

Chapter 6

The Chemicals Industry

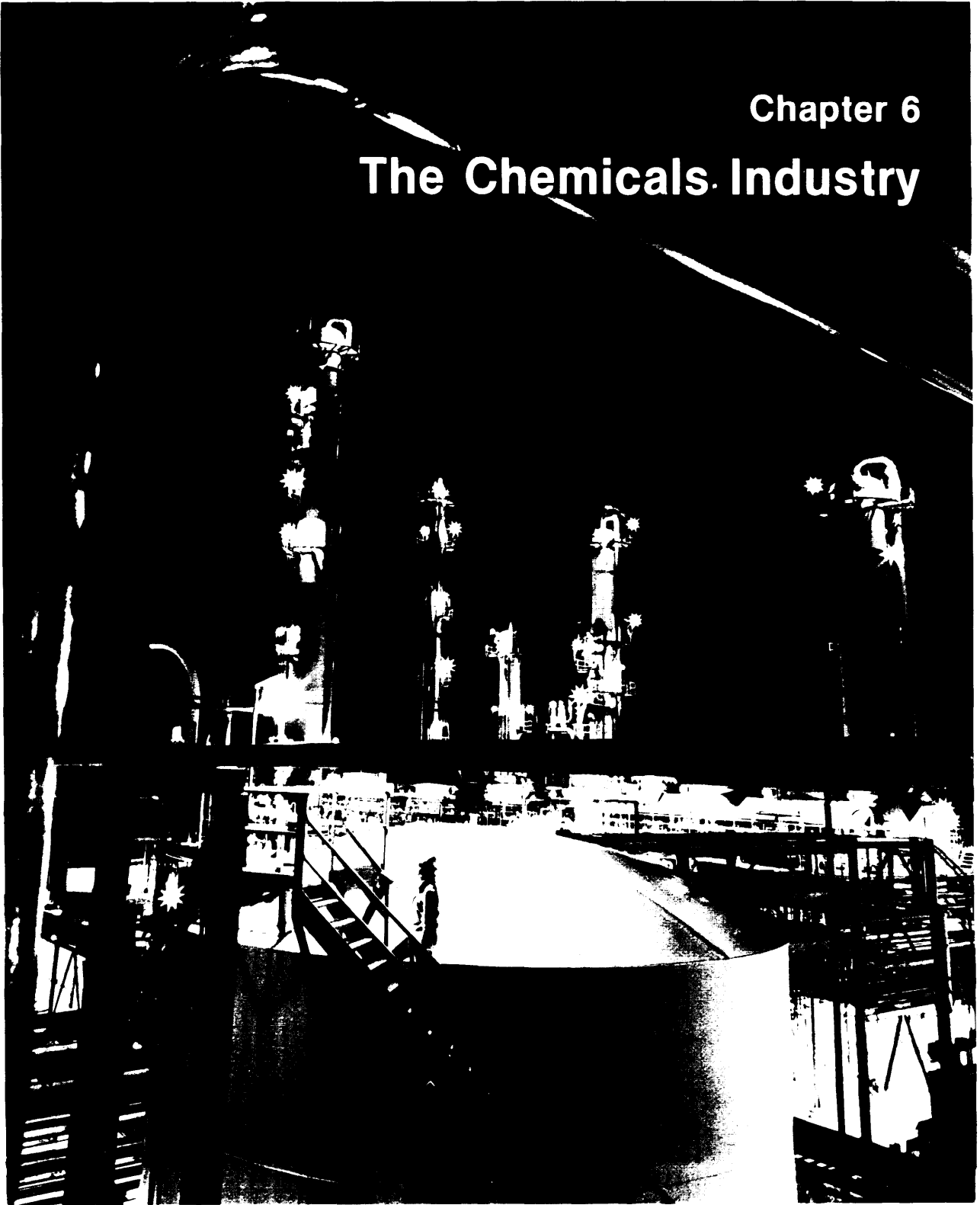


Photo credit: PPG Industries, Inc.

Contents

	<i>Page</i>
Industry Overview	115
Industry Structure	115
Product Mix	115
Economics of Chemicals Production	116
Energy and Technology	119
Production Processes	119
Energy Use	120
Energy Conservation	121
Energy Conservation Through Technology	126
Investment Choices for the Chemicals industry.....	128
impacts of Policy Options on the Chemicals Industry	129
investment Strategy.....	130
The Reference Case	130
Projected Effects of Policy Options	131

TABLES

<i>Table No.</i>	<i>Page</i>
30. Definition of SIC 28-The Chemