a primary ethylene derivative, is produced in a two-stage oxo process. In the first stage, ethylene and carbon monoxide are reacted to form propionaldehyde. In the second stage, propionaldehyde is oxidized to form propionic acid.

Propionic acid serves four markets. It is used as a feedstock to produce sodium and calcium propionate salts, to produce cellulose propionate plastics, and as a herbicide feedstock. It is also used directly as a grain preservative. Sodium and calcium propionate salts, which consume about 40% of propionic acid production, are used in the baking industry as preservatives. These salts are in the mature phase of the product life cycle and will experience only population growth for the future. Cellulose propionate plastics have been a stagnant market for propionate acid for the past ten years as other, less expensive, plastics become available. This market will remain stagnant at best and may go into slow decline.

Propionic acid's use as a grain preservative is the only market with any growth potential. In past years, the controlled low price of propane made a drying process the economic method for grain preservation and storage, and the use of propionic acid in this market has not become significant; but when propane price controls are lifted, the grain preservation market will present significant opportunities for propionic acid producers. Marketing propionic acid to agricultural users will be the key to converting potential into actual sales.

Herbicide production has been the other market contributing to propionic acid's growth. However, the use of chlorinated hydrocarbons as herbicides is controversial, and public acceptance and potential environmental hazards present obstacles to continued growth in this market.

The supply/demand balance for propionic acid should be evaluated with the oxo process' flexibility in mind. Integrated producers such as Union Carbide Corporation and Tennessee Eastman have designed considerable flexibility into their facilities and have the capacity to convert propionaldehyde in oxo-chemicals other than propionic acid. The capacity data presented in Table A-10 should be regarded only as the maximum domestic propionic acid capability.

A.6.3 Lactic Acid

Lactic acid, a secondary derivative of ethylene, is produced via the reaction of acetaldehyde and hydrogen cyanide to form lactonitrile. The lactonitrile intermediate is then converted to crude lactic acid. The crude product is further purified and concentrated to produce the primary commercial product—88% food-grade lactic acid. Until 1961 when fatty acid lactylates were approved for use as a bread additive, all lactic acid was produced via fermentation of hexose sugars. In 1963, Monsanto brought its synthetic lactic acid plant on-stream and quickly displaced all fermentation-based producers but one. Monsanto was able to produce a higher quality product less expensively with its new

**Table A-10. Historical and Forecasted Propionic Acid Supply/
Demand Balances**
(million pounds)

| Year | Consumption | Actual Capacity | % Utilization |
|------|-------------|---------------------|-------------------------------------|
| 1975 | 51 | 80 | 64 |
| 1976 | 76 | 208 | 37 |
| 1977 | 84 | 208 | 40 |
| 1978 | 83 | 243 | 34 |
| 1979 | 98 | 243 | 40 |
| 1980 | 93 | 243 | 150 |
| 1981 | 105 | 243 | 138 |
| | | Forecasted Capacity | Domestic Capacity Surplus/(Deficit) |
| 1982 | 110 | 243 | 133 |
| 1983 | 115 | 243 | 128 |
| 1984 | 120 | 243 | 123 |
| 1985 | 123 | 243 | 120 |
| 1990 | 146 | 243 | 97 |

synthetic process, and most of the fermentation producers could not compete. The availability of lactonitrile as a by-product from their acrylonitrile process was Monsanto's key competitive edge. Monsanto's manufacturing economics changed significantly in 1970 when they converted the acrylonitrile plant to a propylene feedstock, which eliminated lactonitrile as a by-product. Hydrogen cyanide was, however, produced as an acrylonitrile by-product, and Monsanto expanded and modified the lactic acid plant to utilize available hydrogen cyanide. The process and manufacturing economics change did not result in a loss of market share to Monsanto's domestic competitors. As a result, they are still the dominant force in the lactic acid market today. Their annual production capacity is estimated to be 10-15 million pounds.

The availability of lower-priced lactic acid imports has begun to play a significant role in the supply/demand balance for the United States. Imported lactic acid is sold in ports of entry for two to three cents per pound below domestic market prices. As a result, imports have been a growing force in the lactic acid supply picture and currently represent about 20%-25% of domestic consumption.

The concentration of essentially all domestic lactic acid capacity in Monsanto's Texas City, Texas, plant makes inappropriate a definitive assessment of the domestic supply/demand balance. Domestic market requirements and import availability will dictate Monsanto's business strategy. They will probably expand production capacity as their markets grow. The key to lactic acid's pricing will continue to be Monsanto's cost of raw materials and production.

A.7 PROPYLENE

Propylene analysis is more complex than ethylene for two reasons: (1) it is generally not produced intentionally, but occurs as a coproduct in ethylene production and as a by-product in refinery catalytic cracking (recovery and purification is of course intentional), and (2) propylene, unlike ethylene, has alternate uses—in gasoline alkylate and as fuel. The approach used to develop propylene supply/demand balances is to: (1) determine demand for propylene in petrochemicals, using standard Pace forecasting techniques; (2) calculate the amount of propylene coproduced in ethylene plants and assume that it is all recovered and used in petrochemicals (this has always essentially been true); and (3) obtain the remainder from refineries. To be consistent, we also estimate refinery propylene production and consumption to verify adequate availability to meet chemical needs.

A.7.1 Propylene Demand

Total demand for propylene in chemical uses in the United States was developed by projecting the demand for propylene derivatives based on their consumption in end-use products such as plastics, fibers, and other chemical products. Propylene requirements for consumption in each derivative were calculated, taking into account process efficiencies and changing technology. These were then summed to provide the total domestic demand for each year.

Forecasts through 1981 were based on a detailed analysis of current and near-term economic and product production trends prepared for Pace's multi-client continuing service, "Quarterly Outlook for Petrochemicals." The longer-range propylene and derivatives demands were based on an independent analysis reflecting our current outlook and consistent with the economy and energy situations.

Future demand for propylene derivatives in the United States is expected to grow faster than ethylene. Historically, propylene consumption has been 45%-50% that of ethylene, but by 1990 this ratio of consumption will be about 55% and the trend will continue thereafter. Propylene demand will exhibit a growth rate of about 3.7% through 1990 versus 3.6% for ethylene, reflecting the price differentials between the two petrochemicals.

Propylene is a mature commodity petrochemical with a wide variety of end uses. However, the five largest volume derivatives account for almost 80% of all propylene consumed in chemical production. Propylene consumption in chemicals by derivative is summarized in Table A-11.

Refinery operations consume the largest amounts of propylene. Propylene alkylation uses about half of the propylene derived from refineries. Propylene, as well as butylene, is reacted with iso-butane to form a high-octane component used in gasoline blending. Polymer gasoline is also used in gasoline but consumes only modest amounts of propylene today. Propylene can also be used as a mixture with propane in liquefied petroleum gas (LPG). For certain internal combustion engine applications, the propylene content cannot exceed 5%. As a last resort, propylene can be burned as plant fuel, but this is usually a more expensive alternative than using other refinery streams for this purpose.

A.7.2 Propylene Supply

As noted, analysis of the propylene supply in the United States is complicated by the fact that it is supplied by both refineries and chemical plants. In both cases propylene is made only as a coproduct (in ethylene plants) or as a by-product (refinery catalytic cracking). The amount of propylene available from refineries is very difficult to determine because of the many variables affecting propylene production; e.g., crude oil characteristics, catalytic cracking, operating severity, catalyst type, and refinery product slate. The total amount of propylene produced in refineries is conservatively estimated at 20 billion pounds per year. Geographic limitations make total recovery impractical, but availability of a least 17 billion pounds per year is reasonable.

The method used to determine propylene supply is to determine the amount of propylene coproduct from ethylene plants. All propylene from this source is considered used in chemical derivatives. The remainder of propylene demand is supplied by refineries. To be consistent, we also estimate refinery propylene production and consumption to verify adequate availability of propylene to chemical derivatives. Using this approach, the U.S. propylene balance was forecast and is summarized in Table A-12.

Supply/demand imbalances for propylene have historically been more common than for ethylene. This is primarily because of the unintentional nature of its production. The factors affecting propylene supply are discussed in the subsections that follow.

A.7.2.1 Propylene From Olefins Plants

Propylene coproduced with ethylene in olefins plants is the primary source of propylene for chemicals. About 60% of propylene used in chemical derivatives came from olefins plants in 1979. The growth of propylene from this source has been substantial since 1977; it will continue to grow as new ethylene plants are designed to feed predominantly heavy liquids. The quality of propylene from this source is "chemical-grade" propylene—about 92% propylene and 8% propane.

Table A-11. Historical and Forecasted U.S. Propylene Consumption
(billion pounds)

| | 1977 | 1978 | 1979 | 1980 | 1985 | 1990 |
|-------------------|-------|-------|-------|-------|-------|-------|
| Polypropylene | 3.02 | 3.38 | 4.12 | 4.14 | 5.70 | 8.31 |
| Acrylonitrile | 2.06 | 2.19 | 2.52 | 2.19 | 2.19 | 2.42 |
| Isopropyl alcohol | 1.60 | 1.47 | 1.67 | 1.73 | 1.96 | 2.19 |
| Propylene oxide | 1.59 | 1.74 | 1.91 | 1.97 | 2.41 | 3.08 |
| Cumene | 1.08 | 1.39 | 1.64 | 1.43 | 1.85 | 2.31 |
| Other | 2.39 | 2.67 | 2.96 | 2.91 | 3.51 | 4.03 |
| Total | 11.73 | 12.84 | 14.82 | 14.37 | 17.62 | 22.34 |

**Table A-12. Historical and Forecasted U.S. Propylene Supply/
Demand for Chemicals**
(billion pounds)

| | 1978 | 1979 | 1980 | 1985 | 1990 |
|----------------|------|------|------|------|------|
| Consumption | 12.8 | 14.9 | 14.4 | 17.6 | 22.3 |
| Supply | | | | | |
| Olefins plants | 8.8 | 8.7 | 8.8 | 9.3 | 15.3 |
| Refineries | 3.7 | 5.7 | 5.3 | 8.3 | 7.0 |
| Imports | 0.3 | 0.5 | 0.3 | 0.0 | 0.0 |
| Total | 12.8 | 14.9 | 14.4 | 17.6 | 22.3 |

The choice of feedstock to an ethylene plant substantially affects the amount of coproduct propylene produced. Table A-13 shows typical yields of coproduct propylene from ethylene production using various feedstocks.

Table A-13. Typical Yields of Coproduct Propylene from Various Feedstocks

| Feed ^a | Pounds of Propylene Obtained per Pound of Ethylene Produced |
|--------------------|---|
| Ethane | 0.04 |
| Propane | 0.38 |
| Normal butane | 0.56 |
| Full-range naphtha | 0.43 |
| Gas Oil | 0.60 |

^aCracked under high severity conditions.

All ethylene plants are somewhat flexible as to feedstock especially within the major groups categorized as light (ethane, propane, and butane) and heavy (naphtha and gas oils). New facilities are being designed with an increasing amount of flexibility to process some lighter feedstocks (propane/butane) in conjunction with heavy feeds. This flexibility, although limited currently, has contributed toward a reduction in the amount of propylene produced in ethylene plants. As the crude oil price has risen faster than the natural gas price, light feedstocks (LPGs) are more economical but also produce less propylene per pound of ethylene. Since ethylene plants operate to meet ethylene demand, propylene production has been reduced.

A.7.2.2 Propylene From Refineries

Even with the rapid growth of propylene production from ethylene plants, propylene from refinery production is still necessary to balance demand. Refinery sources have historically supplied 4-6 billion pounds of propylene per year to the chemical industry. The bulk of refinery propylene is produced as offgas in fluid catalytic cracking units (FCCU). Less significant quantities of propylene come from thermal cracking and coking operations. Propylene quality from refineries is usually 40%-60% and, therefore, requires a splitter tower to achieve the desired chemical-grade quality.

The supply of propylene available to chemical derivatives is affected by the internal consumption of propylene in the refinery. Propylene consumption in refineries is dominated by alkylation, the product of which is blended into gasoline. Approximately 6-7 billion pounds of propylene are consumed each year in alkylation. Propylene in excess of alkylation and chemical demands is used as LPG or plant fuel.

The supply/demand outlook for gasoline in the United States has the most direct influence on propylene available from refineries, both in terms of consumption in alkylation and in terms of production from FCC units. We assume that U.S. demand for gasoline will peak around 1980 and decline through 1990 because of improvements in automobile engine efficiency and higher gasoline prices. However, octane demand will continue to rise in order to power the more gasoline-efficient engines. Therefore, alkylate will continue to be a part of the unleaded-gasoline pool.

Alkylation of olefins with iso-butane, to produce high octane components, can use either propylene or butylenes. Butylenes are preferred, because they make higher octane alkylate and consume less iso-butane, the limiting alkylation feedstock. The growing output of butylenes from heavy liquid ethylene crackers will be used in alkylation plants to account for any future growth in alkylation output. A moderate amount of propylene could be backed out of the alkylate pool, especially if gasoline demand drops faster than anticipated. Butylenes will also be used in the manufacture of MTBE, but this will consume only minor quantities of iso-butylene relative to total butylenes produced in new ethylene plants.

Even though catalytically cracked gasoline will decline as a portion of the overall gasoline pool, propylene will continue to be produced in large quantities from this source. The required reductions of catalytically cracked gasoline will be met by trimming back the end point on the catalytically cracked gasoline product, yet keeping the unit running at full capacity.

A.7.2.3 Propylene Availability Trends

During the early 1970s, propylene was generally in strong supply with only occasional temporary shortages. In mid-1974, a very tight situation developed as a result of a combination of circumstances. Propylene demand was growing at a faster rate than ethylene and the corresponding production of coproduct propylene. At the same time, a slowdown in gasoline production kept refinery propylene availability at a fairly constant level. By the end of 1974, a sharp decline in demand for polypropylene and other derivatives eased the propylene supply situation considerably. Throughout 1975, supply was generally more than adequate. Propylene availability in 1976-1978 varied from "loose" to "snug" to "tight" during the summer as refineries needed to allocate much of their propylene to alkylate feed to meet seasonally high gasoline demands. Coproduct propylene availability had been reduced because of sluggish ethylene demand.

In 1979, propylene was in a fairly tight position for two reasons. First, ethylene plants converted to light feedstocks to as great an extent as possible, reflecting higher profitability of cracking LPG feedstocks versus crude-based feedstocks. This shift reduced the amount of coproduct propylene by as much as half a billion pounds on an annual basis. The second reason for the tight market was the higher-than-expected demand for gasoline, coupled with a shortage of crude oil. Propylene use in alkylation reduced its availability to chemicals.

Future trends seem favorable for improving propylene availability. Rapidly increasing production of coproduct propylene from ethylene plants offsets most of the growth in propylene derivative demand, leaving a gradually increasing amount to be supplied by refineries. In the early 1980s, some propylene will be backed out of alkylation to be replaced with the growing coproduct butylene supplies from ethylene plants.

Table A-14 illustrates that ample propylene will be available from refineries to meet chemical demands. We have been deliberately conservative in our estimate of total availability and optimistic in forecasts of usage in gasoline components. This approach reinforces our belief that propylene supplies for chemicals will be more than adequate.

The excess propylene will be used as plant fuel or blended with LPG. It is alternately and preferably available for chemical use if required. The excesses indicated in Table A-14 are conservative. Propylene usage in gasoline could decline more rapidly than indicated, adding to the amount available for chemicals.

Table A-14. Estimated Refinery Propylene Availability
(billion pounds)

| | 1980 | 1985 | 1990 |
|--|------|------|------|
| Total produced | 20 | 20 | 20 |
| Amounts realistically available | 17 | 17 | 17 |
| Alkylation and polymer gasoline demand | 8 | 7 | 6 |
| Chemical demand (see Table A-12) | 5 | 8 | 7 |
| Excess | 4 | 2 | 4 |

A.7.3 Propylene Derivatives

About two-thirds of normal butanol available in the United States is produced by means of the oxo process, which oxidizes propylene to normal butyraldehyde. Normal butyraldehyde is then catalytically hydrogenated to produce normal butanol. Normal butanol is also produced in a Ziegler process, which involves ethylene growth to higher oligomers and conversion to linear alcohols. The Ziegler process is, however, designed to produce longer molecules in the C6 to C20 carbon number range. Oxo process economics are one of the bases for normal butanol pricing. Because oxo processes are usually designed for flexibility of normal butyraldehyde conversion, the price for normal butanol is also strongly influenced by the supply and demand for other oxo chemicals, such as 2-ethylhexanol and butyric acid, as integrated manufacturers continue to produce the most profitable products.

Normal butanol and its derivatives are used in a variety of applications. The largest market for normal butanol historically has been its use as a solvent in protective surface coatings formulations. This market for normal butanol is a mature and low-growth application. Butyl acetate—a normal butanol derivative—also serves as a solvent in the coatings market. The combined consumption of butanol and butyl acetate in the solvents market accounted for over one-third of total consumption in 1978. This market will grow—but will be tied to the growth rate of the domestic economy. The production of two other derivatives—butyl acrylate and butyl methacrylate—is the second largest normal butanol market. These products also serve the coatings and finishes market. They have been successful as a result of their environmentally acceptable properties. Finally, butanol is used as a plasticizer raw material in the production of dibutyl phthalate. The market for dibutyl phthalate is in various flexible PVC formulations.

Oxo process flexibility makes a definitive supply/demand assessment inappropriate. The presentation of the supply/demand evaluation (Table A-15) should be treated as a comparison of consumption and estimated maximum production capability.

A.7.4 Glycerol

Glycerol (or glycerine as it is more commonly known) is available via two very different processes. Synthetic glycerine is produced via caustic hydration of epichlorohydrin (produced from alkyl alcohol); natural glycerine is a by-product of the hydrolysis of natural fats and oils in the soap process. Both natural and synthetic glycerine are available commercially in two grades—96% and 99.5% by weight. Glycerine is produced synthetically by Dow Chemical Company and by FMC Corporation in a tolling arrangement with Oxirane Corporation. Until June 1980, Shell Chemical Company also produced synthetic glycerine, but they have announced their withdrawal from the glycerine business. Shell's exit from the glycerine business is not surprising. The synthetic process is the most expensive supply increment because of high raw materials costs. In the current glycerine market, characterized by stagnant demand and overcapacity, the production cost advantage enjoyed by producers of the natural product allows them to price glycerine at four to five cents below prices posted by producers of synthetics. The result is a market that yields only marginal profits at best for the synthetics producers.

Dow and FMC have not announced plans to withdraw from the glycerine business but have expressed intentions to implement price increases to recover raw materials price increases and to increase the profitability of glycerine production. Producers of the natural product probably will not raise their prices to match the synthetics producers' posted prices, but they have typically followed the pricing trend established by synthetics producers and will probably continue to sell their product at a discount.

Synthetically produced glycerine does serve specific markets because the supply is more dependable and good quality is available from synthetics producers. Natural glycerine supply and quality tend to fluctuate with the fluctuating production requirements for soap. The more dependable supply available from synthetics producers is the primary justification for the two-tier price structure of the glycerine market.

Glycerine is used in a variety of markets including drugs and cosmetics, alkyd resins, tobacco products, foods and beverages, cellophane, explosives, and polyether polyols. The explosives, cellophane, and alkyd resins markets have been stagnant or declining for several years. Glycerine has been replaced by other products, and some end products, such as cellophane, have been replaced. Other markets are very mature and have grown only as has the population. The growth in these markets has offset the decline in the other markets to some extent, but overall, the outlook for growth in glycerine consumption is bleak. Our estimate of the historic and projected supply/demand balances are listed in Table A-16. The data presented are for synthetic glycerine only.

A.8 BUTADIENE

Styrene-butadiene rubber will remain the largest outlet for butadiene, but only modest growth is anticipated because of a continuing trend to longer-wearing radial tires; smaller cars and, therefore, smaller tires; more natural rubber used in many tire formulation; and growing use of specialty elastomers and plastics at the expense of styrene-butadiene rubber in nontire applications. Growth in other butadiene derivatives—ABS,

**Table A-15. Historical and Forecasted Normal Butanol Supply/
Demand Balances**
(million pounds)

| Year | Consumption | Actual Capacity | % Utilization |
|------|-------------|------------------------|--|
| 1975 | 490 | 585 | 84 |
| 1976 | 625 | 830 | 75 |
| 1977 | 637 | 830 | 77 |
| 1978 | 646 | 770 | 84 |
| 1979 | 731 | 950 | 77 |
| 1980 | 635 | 950 | 315 |
| 1981 | 750 | 950 | 200 |
| | | Forecasted Capacity | Domestic Capacity Surplus/(Deficit) |
| 1982 | 770 | 950 | 180 |
| 1983 | 795 | 950 | 155 |
| 1984 | 820 | 950 | 130 |
| 1985 | 845 | 950 | 105 |
| 1990 | 980 | 950 | (30) |

**Table A-16. Historical and Forecasted Synthetic Glycerine
Supply/Demand Balances**
(million pounds)

| Year | Consumption | Actual Capacity | % Utilization |
|------|-------------|------------------------|--|
| 1975 | 136 | 250 | 54 |
| 1976 | 157 | 190 | 83 |
| 1977 | 140 | 190 | 74 |
| 1978 | 134 | 190 | 71 |
| 1979 | 140 | 190 | 74 |
| 1980 | 115 | 140 | 25 |
| 1981 | 120 | 140 | 20 |
| | | Forecasted Capacity | Domestic Capacity Surplus/(Deficit) |
| 1982 | 125 | 140 | 15 |
| 1983 | 130 | 140 | 10 |
| 1984 | 135 | 140 | 5 |
| 1985 | 135 | 140 | 5 |
| 1990 | 135 | 140 | 5 |

polybutadiene, and hexamethylenediamine (intermediate for Nylon 66)—is expected to be steady but unspectacular. However, conversion of nylon production from cyclohexane to a butadiene-based process by more companies than just DuPont could affect future demand significantly.

Table A-17 depicts U.S. butadiene supply/demand balances. Butadiene produced by means of dehydrogenation will continue to decline as coproduct from olefins plants production increases. In 1980, about 28% of total demand will be produced by dehydrogenation. Of this, essentially all will be based on butylenes. Recently, only tire manufacturers who were unable to obtain butadiene or butylenes operated dehydrogenation units on butane. By 1985, normal butane will not be used for butadiene, and butylene feedstocks will account for less than 20% of total production. After 1990, dehydrogenation processes will be nonexistent.

Table A-17. Historical and Forecasted U.S. Butadiene Supply/Demand (billion pounds)

| | 1978 | 1979 | 1980 | 1985 | 1990 |
|-----------------|-------------|-------------|-------------|-------------|-------------|
| Consumption | 4.04 | 4.01 | 3.96 | 4.40 | 5.04 |
| Supply | | | | | |
| Olefins | 2.05 | 2.44 | 2.44 | 3.20 | 4.20 |
| Dehydrogenation | 1.46 | 1.12 | 1.12 | 0.70 | 0.10 |
| Net imports | <u>0.53</u> | <u>0.45</u> | <u>0.40</u> | <u>0.50</u> | <u>0.74</u> |
| Total | 4.04 | 4.01 | 3.96 | 4.40 | 5.04 |

Imports of butadiene are expected to increase gradually through 1990. Imports were a record 650 million pounds in 1978 and would have been higher if material had been available. We anticipate continuing long-term surpluses of butadiene in Europe and Japan although short-term shortages could occur in Japan. All of this is coproduct and thus can be sold in the United States at prices that would not provide an economical return for butadiene from dehydrogenation. There are few alternative uses for butadiene; it is not readily used as a fuel because of a problem in clogging burner tips.

It should be noted that butadiene availability and price are dependent on a number of interrelated factors. Among the items that influence butadiene are:

- Butadiene is an internationally traded bulk commodity; shortages/excesses tend to balance each other in any major geographic area.
- Economic conditions and petrochemical operations in Europe and Japan have direct and indirect effects on the U.S. butadiene market. In both countries, butadiene is supplied only by coproduction in ethylene plants. Supply traditionally exceeds demand and large volumes are readily available for export to the United States as long as ethylene demand remains reasonably strong. Recently there have been some dramatic deviations from this pattern. In Japan, ethylene demand has been weak, but butadiene demand has been very strong because of

high production rates of automobiles and tires. At the same time, coproduct butadiene relative to ethylene declined because of a shift to a lighter feedstock slate. Thus, Japan was forced to become an importer of butadiene and turned to the only available source—Europe. Insufficient European material existed to satisfy both Japanese and American requirements. Butylenes dehydrogenation, then, was required in the United States.

- A long-range trend to lighter ethylene feedstocks in Europe (ethane/propane derived from North Sea natural gas) could result in a permanent reduction of European surplus butadiene.

The collective effect of these and other factors, coupled with domestic butadiene demands, will determine the need for dehydrogenation and thus will determine the price of butadiene. Only fairly minor shifts in one or more of the influencing forces can have a dramatic impact on the U.S. situation. In summary, butadiene will continue to be a very highly leveraged product with volatile prices.

A.9 BENZENE

Benzene is the most important aromatic building block in the petrochemical industry. Annual consumption in the United States is roughly half that of ethylene and equal to propylene. Like these other major basic petrochemicals, benzene is used for many derivatives, especially plastics and fibers.

While ethylene production is completely intentional and propylene is virtually all coproduct or by-product, benzene is obtained by all of these methods. There are four sources of benzene—refineries, pyrolysis gasoline (ethylene plants), coal tar, and toluene hydrodealkylation. Benzene production in the United States is closely tied to gasoline and other fuels. Extraction from pyrolysis gasoline has been of less significance historically because ethylene has been predominantly produced from light feedstocks (ethane and propane), which yield relatively low quantities of aromatics. Benzene from ethylene plants will increase in importance as new facilities based on heavy feedstocks are built, but the shift will be gradual as old capacity is retired.

In 1950, nearly all benzene was derived from coal. The product was expensive and markets were limited. By 1960, about two-thirds of U.S. production was petroleum-based; benzene attained commodity status, and yearly consumption increased to nearly 500 million gallons. Between 1960 and 1970, U.S. benzene use grew at an average annual rate of about 9%, passing the one-billion-gallons/yr mark by 1970. During this period, the United States was a net exporter. Access to low-cost, highly naphthenic domestic crudes and a refining industry oriented toward gasoline production (and reforming) were responsible. This situation was reversed in 1971, and the United States has since been a net importer of benzene.

A.9.1 Benzene Demand

Our forecasts of benzene consumption are shown in Table A-18. The major outlets for benzene are large commodity items and will exhibit only moderate growth—less than 4% annually through 1990 for all derivatives combined. Higher prices and less price stability relative to olefins-based products will also tend to suppress growth.

Table A-18. Historical and Forecasted U.S. Benzene Consumption
(million gallons)

| | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1985 | 1990 |
|--------------|------|------|------|------|------|------|------|------|
| Cumene | 185 | 249 | 245 | 313 | 370 | 322 | 418 | 522 |
| Cyclohexane | 174 | 227 | 233 | 247 | 258 | 241 | 321 | 382 |
| Ethylbenzene | 569 | 757 | 817 | 859 | 883 | 848 | 903 | 1027 |
| Other | 148 | 231 | 232 | 226 | 222 | 215 | 240 | 270 |
| Total | 1076 | 1464 | 1527 | 1645 | 1733 | 1626 | 1882 | 2201 |

A.9.2 Benzene Supply

Most of the significant trends and developments for benzene will be in the supply rather than the demand area. Table A-19 summarizes benzene estimates, and the following discussions note key items in each element of supply.

A.9.2.1 Coal-Based Benzene

Originally, coal tar was the sole source of benzene. Benzene from coal, because of its by-product nature, has been the most economical increment. The light oils that result from carbonization of coal in coke manufacture are processed by both coal tar distillers (usually steel and coke companies) and refiners who buy the light oil streams. For several years, there was a gradual decline in benzene from coal because new steel-making technology required less coke per ton of steel. The effects of this trend have now been completely absorbed, and benzene from light oils is expected to exhibit moderate growth, generally in relation to steel production. Until benzene from coal gasification/liquefaction develops, coal-based benzene supply is essentially independent of demand.

A.9.2.2 Pyrolysis Gasoline

Pyrolysis gasoline, also called dripolene or "drips," is a coproduct of ethylene production. Significant quantities of pyrolysis gasoline (and contained benzene) are produced from cracking heavy feedstocks—naphtha, gas oil, etc. Ethylene plants based on light feedstocks—ethane and propane—yield much lower amounts. Producers of ethylene who use heavy feedstocks generally recover benzene from the drip streams. Those producers using light feedstocks cannot justify benzene extraction because of the small quantities involved. These drip streams are usually sold either to a processor or to a refiner for use in gasoline.

In 1973, about 12% of total U.S. benzene production was derived from pyrolysis gasoline and by 1977 the share was about 20%. These extraction units provide an economical source of benzene and traditionally are run at maximum recovery as determined by the rate of ethylene production. The amount of benzene available from pyrolysis gasoline will increase significantly as major new ethylene capacity, based on heavy liquid feedstocks, comes on stream. By 1985 about 25% of total U.S. benzene output will be from pyrolysis gasoline.

Table A-19. U.S. Benzene Supply/Demand Estimates
(million gallons)

| | 1977 | 1978 | 1979 | 1980 | 1985 | 1990 |
|----------------------|------|-------|------|------|------|------|
| Consumption | 1527 | 1645 | 1733 | 1626 | 1882 | 2201 |
| Supply | | | | | | |
| Coal-based | 144 | 148 | 155 | 153 | 214 | 230 |
| Olefins plants | 305 | 330 | 380 | 370 | 468 | 615 |
| Reformate | 746 | 735 | 791 | 737 | 859 | 981 |
| HDA | 240 | 275 | 405 | 366 | 341 | 375 |
| Imports (net) | 29 | 22 | 52 | — | — | — |
| Total supply | 1464 | 1510 | 1783 | 1626 | 1882 | 2201 |
| Inventory adjustment | (63) | (135) | 50 | — | — | — |

A.9.2.3 Reformate

Extraction of benzene from reformate streams in refineries will continue to be the major source of benzene in the United States. Since reformers and extraction units are run in conjunction with other refinery facilities, benzene availability is affected by demand for other products, especially gasoline.

In the long term, benzene from reformate will increase at a lower rate than total demand. There are two general reasons:

- Little new refining/reforming capacity is being added because of the flat growth situation anticipated in gasoline.
- The proportion of naphthenic-rich domestic crude in the total slate will decline as Middle East and North Slope crude consumption increases. As the aromatics concentration in reformate decreases, the economics of extraction become less attractive because of higher required throughput.

A.9.2.4 Hydrodealkylation (HDA)

Hydrodealkylation of toluene, also referred to as TDA, historically has been the second largest increment of benzene supply in the United States. The terms HDA and TDA may usually be considered synonymous, although materials other than toluene are sometimes fed to an HDA unit. For example, Dow Chemical processes dripolene streams from ethylene plants as well as toluene in HDA units. Also, light oils from coal may sometimes be fed to an HDA unit. HDA-derived benzene is the most expensive increment of supply, and, as such, capacity utilization varies with demand.

There are two distinct groups of HDA plants in the United States: those operated by chemical companies and those controlled by refineries. The basic difference between them is that chemical companies usually operate their units at a steady rate, since they have no alternative outlet for the toluene and usually need the benzene. On the other hand, refiners run their units only when justified by demand/price for benzene; otherwise, the toluene is left in the gasoline pool. In the future, as new ethylene facilities are built by oil companies at or near refineries, the cost differences between the two types of operations should tend to become less pronounced.

Requirements for HDA benzene through 1990 will be flat because:

- a major segment of domestic supply—reformate—is forecast to increase at a rate less than chemical demand for benzene; and
- benzene recovered from olefins plants (pyrolysis gasoline) and coal-based benzene will increase at rates above total demand, but not sufficiently flat to displace the other sources.

The need for HDA benzene could be altered if foreign material becomes available at prices that preclude economic dealkylation of toluene. This benzene would have to be produced in an oil-rich area, most likely the Middle East. Although such a scheme does not make economic sense from a western point of view, it might be done anyway as a means of establishing an industrial base in an oil-producing country(ies).

Because of the uncertainty of future availability of foreign benzene, we have assumed no imports beyond 1979 (Table A-19). If they occur, they would displace material from the HDA category.

Requirements for HDA benzene will steadily increase for these reasons:

- Two segments of domestic supply—coal and reformat—are forecast to increase at rates less than chemical demand for benzene. These sources are related to steel and gasoline production and do not dominate benzene markets.
- Benzene recovered from olefins plants (pyrolysis gasoline) will increase at rates above total demand, but not sufficiently to displace existing sources.

A.10 ACETONE

Acetone is produced by means of isopropanol dehydrogenation and as a coproduct of cumene oxidation to phenol. Most U.S. acetone capacity is based on cumene oxidation, and acetone is, therefore, classified as a benzene derivative. Isopropanol-based acetone capacity represents slightly less than 40% of the total capacity, but this process is much more flexible and responsive to changes in market requirements. During soft market conditions, when demand for phenol is strong and coproduct acetone is readily available, isopropanol-based acetone is usually withdrawn from the market to reestablish a higher price equilibrium. Since the ratio of coproduct acetone and phenol from the cumene oxidation process is essentially fixed, the phenol producers resort to price competition to move acetone inventory. During strong markets for acetone, production from the isopropanol process increases to balance the demand, and prices tend to increase to permit the isopropanol producers to recover costs and generate an acceptable level of investment return. Acetone pricing is, therefore, market driven.

Acetone has been used primarily as a solvent, but environmental regulations have limited acetone's growth in this market. It is now used primarily as a feedstock for production of various methacrylates. Another feedstock market which has been growing rapidly in recent years is bisphenol A production. Bisphenol A has experienced growth rates of 10% and is used in the automotive, construction, and electronic industries. Although it currently accounts for only 5% of total acetone consumption, it is expected to become a significant market. The supply/demand balances are summarized in Table A-20.

A.11 MISCELLANEOUS CHEMICALS

A.11.1 Furfural

Furfural is one of the two chemicals investigated in this Appendix that is not derived from petroleum-based feedstocks. It is produced in the United States solely by the Quaker Oats Company by means of acid hydrolysis of agricultural residue such as rice hulls, corn cobs, and sawdust. Obtaining dependable supplies of these raw materials has proved to be a significant problem for Quaker Oats. To minimize freight costs for transporting raw materials to its extraction plants, Quaker Oats has built its plants in areas where the potential raw material supply is relatively concentrated. However, in recent years, Quaker Oats has experienced difficulty in maintaining the cooperation of corn farmers because of low prices.

**Table A-20. Historical and Forecasted Acetone Supply/
Demand Balances**
(million pounds)

| Year | Consumption | Actual Capacity | % Utilization |
|------|-------------|---------------------|-------------------------------------|
| 1975 | 1,640 | 2,584 | 63 |
| 1976 | 1,921 | 2,645 | 73 |
| 1977 | 2,219 | 3,035 | 73 |
| 1978 | 2,115 | 3,035 | 70 |
| 1979 | 2,300 | 3,460 | 66 |
| 1980 | 1,920 | 3,700 | 1,780 |
| 1981 | 2,400 | 4,070 | 1,670 |
| | | Forecasted Capacity | Domestic Capacity Surplus/(Deficit) |
| 1982 | 2,484 | 4,070 | 1,586 |
| 1983 | 2,571 | 4,070 | 1,499 |
| 1984 | 2,660 | 4,070 | 1,410 |
| 1985 | 2,754 | 4,070 | 1,316 |
| 1990 | 3,270 | 4,070 | 800 |

Rice hulls, which were at one time available from rice mills for the transportation cost to the plant, have become scarce and more expensive as a result of their increasing use as a boiler fuel by rice-milling companies. Wood chips and sawdust from lumber mills are also increasing in price.

Quaker Oats has an estimated 215 million pounds of furfural capacity distributed across five plants. Furfural produced by Quaker Oats is used as a chemical intermediate in furfural alcohol and tetra hydrofuran production and as a solvent in lube oil refining. The major end use of furfural via furfuryl alcohol is in the manufacture of furan resins, consumed by the foundry industry. The use of furan resins in this application is declining as foundries implement energy-conservation techniques in production. Furfural's use as a THF raw material has also declined in recent years after one of the major producers of THF converted its process to utilize captively available 1,4 butanediol. The solvents market for furfural is essentially a stagnant market.

A.11.2 Citric Acid

Citric acid is produced via fermentation of sugar, usually in one of two different processes. The older process, shallow tray fermentation, is a labor-intensive process. Deep-tank or submerged fermentation was developed more recently and is being used to produce citric acid by Miles Laboratories in the United States. Both fermentation processes can use a variety of raw materials, including beet and cane molasses, dextrose from corn syrup, and normal paraffins. The process flexibility allows the producer to choose the most economical raw material for his process at any time and minimize price increases from raw materials.

During the last two years, a general world shortage of sugar and molasses developed, which resulted in dramatic price increases for cane and beet molasses. The rapid increase in prices resulted from the Brazilian government's decision to achieve independence from imported oil by converting its sugarcane production to alcohol fuels for use in automobiles. The price of molasses will probably stabilize or perhaps decline slightly but is not expected to return to pre-1977 levels. Crude oil prices have increased significantly during the same period and normal paraffins have not become more economical as fermentation substrates. As a result, most citric acid production will continue to be based on beet molasses.

A.11.2.1 Markets

Citric acid is used in a variety of markets including foods and beverages, pharmaceuticals, detergents, and industrial applications. The food and beverage industry traditionally has accounted for more than half of total domestic citric acid consumption. This market is maturing, however, and will grow more slowly than it has historically. Citric acid's growth markets will probably be in detergent and industrial applications. Citric acid is replacing phosphate-based sequestrants in liquid detergent formulations as the phosphates continue to be phased out for environmental reasons. Some industrial markets in which citric acid is being used more widely include metal cleaning applications (e.g., tarnish and rust removal), buffering applications, pH control, and steel pickling operations.

A.11.2.2 Domestic Supply/Demand

Miles Laboratories and Pfizer, Inc., are the only U.S. producers of citric acid. Pfizer currently accounts for over 60% of domestic capacity; Miles Laboratories is expanding its capacity by 25 million pounds by 1983 but will still be the smaller producer. Since only these two companies produce citric acid, its production is not reported by the United States International Trade Commission. The supply/demand balances presented in Table A-21 are estimates based on trade sources.

A.11.3 Fumaric Acid

Fumaric acid is produced by means of isomerization of maleic acid in the maleic anhydride process. It is produced in technical and food grades. The food grade has a lower allowable heavy metals content. Technical-grade fumaric acid is the more important commercial product and forms the basis for our fumaric acid price forecast. Technical-grade fumaric acid is used primarily in the production of paper size resins and polyester resins. Other markets for fumaric acid include the alkyd resins and plasticizer markets. None of the fumaric acid markets are experiencing strong growth, and the outlook is for moderate consumption growth. The historical supply/demand balances and our projections indicate that existing capacity is adequate to supply domestic requirements through the year 2000. The supply/demand balance projections are summarized in Table A-22.

**Table A-21. Historical and Forecasted Citric Acid Supply/
Demand Balances**
(million pounds)

| Year | Consumption | Actual Capacity | % Utilization |
|------|-------------|------------------------|--|
| 1975 | 190 | 255 | 75 |
| 1976 | 200 | 255 | 78 |
| 1977 | 225 | 325 | 69 |
| 1978 | 238 | 325 | 73 |
| 1979 | 268 | 340 | 79 |
| 1980 | 260 | 340 | 80 |
| 1981 | 286 | 350 | 64 |
| | | Forecasted Capacity | Domestic Capacity Surplus/(Deficit) |
| 1982 | 303 | 350 | 47 |
| 1983 | 320 | 365 | 45 |
| 1984 | 342 | 365 | 23 |
| 1985 | 362 | 365 | 3 |
| 1990 | 484 | 365 | (119) |

**Table A-22. Historical and Forecasted Fumaric Acid Supply/
Demand Balances**
(million pounds)

| Year | Consumption | Actual Capacity | % Utilization |
|------|-------------|---------------------|-------------------------------------|
| 1975 | 21.0 | 75 | 28.0 |
| 1976 | 34.0 | 75 | 45.0 |
| 1977 | 34.0 | 75 | 45.0 |
| 1978 | 28.0 | 75 | 37.0 |
| 1979 | 29.0 | 75 | 39.0 |
| 1980 | 28.0 | 75 | 47.0 |
| 1981 | 29.0 | 75 | 46.0 |
| | | Forecasted Capacity | Domestic Capacity Surplus/(Deficit) |
| 1982 | 29.6 | 75 | 45.4 |
| 1983 | 30.0 | 75 | 45.0 |
| 1984 | 31.0 | 75 | 44.0 |
| 1985 | 31.4 | 75 | 43.6 |
| 1990 | 35.0 | 75 | 40.0 |

APPENDIX B
COSTS AND PRICES FORECASTS FOR PETROCHEMICALS

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APPENDIX B

COSTS AND PRICES FORECASTS FOR PETROCHEMICALS

B.1 INTRODUCTION

The cost and price forecasts that follow are calculated from a proprietary model that represents the interactions between the general economy and petrochemicals markets. Documentation of this model is available from the Pace Company Houston, Texas. The Solar Energy Research Institute (SERI) neither endorses or refutes the forecasts. Our principal purpose in reporting these forecasts is to provide a starting point for future petrochemical market studies and a basis for computing costs among petroleum-, syn-fuel-, coal-, gas-, and biomass-derived chemicals. Biomass feedstocks are not assessed in the Pace Co. framework. The following forecasts provide only a "base case" for judging biomass substitution possibilities in petrochemical feedstock markets. The costs and prices represent only the conclusions of the Pace Co.

B.2 CRUDE OIL PRICING

Development of a consistent crude oil pricing scenario is basic to determining prices for refined products; hence, petrochemical raw materials and ultimately intermediates and polymers. The Pace Co. price forecasts are presented in Table B-1 in current and constant dollars. In addition to the annual crude oil prices presented in Table B-1, quarterly prices through 1981 are shown in Table B-2. These data illustrate the recent dramatic increases in crude oil prices.

The relative costs presented below are primarily for illustrative purposes. The examples selected represent second-quarter 1979 conditions; accordingly, the crude oil price is \$15.65 per barrel. Note that this is about \$2.00 per barrel below the 1979 annual average, and about \$11.00 per barrel less than the prevailing price in the second quarter of 1980.

B.3 REFINED-PRODUCT AND PETROCHEMICAL PRICES

Historical and projected refined-product and petrochemical prices are consolidated in Table B-3. Note that the prices are annual averages. Through 1979 the prices are actual (current dollars); for forecast years 1980 through 1990, they are expressed in constant 1979 dollars.

The following discussions detail the more important factors underlying the price forecasts, with emphasis on the price-setting mechanisms influencing products of particular interest to new feedstock sources.

The overall complexity of refining operations already has been addressed. The complexity arises from a combination of several factors. First, crude oils are highly variable as to composition. Second, individual refined products, exclusive of LPGs, are blends of many hydrocarbon streams which themselves vary in composition. Third, processing and refinery configurations are almost infinite.

Table B-1. U.S. Crude Oil Price Forecasts
(current 1979 U.S. dollars)

| Period | Controlled Domestic ^a | | Decontrolled Domestic ^b | | Alaskan North Slope | | Foreign | | Average U.S. Refiner Acquisition Cost |
|--------|----------------------------------|-------|------------------------------------|-------|---------------------|------|---------|-------|---------------------------------------|
| | \$/bbl | % | \$/bbl | % | \$/bbl | % | \$/bbl | % | \$/bbl |
| 1976 | 8.19 | 51.22 | 12.84 | 4.16 | 0.00 | 0.00 | 13.58 | 44.62 | 10.79 |
| 1977 | 8.32 | 42.25 | 13.97 | 7.51 | 13.35 | 2.10 | 14.60 | 48.13 | 11.87 |
| 1978 | 9.21 | 37.97 | 14.39 | 8.15 | 13.02 | 6.65 | 14.59 | 47.24 | 12.43 |
| 1979 | 10.52 | 33.89 | 22.93 | 11.69 | 17.82 | 8.03 | 21.60 | 46.38 | 17.70 |
| 1980 | 12.01 | 22.78 | 32.98 | 24.99 | 23.52 | 6.70 | 32.22 | 45.53 | 27.22 |
| 1981 | 12.98 | 7.10 | 34.23 | 43.68 | 24.90 | 1.59 | 33.71 | 47.63 | 32.32 |
| 1982 | 34.63 | 0.00 | 35.44 | 49.51 | 33.32 | 0.00 | 35.32 | 50.49 | 35.38 |
| 1983 | 38.46 | 0.00 | 39.32 | 47.96 | 37.21 | 0.00 | 39.21 | 52.04 | 39.26 |
| 1984 | 42.64 | 0.00 | 43.53 | 47.05 | 41.43 | 0.00 | 43.43 | 52.95 | 43.48 |
| 1985 | 47.03 | 0.00 | 47.97 | 46.11 | 45.84 | 0.00 | 47.84 | 53.89 | 47.90 |
| 1986 | 51.64 | 0.00 | 52.64 | 44.90 | 50.52 | 0.00 | 52.52 | 55.09 | 52.57 |
| 1987 | 56.58 | 0.00 | 57.64 | 43.65 | 55.50 | 0.00 | 57.50 | 56.35 | 57.56 |
| 1988 | 61.92 | 0.00 | 63.05 | 42.27 | 60.88 | 0.00 | 62.88 | 57.73 | 62.95 |
| 1989 | 67.67 | 0.00 | 68.89 | 41.14 | 66.72 | 0.00 | 68.72 | 58.86 | 68.79 |
| 1990 | 74.85 | 0.00 | 76.16 | 40.30 | 73.95 | 0.00 | 75.95 | 59.70 | 76.03 |



Table B-1. U.S. Crude Oil Price Forecasts (Concluded)
(constant U.S. dollars)

| Period | Controlled Domestic ^a | | Decontrolled Domestic ^b | | Alaskan North Slope | | Foreign | | Average U.S. Refiner Acquisition Cost |
|--------|----------------------------------|-------|------------------------------------|-------|---------------------|------|---------|-------|---------------------------------------|
| | \$/bbl | % | \$/bbl | % | \$/bbl | % | \$/bbl | % | \$/bbl |
| 1976 | 10.14 | 51.22 | 15.89 | 4.16 | 0.00 | 0.00 | 16.81 | 44.62 | 13.36 |
| 1977 | 9.72 | 42.25 | 16.32 | 7.51 | 15.59 | 2.10 | 17.06 | 48.13 | 13.87 |
| 1978 | 10.03 | 37.97 | 15.67 | 8.15 | 14.18 | 6.65 | 15.89 | 47.24 | 13.53 |
| 1979 | 10.52 | 33.89 | 22.93 | 11.69 | 17.83 | 8.03 | 21.60 | 46.38 | 17.70 |
| 1980 | 11.00 | 22.78 | 30.20 | 24.99 | 21.53 | 6.70 | 29.50 | 45.53 | 24.93 |
| 1981 | 10.86 | 7.10 | 28.64 | 43.68 | 20.83 | 1.59 | 28.21 | 47.63 | 27.05 |
| 1982 | 26.55 | 0.00 | 27.17 | 49.51 | 25.54 | 0.00 | 27.07 | 50.49 | 27.12 |
| 1983 | 27.36 | 0.00 | 27.96 | 47.96 | 26.46 | 0.00 | 27.89 | 52.04 | 27.92 |
| 1984 | 28.20 | 0.00 | 28.79 | 47.05 | 27.40 | 0.00 | 28.73 | 52.95 | 28.76 |
| 1985 | 29.10 | 0.00 | 29.68 | 46.11 | 28.36 | 0.00 | 29.60 | 53.89 | 29.64 |
| 1986 | 29.98 | 0.00 | 30.56 | 44.90 | 29.33 | 0.00 | 30.49 | 55.09 | 30.52 |
| 1987 | 30.89 | 0.00 | 31.48 | 43.65 | 30.30 | 0.00 | 31.40 | 56.35 | 31.43 |
| 1988 | 31.83 | 0.00 | 32.42 | 42.27 | 31.30 | 0.00 | 32.33 | 57.73 | 32.37 |
| 1989 | 32.80 | 0.00 | 33.38 | 41.14 | 32.33 | 0.00 | 33.30 | 58.86 | 33.34 |
| 1990 | 34.26 | 0.00 | 34.86 | 40.30 | 33.85 | 0.00 | 34.76 | 59.70 | 34.80 |

^aIncludes old and new oil under price controls.

^bIncludes production from stripper wells, production by tertiary methods, and production from the Naval Petroleum Reserve, whose prices were decontrolled September 1, 1976.

Note: Prices are in July 1979 dollars.

Table B-2. U.S. Quarterly Crude Oil Prices Forecasts
(current U.S. dollars)

| Period | Controlled Domestic ^a | | Decontrolled Domestic ^b | | Alaskan North Slope | | Foreign | | Average U.S. Refiner Acquisition Cost |
|--------|----------------------------------|-------|------------------------------------|-------|---------------------|------|---------|-------|---------------------------------------|
| | \$/bbl | % | \$/bbl | % | \$/bbl | % | \$/bbl | % | \$/bbl |
| 1976:1 | 8.15 | 57.86 | 11.30 | 2.04 | 0.00 | 0.00 | 13.49 | 40.10 | 10.35 |
| 1976:2 | 8.16 | 53.33 | 11.72 | 2.46 | 0.00 | 0.00 | 13.56 | 44.21 | 10.63 |
| 1976:3 | 8.23 | 49.86 | 12.63 | 4.14 | 0.00 | 0.00 | 13.59 | 45.99 | 10.88 |
| 1976:4 | 8.24 | 45.91 | 13.63 | 7.28 | 0.00 | 0.00 | 13.64 | 46.81 | 11.16 |
| 1977:1 | 8.23 | 43.74 | 13.63 | 7.31 | 0.00 | 0.00 | 14.39 | 48.95 | 11.64 |
| 1977:2 | 8.14 | 42.91 | 13.69 | 7.39 | 0.00 | 0.00 | 14.61 | 49.71 | 11.77 |
| 1977:3 | 8.26 | 41.73 | 14.14 | 7.64 | 13.34 | 3.09 | 14.65 | 47.55 | 11.91 |
| 1977:4 | 8.66 | 40.65 | 14.39 | 7.71 | 13.35 | 5.32 | 14.76 | 46.32 | 12.18 |
| 1978:1 | 8.79 | 41.24 | 14.31 | 8.09 | 13.32 | 4.97 | 14.61 | 45.70 | 12.12 |
| 1978:2 | 9.09 | 38.82 | 14.40 | 8.28 | 12.96 | 6.90 | 14.49 | 45.99 | 12.28 |
| 1978:3 | 9.34 | 36.45 | 14.40 | 7.96 | 12.95 | 7.25 | 14.49 | 48.33 | 12.50 |
| 1978:4 | 9.63 | 35.68 | 14.45 | 8.26 | 12.97 | 7.33 | 14.76 | 48.73 | 12.77 |
| 1979:1 | 9.81 | 37.10 | 15.22 | 9.34 | 13.58 | 7.45 | 15.91 | 46.11 | 13.41 |
| 1979:2 | 10.27 | 35.60 | 18.26 | 10.15 | 15.53 | 7.97 | 19.23 | 46.28 | 15.65 |
| 1979:3 | 10.85 | 32.65 | 24.75 | 12.56 | 19.94 | 8.06 | 24.02 | 46.73 | 19.48 |
| 1979:4 | 11.31 | 30.31 | 29.36 | 14.64 | 21.52 | 8.65 | 27.00 | 46.40 | 22.12 |
| 1980:1 | 11.52 | 28.47 | 33.39 | 18.25 | 23.65 | 8.82 | 31.87 | 44.46 | 25.63 |
| 1980:2 | 11.99 | 25.17 | 33.14 | 22.76 | 23.20 | 7.40 | 32.57 | 44.67 | 26.82 |
| 1980:3 | 12.30 | 20.82 | 32.85 | 27.28 | 23.50 | 5.99 | 32.28 | 45.90 | 27.75 |
| 1980:4 | 12.49 | 16.88 | 32.76 | 31.42 | 23.79 | 4.66 | 32.15 | 47.04 | 28.63 |
| 1981:1 | 12.75 | 13.29 | 33.33 | 35.30 | 24.64 | 3.40 | 33.59 | 48.01 | 30.42 |
| 1981:2 | 13.06 | 9.60 | 33.73 | 41.67 | 25.08 | 2.14 | 33.75 | 46.59 | 31.57 |
| 1981:3 | 13.39 | 5.61 | 34.73 | 45.96 | 25.50 | 0.83 | 33.75 | 47.60 | 32.99 |
| 1981:4 | 33.22 | 0.00 | 34.79 | 51.69 | 0.00 | 0.00 | 33.75 | 48.31 | 34.29 |

^aIncludes old and new oil under price controls.

^bIncludes production from stripper wells, production by tertiary methods, and production from the Naval Petroleum Reserve, whose prices were decontrolled September 1, 1976.

Note: Prices are in July 1979 dollars.

Table B-3. PETROCHEMICAL PRICES FORECASTS

(constant 1979 dollars)

| | Units | Actual | | | | | | Forecast | | | | | | | |
|--------------------------|--------|--------|-------|-------|-------|-------|-------|----------|-------|-------|-------|-------|-------|-------|-------|
| | | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1990 | 1995 | 2000 |
| Ethane | ¢/gal | — | 14.4 | 14.8 | 13.5 | 17.7 | 25.7 | 27.9 | 28.5 | 30.7 | 34.1 | 37.5 | 58.7 | 66.4 | 76.8 |
| Propane | ¢/gal | — | 20.0 | 27.0 | 22.8 | 28.3 | 38.3 | 39.1 | 42.2 | 43.9 | 42.8 | 41.7 | 69.2 | 79.4 | 91.6 |
| Normal butane | ¢/gal | — | 25.3 | 29.0 | 24.4 | 54.3 | 53.7 | 59.1 | 71.2 | 73.9 | 68.2 | 64.7 | 76.7 | 88.1 | 101.6 |
| Iso-butane | ¢/gal | — | 27.9 | 35.6 | 27.8 | 72.4 | 72.7 | 68.1 | 78.4 | 80.3 | 73.2 | 68.7 | 80.7 | 92.1 | 105.6 |
| Ethylene | ¢/lb | — | 11.9 | 12.5 | 13.0 | 15.6 | 20.5 | 20.5 | 23.1 | 25.1 | 27.3 | 29.8 | 34.9 | 39.5 | 45.1 |
| Chemical-grade propylene | ¢/lb | — | 8.4 | 9.2 | 9.2 | 11.3 | 16.4 | 16.1 | 16.5 | 16.3 | 16.2 | 16.2 | 20.6 | 23.3 | 26.7 |
| Benzene | ¢/gal | — | 81.9 | 78.8 | 72.5 | 135.0 | 145.7 | 131.7 | 157.5 | 162.3 | 168.3 | 177.2 | 205.4 | 231.1 | 267.8 |
| Butadiene | ¢/lb | — | 18.5 | 19.5 | 20.5 | 23.5 | 25.1 | 26.1 | 31.0 | 32.0 | 32.3 | 32.9 | 17.7 | 19.8 | 22.3 |
| Methanol | ¢/gal | — | 40.6 | 41.5 | 43.0 | 48.3 | 53.6 | 59.6 | 57.1 | 58.2 | 56.0 | 47.2 | 98.0 | 107.9 | 119.7 |
| Ammonia | \$/ton | — | 107.6 | 113.9 | 100.5 | 107.9 | 129.8 | 162.8 | 176.9 | 187.9 | 200.1 | 209.0 | 317.3 | 350.6 | 388.3 |
| Acetic acid | ¢/lb | 12.5 | 14.4 | 15.3 | 16.2 | 17.1 | 18.0 | 20.7 | 22.4 | 23.0 | 23.0 | 23.4 | 27.7 | 30.5 | 33.7 |
| Butylene | ¢/gal | — | 26.3 | 27.8 | 30.7 | 38.8 | 57.2 | 55.0 | 49.1 | 52.0 | 57.7 | 66.6 | 73.2 | 83.0 | 95.1 |
| Acetone | ¢/lb | 12.5 | 13.4 | 14.3 | 15.2 | 16.9 | 23.3 | 23.3 | 20.8 | 20.8 | 20.8 | 20.8 | 20.8 | 20.8 | 20.8 |
| Fumaric acid | ¢/lb | 43.0 | 43.0 | 43.0 | 43.0 | 45.0 | 45.9 | 47.2 | 53.4 | 55.4 | 56.9 | 58.8 | 65.2 | 70.3 | 77.7 |
| Lactic acid | ¢/lb | 44.5 | 61.0 | 61.0 | 66.0 | 71.5 | 74.1 | 75.7 | 77.2 | 78.3 | 79.5 | 80.9 | 90.8 | 95.2 | 100.7 |
| Propionic acid | ¢/lb | 15.0 | 14.9 | 18.8 | 18.7 | 18.6 | 21.1 | 23.0 | 25.5 | 27.4 | 28.7 | 30.1 | 36.2 | 40.3 | 45.1 |
| Ethanol | ¢/gal | 101.0 | 115.9 | 115.8 | 114.7 | 123.1 | 144.1 | 151.6 | 169.0 | 180.7 | 189.1 | 198.3 | 225.6 | 250.3 | 279.6 |
| Normal Butanol | ¢/lb | 15.5 | 18.4 | 17.3 | 19.2 | 20.0 | 24.8 | 27.8 | 29.8 | 30.5 | 30.0 | 30.9 | 38.3 | 42.6 | 47.5 |
| 1,4 butanediol | ¢/lb | 55.0 | 55.0 | 50.0 | 50.0 | 56.5 | 54.9 | 58.5 | 59.8 | 60.3 | 60.4 | 62.0 | 68.7 | 71.1 | 74.3 |
| Furfural | ¢/lb | 37.0 | 47.0 | 47.0 | 51.5 | 51.5 | 49.6 | 54.3 | 58.6 | 61.4 | 61.4 | 61.3 | 59.5 | 58.6 | 57.7 |
| Glycerine | ¢/lb | 50.0 | 50.0 | 50.0 | 52.5 | 55.0 | 58.0 | 64.4 | 67.3 | 69.1 | 70.4 | 72.3 | 99.1 | 108.5 | 119.5 |
| Citric Acid | ¢/lb | 55.5 | 55.5 | 58.5 | 62.0 | 62.0 | 63.2 | 63.6 | 62.8 | 63.5 | 64.1 | 64.8 | 67.1 | 78.7 | 93.5 |

Current Dollars

| | | | | | | | | | | | | | | | |
|--------------------------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|--------|
| Ethane | ¢/gal | — | 14.4 | 14.8 | 13.5 | 17.7 | 30.2 | 33.4 | 37.3 | 43.2 | 51.6 | 60.5 | 128.3 | 190.4 | 288.4 |
| Propane | ¢/gal | — | 20.0 | 27.0 | 22.8 | 28.3 | 41.8 | 46.8 | 55.2 | 61.7 | 64.7 | 67.3 | 151.2 | 227.1 | 342.9 |
| Normal butane | ¢/gal | — | 25.3 | 29.0 | 24.4 | 54.3 | 58.6 | 70.6 | 92.9 | 103.9 | 103.1 | 104.5 | 167.7 | 251.9 | 380.3 |
| Iso-butane | ¢/gal | — | 27.9 | 35.6 | 27.8 | 72.4 | 79.3 | 81.4 | 102.3 | 113.0 | 110.6 | 111.0 | 176.5 | 263.5 | 395.7 |
| Ethylene | ¢/lb | — | 11.9 | 12.5 | 13.0 | 15.6 | 22.2 | 24.5 | 30.3 | 35.3 | 44.1 | 48.1 | 76.3 | 113.6 | 170.0 |
| Chemical-grade propylene | ¢/lb | — | 8.4 | 9.2 | 9.2 | 11.3 | 17.9 | 19.3 | 21.6 | 22.9 | 24.4 | 26.1 | 45.1 | 66.9 | 100.4 |
| Benzene | ¢/gal | — | 81.9 | 78.8 | 72.5 | 135.0 | 158.8 | 157.1 | 205.6 | 227.7 | 253.3 | 285.1 | 447.5 | 661.4 | 1007.2 |
| Butadiene | ¢/lb | — | 18.5 | 19.5 | 20.5 | 23.5 | 28.3 | 31.2 | 40.4 | 45.1 | 48.9 | 53.2 | 38.6 | 56.6 | 83.9 |
| Methanol | ¢/gal | — | 40.6 | 41.5 | 43.0 | 48.3 | 63.9 | 71.2 | 74.8 | 81.9 | 84.5 | 92.4 | 221.8 | 322.3 | 470.4 |
| Ammonia | \$/ton | — | 107.6 | 113.9 | 100.5 | 107.9 | 152.4 | 194.6 | 231.4 | 264.5 | 302.2 | 337.5 | 694.0 | 1007.5 | 1464.0 |
| Acetic acid | ¢/lb | 12.5 | 14.4 | 15.3 | 16.2 | 17.1 | 20.0 | 24.8 | 29.3 | 32.3 | 34.7 | 37.8 | 61.4 | 88.8 | 129.2 |
| Butylene | ¢/gal | — | 26.3 | 27.8 | 30.7 | 38.8 | 62.3 | 65.7 | 64.0 | 73.2 | 87.2 | 107.4 | 159.9 | 237.5 | 356.2 |
| Acetone | ¢/lb | 12.5 | 13.4 | 14.3 | 15.2 | 16.9 | 25.3 | 27.8 | 27.3 | 29.2 | 31.3 | 33.4 | 45.4 | 60.1 | 79.7 |
| Fumaric acid | ¢/lb | 43.0 | 43.0 | 43.0 | 43.0 | 45.0 | 50.2 | 56.3 | 69.9 | 77.8 | 85.6 | 94.8 | 142.7 | 203.4 | 296.4 |
| Lactic acid | ¢/lb | 44.5 | 61.0 | 61.0 | 66.0 | 71.5 | 81.6 | 90.4 | 101.2 | 110.1 | 119.8 | 130.5 | 199.8 | 277.4 | 388.3 |
| Propionic acid | ¢/lb | 15.0 | 14.9 | 18.8 | 18.7 | 18.6 | 23.3 | 27.5 | 33.3 | 38.5 | 43.3 | 48.6 | 79.2 | 116.0 | 170.4 |
| Ethanol | ¢/gal | 101.0 | 115.9 | 115.8 | 114.7 | 123.1 | 158.3 | 181.2 | 221.2 | 254.3 | 285.4 | 320.0 | 493.7 | 720.2 | 1056.5 |
| Normal butanol | ¢/lb | 15.5 | 18.4 | 17.3 | 19.2 | 20.0 | 27.4 | 33.3 | 39.0 | 42.9 | 45.3 | 49.9 | 84.0 | 122.5 | 179.4 |
| 1,4 butanediol | ¢/lb | 55.0 | 55.0 | 50.0 | 50.0 | 56.5 | 60.4 | 69.8 | 78.4 | 84.8 | 91.0 | 99.9 | 150.8 | 206.9 | 286.2 |
| Furfural | ¢/lb | 37.0 | 47.0 | 47.0 | 51.5 | 51.5 | 53.6 | 64.8 | 76.8 | 86.4 | 92.6 | 99.2 | 132.2 | 174.7 | 231.3 |
| Glycerine | ¢/lb | 50.0 | 50.0 | 50.0 | 52.5 | 55.0 | 65.7 | 76.9 | 88.1 | 97.3 | 106.3 | 116.9 | 217.8 | 314.8 | 456.9 |
| Citric acid | ¢/lb | 55.5 | 55.5 | 58.5 | 62.0 | 62.0 | 68.7 | 75.9 | 82.5 | 89.3 | 96.3 | 104.1 | 146.3 | 227.5 | 358.3 |

There are many arbitrary mechanisms associated with the real cost of producing a specific refined product. Generally, the cost of a specific product means very little to the refiner. His concern is only with total revenue and total cost of operation. For accounting purposes, and in the daily course of operating the refinery, the refinery may allocate costs (variable and fixed) to individual products; but this is not meant to indicate whether one product is more profitable than another. For example, a refiner may want to sell more gasoline because its price is high. In order to process more crude oil he must produce more residual fuel oil—which he might have to sell at a very low price. Hence, he must recover in his price for gasoline the loss he expects on residual fuel oil. In summary, the total refinery's cost structure must be considered since assignment of "cost" to products is arbitrary.

As an illustration, Table B-4 represents an operating income statement of a typical 150 thousand-barrels-per-day, high-conversion refinery operating in second-quarter 1979, running at 84.8% utilization, and selling all products on contract. This refiner produced the product slate listed in Table B-5 (along with other operating and investment data). The refiner's main concern is that he must recover his costs; i.e., 43.7 cents per gallon on average. How much of this total cost he can recover on gasoline is dependent on government regulation and, more importantly, on the strength of the marketplace. In the example cited in Tables B-4 and B-5, the marketplace and the government allowed him to sell products for an average realized value of 49.28 cents per gallon. Thus his gross operating profit was 5.28 cents per gallon (after depreciation charges of 2.52 cents per gallon).

The prices at which this refiner sold his product appear in Table B-6 (average contract values). If we assume that the average cost applies to all products (i.e., 43.7 cents per gallon), those products which sold for less theoretically lost money, while those that sold for more made money. The prices of other products, however (e.g., gasoline, jet fuel, and heating oil), were sufficiently high to allow recovery of all costs of refining, plus a before-tax profit of 16.7%.

B.4 NATURAL GAS PRODUCTS

B.4.1 Normal Butanes

Butane's value as a boiler fuel will set its price through the forecast horizon after 1985. In the short term (1980-1985), its value as a gasoline blend stock will be the price-setting basis.

B.4.2 Iso-Butane

Iso-butane's principal use as a raw material for gasoline alkylation will determine its price in the short term. As alkylation requirements stagnate, iso-butane will become more competitive (on a Btu basis) to normal butane as a boiler fuel.

Table B-4. Estimated Manufacturing Cost of Refined Products by Existing Refinery

Basis: (1) Size based on: 150000 bbl per day of average mix crude.
 (2) Crude oil priced at 15.65 \$/bbl.
 (3) Nelson's Index = 743.
 (4) Product cost based on: 141479.9 bbl per day of refined products.
 (5) Mfg. cost includes profit at 16.7% and depreciation at 10.0%.
 (6) Utilization factor is: 84.8%.

| Investments | | \$ (millions) | |
|------------------|--|------------------|--|
| On site | | 227371.3 | |
| Off site | | 210188.8 | |
| Total plant inv. | | 437560.1 | |
| Royalty | | 7255.5 | |
| Total fixed inv. | | 444815.6 | |
| Catalysts | | 2508.1 | |
| Working cap. | | 90962.4 | |
| Total inv. | | 538286.0 | |

| Manufacturing Costs | Rate | \$/Yr (millions) | Refined Products (¢/gal) |
|---|-------------------------|------------------|-----------------------------|
| Raw materials cost | | | |
| Average mix crude | 15.65 \$/bbl | 696737.9 | 39.51 |
| N-butane | 55.00¢/gal | 19643.8 | 1.11 |
| Total | | 716381.7 | 40.62 |
| By-product credits | | | |
| Chem-G propylene | 9.80 ¢/lb | -20087.2 | -1.14 |
| Propane LPG | 25.20 ¢/gal | -11451.4 | -0.65 |
| Fuel production | 291.07 ¢/MBtu | -34859.3 | -1.98 |
| Total | | -66397.9 | -3.76 |
| Total raw materials + by-products | | | |
| Salaries and wages | 9.30 \$/Operator-hr | 8016.4 | 0.45 |
| Utilities | | | |
| Fuel | 291.07 ¢/MBtu | 34859.3 | 1.98 |
| Power | 23.10 M/kWh | 5100.9 | 0.29 |
| Make-up water | 0.30 \$/Mgal | 635.4 | 0.04 |
| Total | | 40595.6 | 2.30 |
| Maintenance | 4.0 % on + 2.0% off | 13298.6 | 0.75 |
| Plant supplies | 8.0% Maint. | 1063.9 | 0.06 |
| Catalysts & chemicals | | 4541.0 | 0.26 |
| Taxes and ins. | 2.0% Plant inv. | 8751.2 | 0.50 |
| Depreciation | 10.0% Fixed inv. | 44481.5 | 2.52 |
| Total mfg. cost | | 770732.1 | 43.70 |
| Before-tax profit | 16.7% total inv. | 89867.2 | 5.10 |
| Admin. and mktg. | 1.0% Total mfg. + prof. | 8606.0 | 0.49 |
| Total mfg. cost, incl. profit and marketing: | | 869205.2 | 49.28 |

Table B-5. Estimated Existing Refinery Yields and Operating Data

| Yield Data | | | |
|-------------------------|----|---------------------------------------|----|
| Raw materials | | Vol. fraction | |
| Average mix crude | CR | 1.0000 Bbl/bbl | Cr |
| N-butane | N4 | 0.0191 Bbl/bbl | Cr |
| By-products | | Vol. fraction | |
| Chem-G propylene | PY | 0.0252 Bbl/bbl | Cr |
| Propane LPG | C3 | 0.0243 Bbl/bbl | Cr |
| Fuel production | NG | 0.0427 Foe/bbl | Cr |
| Products | | Vol. fraction | |
| Refined products | RP | 0.9432 Bbl/bbl | Cr |
| BTX-range naphtha | LN | 0.0415 Bbl/bbl | Cr |
| Full-range naphtha | HN | 0.0597 Bbl/bbl | Cr |
| Premium gasoline | G1 | 0.0418 Bbl/bbl | Cr |
| Unleaded gasoline | G2 | 0.2508 Bbl/bbl | Cr |
| Regular gasoline | G3 | 0.1015 Bbl/bbl | Cr |
| Kerosene/Jet-A | KK | 0.0657 Bbl/bbl | Cr |
| No. 2 fuel oil | N2 | 0.2389 Bbl/bbl | Cr |
| No. 6 fuel (0.75%) | R3 | 0.0418 Bbl/bbl | Cr |
| Bunkers | R1 | 0.1015 Bbl/bbl | Cr |
| Operating Data | | | |
| Fuel | | 0.0427 Foe/bbl | Cr |
| Power usage | | 4.9600 kWh/bbl | Cr |
| Make-up water | | 0.0471 Mgal/bbl | Cr |
| Steam usage | | 0.0 Mlb/bbl | Cr |
| Catalysts and chemicals | | 0.1020 \$/bbl | Cr |
| Circ. water | | 0.0 Mgal/bbl | Cr |
| Power distr. | | 0.0 kWh/bbl | Cr |
| Investment Data | | | |
| On site | | 197340.00 \$ (millions) | |
| Off site | | 182427.00 \$ (millions) | |
| Paid-up royalties | | 8100.00 \$ (millions) | |
| Initial cat. chem. | | 2800.00 \$ (millions) | |
| Storage | | 70.00 days | |
| Scale-up factor | | 0.65 | |
| Nelson's Index | | 600.00 | |
| Base size | | 167460.00 bbl/SD of average mix crude | |
| Manpower | | 41.00 Men/shift | |
| Admin. and mktg. cost | | 1.00 Percentage mfg. cost + profit | |
| Stream days per year | | 350.00 days | |

Table B-6. Refined-Product Prices
(second quarter 1979)

| | | |
|--------------------------|--------------|-------------|
| Crude oil | \$/bbl | 15.6 |
| BTX-range naphtha | ¢/gal | 53.9 |
| Full-range naphtha | ¢/gal | 51.4 |
| Premium gasoline | ¢/gal | 55.6 |
| Unleaded gasoline | ¢/gal | 54.4 |
| Regular gasoline | ¢/gal | 51.0 |
| Kerosene/Jet-A | ¢/gal | 52.4 |
| No. 2 fuel oil | ¢/gal | 48.6 |
| No. 6 fuel oil (0.75% S) | ¢/gal | 39.8 |
| Bunkers | ¢/gal | 32.7 |
| <u>Ethane</u> | <u>¢/gal</u> | <u>15.8</u> |
| Propane | ¢/gal | 25.2 |
| Normal butane | ¢/gal | 55.0 |
| Iso-butane | ¢/gal | 77.0 |

B.4.3 Ethane

The natural gas processor's incremental cost of ethane recovery from average-price natural gas will set the minimum ethane price. On the demand side, the producer of ethylene (who is the only market for ethane) will determine the actual selling price for ethane as he compares the prices of available feedstocks. Ethane competes most directly with propane; therefore, it will not be priced much higher than propane. Since propane is expected to be priced at a premium relative to other fuels, ethane's price will be adequate to provide the gas processor with an incentive to recover it.

B.4.4 Propane

Propane pricing will depend on market supply/demand considerations. The projected LPG surplus will have a depressing effect on propane pricing after 1983. However, propane's versatility as a fuel for residential and commercial heating, its use in crop drying, and its potential as an ethylene plant feedstock will provide gas processors with a margin over extraction and shrinkage costs.

B.4.5 Acetic Acid

The price of acetic acid is based on the methanol carbonylation process' costs. Since supplies of acetic acid are projected to be adequate until the late 1980s, the most recent expansions via the methanol carbonylation process will set prices. After 1985, prices will increase to support the new supply increments which we believe will be based on the methanol carbonylation process.

B.4.6 Ammonia

Ammonia's commodity nature has encouraged the construction of large plants that take advantage of economies of scale. Producers tend to accept low-profit margins and depend on high-volume and plant utilization rates to generate favorable returns on investment. Raw material prices, specifically natural gas, will be the basis for ammonia prices unless low-price imports from Russia, for example, force prices below domestic equilibrium levels.

B.4.7 1,4 Butanediol

Capacity for 1,4 butanediol is adequate through the late 1980s. Since the 1,4 butanediol industry is dominated by two producers with significant captive requirements, 1,4 butanediol prices will reflect manufacturing costs plus an incentive above the two producers' alternate captive uses. New capacity probably will be based on the Reppe process used in existing facilities. In order to develop a manufacturing cost basis for 1,4 butanediol, we also developed formaldehyde process economics.

B.4.8 Methanol

The methanol process uses synthesis gas composed of hydrogen and carbon monoxide. Existing methanol plants have been based on natural gas-based synthesis gas conversion plants, but the availability of alternative feedstock gasification will result in a shift to methanol based on coal and biomass as raw materials. Prices will reflect the costs of this emerging technology, but the commodity nature of methanol will continue to result in periods of price volatility, depending on demand fluctuations. Fuel use will be a prime determinant of future total methanol demand. (Methanol is the subject case study of the body of this report.)

B.4.9 Ethylene

The price of ethylene (or any other petrochemical) is set by the highest cost increment of supply needed to meet demand. In a strong ethylene market, consumers must pay a price that will cover the costs of manufacture plus some profit for a new naphtha-based olefins plant. In a very tight market, customers will pay more, increasing the profit; in a weak market where the new heavy liquids facility is not required to meet demand, it will often not make money except on a variable-cost basis. Ethylene produced from a lower-cost plant (i.e., one that is fully depreciated and/or uses lower cost feedstock such as ethane) sells for the same price; its producer simply makes more money.

The means by which ethylene plant and refinery operations and economics are linked is illustrated in Table B-7. This table represents investment and operating costs for a new naphtha-based plant producing ethylene at the rate of 1 billion pounds per year in the second quarter of 1979. Note that the feedstock cost (51.4 cents per gallon) is the same as the price of full-range naphtha shown in Table B-6. By-product prices are also consistent; i.e., normal butane is 55.0 cents per gallon, propane is 25.2 cents per gallon, etc. (All of these quarterly prices are also consistent with the annual values shown in Table B-3.)

During the second quarter of 1979 the market price of ethylene was 14.0 cents per pound, as set by the marketplace. This is shown at last entry in Table B-7. However, at this price the ethylene plant lost money on a full-cost (including depreciation) basis, as seen as the third entry from the last.

With the industry operating at about 80% of capacity, the market would not support an ethylene price required to generate a profit in this most expensive supply increment. An ethylene selling price of 14.8 cents per pound would have been required to break even, and 22.6 cents per pound for a 20% before-tax profit. An older naphtha-based plant with lower investment (hence lower depreciation costs) could have been profitable during this period, and a fully depreciated LPG-based facility would have been extremely profitable. In the future, as ethylene demand grows and operation of new plants as represented by Table B-7 is required, the price of ethylene will rise to the level necessary to yield a profit in these plants.

The same principle applies for ethylene derivatives. The price movements of ethylene are analogous to movements in naphtha prices. The situation is less complex, however, in that there are no coproduct or alternate feedstock considerations. Profitability (or lack thereof) of individual plants is determined largely by the age of the facility and efficiencies concerning energy consumption yields, etc.

Table B-7. Estimated Manufacturing Costs of Ethylene by Ethylene Plant, HS, Heavy Naphtha

| Basis: | | | |
|--------|------------------------------|--------------------------------------|--|
| (1) | Size based on: | 36308. bbl per day of heavy naphtha. | |
| (2) | Crude oil priced at | 15.65 \$/bbl. | |
| (3) | Nelson's Index = | 743. | |
| (4) | Product cost based on: | 2857112.0 lb day of ethylene. | |
| (5) | Mfg. cost includes profit at | 2.1% and depreciation at 10.0%. | |
| (6) | Utilization factor is | 100.0%. | |

| Investments | \$ (millions) | | |
|-------------------|-----------------|--|--|
| On site | 231196.0 | | |
| Off site | 122405.1 | | |
| Total plant inv. | 353601.1 | | |
| Royalty | 1800.0 | | |
| Total fixed inv. | 355401.1 | | |
| Catalysts | 600.0 | | |
| Working cap. | 31052.0 | | |
| Total inv. | 387053.1 | | |

| Manufacturing Costs | Rate | \$/Yr (millions) | Ethylene (¢/lb) |
|--|-------------------------|------------------|-----------------|
| Raw materials cost | | | |
| Heavy naphtha | 51.40 ¢/gal | 274335.3 | 27.43 |
| Total | | 274335.3 | 27.43 |
| By-product credits | | | |
| Fuel gas | 291.07 ¢/MBtu | -41921.5 | -4.19 |
| Propane | 25.20 ¢/gal | -2125.3 | -0.21 |
| Propylene | 9.80 ¢/lb | -41728.5 | -4.17 |
| N-butane | 55.00 ¢/gal | -381.6 | -0.04 |
| Butylene | 30.20 ¢/gal | -8075.9 | -0.81 |
| Butadiene | 21.50 ¢/lb | -31452.5 | -3.15 |
| I-Butane | 77.00 ¢/gal | -534.3 | -0.05 |
| Pyrol C5's | 53.90 ¢/gal | -6472.8 | -0.65 |
| Raffinate | 51.40 ¢/gal | -7269.9 | -0.73 |
| Benzene | 135.00 ¢/gal | -47122.8 | -4.71 |
| Toluene | 110.11 ¢/gal | -23390.2 | -2.34 |
| Mixed xylenes | 112.11 ¢/gal | -18848.6 | -1.88 |
| C9+ aromatics | 65.52 ¢/gal | -8392.6 | -0.84 |
| Gas oil | 47.60 ¢/gal | -3277.3 | -0.33 |
| Pitch | 37.80 ¢/gal | -4377.9 | -0.44 |
| Loss | 0.0 lb. | 0.0 | 0.0 |
| Total | | -245371.5 | -24.54 |
| Total raw materials + by-products | | 28963.8 | 2.90 |
| Salaries and wages | 9.30 \$/Operator-hr | 4888.1 | 0.49 |
| Utilities | | | |
| Fuel | 291.07 ¢/MBtu | 46286.1 | 4.63 |
| Power | 23.10 M/kWh | 10227.3 | 1.02 |
| Make-up water | 0.30 \$/Mgal | 451.1 | 0.05 |
| Total | | 56964.5 | 5.70 |
| Maintenance | 4.0 % on + 2.0% off | 11695.9 | 1.17 |
| Plant supplies | 8.0% Maint. | 935.7 | 0.09 |
| Catalysts & chemicals | | 751.9 | 0.08 |
| Taxes and ins. | 2.0% Plant inv. | 7072.0 | 0.71 |
| Depreciation | 10.0% Fixed inv. | 35540.1 | 3.55 |
| Total mfg. cost | | 146811.9 | 14.68 |
| Before-tax profit | -2.1% total inv. | -8199.5 | -0.82 |
| Admin. and mktg. | 1.0% Total mfg. + prof. | 1386.1 | 0.14 |
| Total mfg. cost, incl. profit and marketing: | | 139998.4 | 14.00 |

B.4.10 Ethanol

Ethanol pricing may develop into a two-tier system if fermentation producers legally are limited to selling to the fuels market. Synthetic ethanol will continue to serve the petrochemical feedstock markets since biomass ethanol processes are subsidized in fuels markets. Biomass ethanol capacity currently exceeds ethylene-based capacity in the United States. Ethanol has been the subject of intensive study at the Solar Energy Research Institute (SERI).

B.4.11 Propionic Acid

Forecasts indicate that the availability of adequate supplies of propionic acid will be based on existing manufacturing economics and raw material prices. As demand gradually expands to use all existing capacity, producers probably will try to increase profit margins.

B.4.12 Lactic Acid

Lactic acid prices will reflect Monsanto's costs and profit requirements. Although imports provide competition in regions near ports of entry, they do not provide sufficient price pressure to change lactic acid's pricing basis.

B.4.13 Propylene

Propylene pricing analysis is more complex than ethylene because propylene production is totally by-product or coproduct; ethylene is a primary product. In addition, propylene is produced in large quantities in both olefins plants and refineries, and the amount of ethylene produced in refineries is insignificant. Further, propylene has alternate uses in gasoline and fuels markets, while ethylene is used only as a petrochemical building block.

Propylene coproduced in ethylene plants is insufficient to meet total chemical demand. The incremental propylene needed for chemicals must be supplied by refineries. An economic incentive must therefore be provided for the refiner to remove propylene from alternative uses. Propylene is priced relative to its value in LPG (propane used as fuel) or in gasoline (propylene alkylate) plus extraction and distillation costs (see Table B-8).

It is important to understand that some refiners must produce a certain amount of alkylate to meet their volume demand and quality of gasoline. It is the next or incremental barrel that is used as a measure of whether the refiner uses propylene for alkylate or turns to an alternate use.

The data shown in Table B-9 reflect second-quarter 1979 conditions. At that time the price of unleaded gasoline was 54.4 cents per gallon and the value of propylene alkylate in gasoline was 55.7 cents per gallon. Normal and iso-butane prices were 55.0 and 77.0 cents per gallon, respectively, and chemical-grade propylene was 9.8 cents per pound. All of the variables of the alkylation economics are fixed (Table B-9) except the profit, which is negative. Obviously the refiner would not use his propylene in alkylate if he must buy iso-butane at 77 cents per gallon but can only sell the product at 55.7 cents per gallon.

Table B-8. Estimated Manufacturing Costs of Propylene Alkylate by Propylene Alkylation

- Basis:**
- (1) Size based on: 1727. bbl per day propylene alkylate.
 - (2) Crude oil priced at \$15.65 per barrel.
 - (3) Nelson's Index = 743.
 - (4) Product cost based on 1,727 bbl per day of propylene alkylate.
 - (5) Mfg. cost includes depreciation of 10%.
 - (6) Utilization factor is 100.0%.

| | Value | \$/Yr (millions) | Propylene Alkylate (¢/gal) |
|--|--------------------------|---------------------|----------------------------------|
| Manufacturing Costs | | | |
| Raw Material cost: | | | |
| Propylene | 9.80 ¢/lb | 6,266.2 | 24.68 |
| Iso-butane | 77.00 ¢/gal | 14,720.2 | 57.99 |
| Total | | 20,986.4 | 82.67 |
| By-product credits | | | |
| N-butane | 55.00 ¢/gal | 226.2 | 0.89 |
| Total raw materials and by-products | | 20,760.2 | 81.78 |
| Salaries and wages | 9.30 \$/Operator/hr | 391.0 | 1.54 |
| Utilities | | | |
| Fuel | 291.07 ¢/MBtu | 754.9 | 2.97 |
| Power | 23.10 Mills/kWh | 35.6 | 0.14 |
| Make-up water | 0.30 \$/Mgal | 14.7 | 0.06 |
| Steam | 3.70 \$/Mlbs | 103.5 | 0.41 |
| Water circulation | 0.07 \$/Mgal | 78.1 | 0.31 |
| Power distribution | | 5.3 | 0.02 |
| Total | | 992.1 | 3.91 |
| Maintenance | 4% On site + 2% off site | 118.7 | 0.47 |
| Plant supplies | 8% Maintenance | 9.5 | 0.04 |
| Catalysts and chemicals | | 32.0 | 0.13 |
| Taxes and insurance | 2% Fixed investment | 68.2 | 0.27 |
| Depreciation | 10% Fixed investment | 340.9 | 1.34 |
| Total manufacturing costs | | 22,712.6 | 89.47 |
| Profit (before tax) | | (8,568.1) | (33.75) |
| Total manufacturing cost including profit | | 14,144.5 | 55.72 |

Table B-9. Estimated Manufacturing Costs of Chemical Grade Propylene by Propylene Splitter

- Basis:
- (1) Size based on: 5000. bbl per day of Chem-G Propylene.
 - (2) Crude oil priced at 15.65 \$/bbl.
 - (3) Nelson's Index = 743.
 - (4) Product cost based on: 5000.0 bbl per day of Chem-G propylene.
 - (5) Mfg. cost includes profit at 65.9% and depreciation at 10.0%.
 - (6) Utilization factor is 100.0%.

| Investments | | \$ (millions) | |
|------------------|--|---------------|--|
| On site | | 10107.7 | |
| Off site | | 2420.2 | |
| Total plant inv. | | 12527.8 | |
| Royalty | | 0.0 | |
| Total fixed inv. | | 12527.8 | |
| Catalysts | | 0.0 | |
| Working cap. | | 1819.0 | |
| Total inv. | | 14346.8 | |

| Manufacturing Costs | Rate | \$/Yr (millions) | Chem-G Propylene (¢/lb) |
|--|-------------------------|------------------|-------------------------|
| Raw materials cost | | | |
| C3 = Rich LPG | 25.20 ¢/gal | 32250.4 | 10.09 |
| Total | | 32250.4 | 10.09 |
| By-product credits | | | |
| Propane (incl. contn.) | 25.20 ¢/gal | -13726.3 | -4.29 |
| Total | | -13726.3 | -4.29 |
| Total raw materials + by-products | | 18524.1 | 5.79 |
| Salaries and wages | 9.30 \$/Operator-hr | 195.5 | 0.06 |
| Utilities | | | |
| Power | 23.10 M/kWh | 658.9 | 0.21 |
| Make-up water | 0.30 \$/Mgal | 9.7 | 0.00 |
| Water circ. | 0.07 \$/Mgal | 88.1 | 0.03 |
| Power distr. | 0.00 \$/kWh | 97.4 | 0.03 |
| Total | | 854.1 | 0.27 |
| Maintenance | 4.0 % on + 2.0% off | 452.7 | 0.14 |
| Plant supplies | 8.0% Maint. | 36.2 | 0.01 |
| Catalysts & chemicals | | 0.0 | 0.0 |
| Taxes and ins. | 2.0% Plant inv. | 250.6 | 0.08 |
| Depreciation | 10.0% Fixed inv. | 1252.8 | 0.39 |
| Total mfg. cost | | 21566.0 | 6.75 |
| Before-tax profit | 65.9% total inv. | 9456.8 | 2.96 |
| Admin. and mktg. | 1.0% Total mfg. + prof. | 310.2 | 0.10 |
| Total mfg. cost, incl. profit and marketing: | | 31333.0 | 9.80 |

Table B-10. Estimated Manufacturing Costs of Polymer Grade Propylene by Propylene Purification

Basis: (1) Size based on: 5000 bbl per day of Poly-G propylene.
 (2) Crude oil priced at 15.65 \$/bbl.
 (3) Nelson's Index = 743.
 (4) Product cost based on: 5000.0 bbl per day of Poly-G propylene.
 (5) Mfg. cost includes profit at 51.0% and depreciation at 10.0%.
 (6) Utilization factor is 100.0%

| Investments | \$ (millions) | | |
|------------------|------------------|--|--|
| On site | 17083.4 | | |
| Off site | 3132.0 | | |
| Total plant inv. | 20215.4 | | |
| Royalty | 0.0 | | |
| Total fixed inv. | 20215.4 | | |
| Catalysts | 0.0 | | |
| Working cap. | 1954.6 | | |
| Total inv. | 22169.9 | | |

| Manufacturing Costs | Rate | \$/Yr (millions) | Poly-G Propylene (¢/lb) |
|---|-------------------------|------------------|----------------------------|
| Raw materials cost | | | |
| C3 = Rich LPG | 25.20 ¢/gal | 32250.4 | 10.09 |
| Total | | 32250.4 | 10.09 |
| By-product credits | | | |
| Propane (incl. contn.) | 25.20 ¢/gal | -13726.3 | -4.29 |
| Total | | -13726.3 | -4.29 |
| Total raw materials + by-products | | 18524.1 | 5.79 |
| Salaries and wages | 9.30 \$/Operator-hr | 195.5 | 0.06 |
| Utilities | | | |
| Power | 23.10 M/kWh | 905.5 | 0.28 |
| Make-up water | 0.30 \$/Mgal | 13.3 | 0.00 |
| Steam | 3.70 \$/Mlb | 396.9 | 0.12 |
| Water circ. | 0.07 \$/Mgal | 109.2 | 0.03 |
| Power distr. | 0.00 \$/kWh | 133.9 | 0.04 |
| Total | | 1558.8 | 0.49 |
| Maintenance | 4.0 % on + 2.0% off | 746.0 | 0.23 |
| Plant supplies | 8.0% Maint. | 59.7 | 0.02 |
| Catalysts & chemicals | | 0.0 | 0.0 |
| Taxes and ins. | 2.0% Plant inv. | 404.3 | 0.13 |
| Depreciation | 10.0% Fixed inv. | 2021.5 | 0.63 |
| Total mfg. cost | | 23509.9 | 7.35 |
| Before-tax profit | 51.0% total inv. | 11311.6 | 3.54 |
| Admin. and mktg. | 1.0% Total mfg. + prof. | 348.2 | 0.11 |
| Total mfg. cost, incl. profit and marketing: | | 35169.7 | 11.00 |

Table B-11. Estimated Manufacturing Costs of Benzene by Toluene Dealkylation

| | |
|--------|---|
| Basis: | (1) Size based on: 2000 bbl per day of toluene. |
| | (2) Crude oil priced at 15.65 \$/bbl. |
| | (3) Nelson's Index = 743. |
| | (4) Product cost based on: 1588.0 bbl per day of benzene. |
| | (5) Mfg. cost includes profit at 15.7% and depreciation at 10.0%. |
| | (6) Utilization factor is 100.0%. |

| Investments | | \$ (millions) | |
|------------------|--|------------------|--|
| On site | | 4959.6 | |
| Off site | | 2078.8 | |
| Total plant inv. | | 7038.4 | |
| Royalty | | 206.3 | |
| Total fixed inv. | | 7244.7 | |
| Catalysts | | 79.4 | |
| Working cap. | | 1773.5 | |
| Total inv. | | 9097.6 | |

| Manufacturing Costs | Rate | \$/Yr (millions) | Benzene (¢/gal) |
|---|-------------------------|------------------|--------------------|
| Raw materials cost | | | |
| Toluene | 110.11 ¢/gal | 32372.7 | 138.68 |
| Hydrogen | 1.57 \$/MSCF | 1857.9 | 7.96 |
| Total | | 34230.6 | 146.64 |
| By-product credits | | | |
| Polymer | 65.52 ¢/gal | -539.4 | -2.31 |
| Fuel gas | 291.07 ¢/MBtu | -3126.9 | -13.40 |
| Total | | -3666.2 | -15.71 |
| Total raw materials + by-products | | 30564.4 | 130.93 |
| Salaries and wages | 9.30 \$/Operator-hr | 391.0 | 1.68 |
| Utilities | | | |
| Fuel | 291.07 ¢/MBtu | 784.3 | 3.36 |
| Power | 23.10 M/kWh | 156.8 | 0.67 |
| Make-up water | 0.30 \$/Mgal | 3.6 | 0.02 |
| Steam | 3.70 \$/Mlb | -440.2 | -1.89 |
| Water circ. | 0.07 \$/Mgal | 19.5 | 0.08 |
| Power distr. | 0.00 \$/kWh | 23.2 | 0.10 |
| Total | | 547.1 | 2.34 |
| Maintenance | 4.0 % on + 2.0% off | 240.0 | 1.03 |
| Plant supplies | 8.0% Maint. | 19.2 | 0.08 |
| Catalysts & chemicals | | 4.0 | 0.02 |
| Taxes and ins. | 2.0% Plant inv. | 140.8 | 0.60 |
| Depreciation | 10.0% Fixed inv. | 724.5 | 3.10 |
| Total mfg. cost | | 32630.9 | 139.79 |
| Before-tax profit | -15.7% total inv. | -1429.1 | -6.12 |
| Admin. and mktg. | 1.0% Total mfg. + prof. | 312.0 | 1.34 |
| Total mfg. cost, incl. profit and marketing: | | 31513.8 | 135.00 |

The next alternative considered is fuel; i.e., the propylene can be left in propane and sold as fuel. In the second quarter of 1979 propane was 25.2 cents per gallon or 5.8 cents per pound. This is better than losing money in alkylate, but is there still a better alternative? The answer is seen in Table B-10, illustrating the cost of producing chemical-grade (92%) propylene from a C₃ refinery stream. At a selling price of 9.8 cents per pound, a 66% before-tax return on investment of the splitter is realized. Even if the market will pay only 6.85 cents per pound for propylene (zero profit), the net return is more than would be realized leaving the propylene in LPG. In Table B-11, the economics of producing polymer-grade propylene (99%) are shown. The concept is the same as for chemical-grade material. In this case, the market price was 11.0 cents per pound and the before tax return was 51%.

The difference between the price of propane (fuel value for propylene) and chemical-grade propylene has increased from about 3 cents per pound in 1977/early 1978 to 5.5 to 6.0 cents per pound in late 1979/early 1980. (In second-quarter 1979 it was 4.0 cents per pound.) The implication is that the profitability of producing chemical propylene in refineries is increasing. As propylene is replaced in alkylate by butylene, there will be growing incentive to place it in chemical markets. This will in turn result in downward pressure on price since refiners will become willing to accept lower rates of return and still exceed the fuel value—the next alternate.

B.4.14 Normal Butanol

The price of normal butanol is a function of: (1) the manufacturing costs associated with the oxo conversion of butyraldehyde into normal butanol, and (2) the relative profitability of other butyraldehyde end uses in comparison with normal butanol. The oxo process costs are the basis for normal butanol's base price, but the oxo process is flexible enough to produce related products using much the same facilities; this also plays an important role in the ultimate determination of price. The interrelationship between the various markets and relative profitabilities for oxo chemicals guides the integrated producer's production and pricing decisions.

B.4.15 Glycerine

Glycerine prices are based on two factors. The synthetic glycerine producer's manufacturing costs and the supply available from the low cost-based natural producers. The by-product nature of glycerine for the natural producers allows them to discount glycerine's price to move volume. The discounting is logical and consistent in view of the existing overcapacity and stagnant demand for glycerine. Although the glycerine market is characterized by overcapacity, an increment of synthetic capacity is currently required by the market. The higher cost of synthetics will continue to play a price-setting role. To develop synthetic glycerine manufacturing costs, we also developed manufacturing economics for epichlorohydrin, a glycerine raw material, and allyl chloride, a precursor to epichlorohydrin. These manufacturing costs were developed to ensure that synthetic glycerine's price-setting bases would be accurately reflected in the price forecast.

B.4.16 Benzene

Benzene is by far the most important aromatic petrochemical building block. Its demand and sources of supply were discussed in Appendix A. Of the four sources of benzene, two are by-product or coproduct (coal-based and pyrolysis gasoline or "dripolene" from olefins plants). This material is essentially fully recovered and used in petrochemical manufacture. The coproduct amount is not nearly enough to meet total benzene demand, and benzene from refineries is required to close the gap.

The largest source of refinery benzene is extraction from reformat; i.e., a naphtha stream which has been processed in a reformer to increase its aromatic content and raise its octane value, hence gasoline blending value, especially in unleaded gasoline. Except in periods of very depressed benzene demand, reformat does not satisfy total needs, and an additional source of supply is required—hydrodealkylation of toluene, referred to as TDA or HDA.

Benzene produced by means of dealkylation is the most expensive increment of supply and, therefore, effectively sets the price of all benzene. Toluene dealkylation is the most expensive increment of benzene because, although the toluene comes from the same source in the refinery as benzene (i.e., reformat) it requires processing, hence higher investment and operating costs in order to be converted to benzene.

Table B-11 illustrates typical costs of a new dealkylation plant that prevailed in the second quarter of 1979, with the market prices of benzene and toluene at \$1.35 and \$1.10 per gallon, respectively. The reasons that the operation would have lost money (about 6 cents per gallon of benzene are:

- The TDA plant represented in Table B-11 is the newest, most expensive unit and has high depreciation charges and hydrogen costs.
- During the second quarter of 1979 the spot price of benzene was about \$2.00 per gallon versus the \$1.35 contract price shown in the table. TDA benzene is often directed to the spot market where the higher price realizes higher profitability.

The price of benzene is determined by the costs of dealkylation of toluene. The price of toluene is set by its value in gasoline plus extraction/distillation costs and profit. In the second quarter of 1979, with unleaded gasoline at 54.4 cents per gallon, toluene's value in the gasoline pool was 67.4 cents per gallon. This was at the upper edge of the blending value of 10 to 13 cents per gallon above unleaded gasoline, based on 8 to 10 cents for octane improvement and 2 to 3 cents for Reid Vapor Pressure (RVP) at prevailing butane values. It is important to note that this value applies only when gasoline price is market limited. In other words, if a refiner paid more than this difference for toluene in a market-limited environment, he could not increase his gasoline price to recover his cost of toluene (at least not without losing market share).

In the regulated, supply-constrained environment, which existed in mid-1979, with virtually all refiners at ceiling price, gasoline prices could rise only on the basis of cost pass-through justification. Unlike certain other refinery costs (e.g., crude oil, operating expenses, etc.) which have to be allocated across the barrel, the purchased costs of toluene (and other purchased blendstocks) were passed on to gasoline only.

This unusual upward pressure on toluene price, caused by refiners in effect selling toluene to each other and recovering the costs in gasoline, resulted in increased investment for all aromatics reforming/extraction/distillation operations. With the toluene market price of \$1.10 per gallon and a gasoline value of 67.4 cents per gallon, the implied extraction/distillation cost plus profit was 42.6 cents per gallon. In the first quarter of 1980, when gasoline was demand- rather than supply-limited, the differential declined to 24 cents per gallon—which is much less of a premium but still highly profitable.

In the future, if gasoline prices are demand-limited, the price at which refiners will be willing to sell toluene will be more closely related to its gasoline value rather than the unusual circumstances that prevailed in 1979. However, toluene, benzene, and its petrochemical derivatives will always be subject to fluctuations and trends in the gasoline market—supply/demand/octane requirements and price. This element of instability is a disadvantage for benzene derivatives such as polystyrene and phenolics vis-à-vis olefins derivatives.

B.4.17 Acetone

Acetone's price is currently based on isopropanol dehydrogenation costs. This process represents the most expensive increment of supply. Acetone's availability, however, is more a function of demand for phenol and its price and supply/demand which are strongly influenced by coproduction in the cumene-to-phenol process. In periods of more than adequate acetone supply, the price tends to fall and the most expensive increment of supply—isopropanol dehydrogenation—is withdrawn from the market until prices rise. Acetone's price is, therefore, based on the isopropanol costs economics and profitability.

B.4.18 Furfural

Furfural is produced domestically only by Quaker Oats Company by means of acid hydrolysis of a variety of agricultural and biomass residues. Quaker Oats' process costs and profit margin will continue to be the basis for furfural prices.

B.4.19 Citric Acid

Citric acid prices are currently based on the fermentation of molasses. Other fermentation substitutes such as normal paraffins are not economically attractive in comparison with molasses. Dextrose from corn sugar is the substitute for one of the domestic producers, but the bulk of citric acid production is based on molasses and that process route will continue to underpin citric acid prices.

B.4.20 Fumaric Acid

The process costs of maleic anhydride production is the basis for fumaric acid prices since maleic anhydride is the only raw material involved in fumaric acid production. Currently all maleic anhydride capacity is based on benzene oxidation. Some producers, however, feel that butane will become an important maleic anhydride feedstock during the late 1980s. The rate of conversion away from benzene will be an important determinant in fumaric acid pricing during 1985-1990. The butane-based maleic anhydride costs will then set the raw-material cost basis for fumaric acid. The supply/demand balance will moderate future fumaric acid price increases since existing capacity will not be fully utilized through the year 2000.

APPENDIX C
COAL AND BIOMASS GASIFICATION
TECHNOLOGY DESCRIPTION

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APPENDIX C

COAL AND BIOMASS GASIFICATION TECHNOLOGY DESCRIPTION

Gasification or partial oxidation of prepared biomass and coal feedstocks may be accomplished with several commercially available processes. The cost comparisons presented in Table 4-2 are representative of three of the more advanced of these technologies. Although individual processes differ and the compositions of the raw gases from each gasifier may differ, the synthesis gas produced from each process is essentially the same.

Five basic processing steps are common to gasification technologies: pretreatment of feedstocks, gasification of the carbonaceous material, gas stream clean-up, shift conversion, and catalytic synthesis of methanol under pressure. Gasifiers are generally classified according to the method by which the solids and fluids are mixed in the reactor. All the processes presented in Table 4-2 operate at atmospheric pressure.

The Wellman-Galusha gasifier employs a revolving grate to gasify the feedstock and mix oxygen in the reaction chamber at elevated temperatures of 1000° F-1200° F. The Koppers-Totzek gasifier differs in that the charged feedstock and oxygen are mixed by an entrained flow in the reaction chamber. Also, the Koppers-Totzek process requires high temperatures of 3300° F. The Purox gasifier is a vertical shaft, fixed-bed reactor vessel that operates at temperatures of 3000° F. The product gases from the reactor vessels consist primarily of carbon monoxide, carbon dioxide, methane, hydrogen, and small amounts of hydrocarbons having an overall heating value that ranges from 270-350 Btu/SCF.

Before methanol synthesis occurs, these product gases are scrubbed of any impurities. Carbon dioxide, tar, and hydrocarbon liquids must be removed from coal and biomass synthesis gases. Impurities peculiar to coal-derived synthesis gases include hydrogen sulfide, organic sulfates, fly ash, and soot—which add to the capital and operating costs for coal processes (Reed 1980).

After scrubbing these gas impurities out of the product stream, the synthesis gas (carbon monoxide and hydrogen) undergoes a shift conversion, similar to natural gas reforming to adjust the hydrogen/carbon monoxide ratio to 2:1, which is then suitable for conventional methanol synthesis reaction processing.

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|--|----------------------------------|---|---|
| Document Control Page | 1. SERI Report No. TR-734-762 | 2. NTIS Accession No. | 3. Recipient's Accession No. |
| 4. Title and Subtitle Biomass Feedstocks for Petrochemical Markets: An Overview and Case Study | | 5. Publication Date May 1981 | 6. |
| 7. Author(s) Silvio J. Flaim; Andrew M. Hill; Dan Lippe | | 8. Performing Organization Rept. No. | |
| 9. Performing Organization Name and Address Solar Energy Research Institute 1617 Cole Boulevard Golden, Colorado 80401 | | 10. Project/Task/Work Unit No. 3346.40 | 11. Contract (C) or Grant (G) No. (C) (G) |
| | | 13. Type of Report & Period Covered Technical Report | |
| 12. Sponsoring Organization Name and Address | | 14. | |
| 15. Supplementary Notes The Pace Co., Houston, Texas, supplied the material for two of the three appendices. | | | |
| 16. Abstract (Limit: 200 words) Recent price increases in petroleum and natural gas feedstocks in the petrochemical industry justify a reexamination of biomass feedstocks as potential substitutes, to reduce U.S. demand on expensive petroleum imports. In this report a method of analysis is developed identifying several target chemicals for potential biomass feedstock substitution. An overview of the petroleum/petiochemical industries is presented and a general discussion of refinery trends. A case study of methanol production for formaldehyde manufacturing is presented. The technical, economic, and market implications of producing biomass-derived methanol for formaldehyde manufacturing appear highly favorable. The appendices in this report provide general discussions of market and economic factors (e.g., supply and demand) for all petrochemicals with emphasis on the identified target chemicals. | | | |
| 17. Document Analysis a. Descriptors Biomass ; Chemical Feedstocks:T1 ; Economic Analysis ; Formaldehyde ; Marketing Research:Q1,Q2 ; Methanol ; Petrochemicals:T2 ; Petroleum Industry ; Refining ; Alcohols ; Aldehydes ; Economics ; Energy Sources ; Fossil ; Hydroxy b. Identifiers/Open-Ended Terms Compounds ; Industry ; Organic Compounds ; Petroleum Products ; Renewable Energy Sources ; Case Studies c. UC Categories 61, 61a | | | |
| 18. Availability Statement National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, Virginia 22161 | | 19. No. of Pages 111 | |
| | | 20. Price \$6.50 | |



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02LIB119281

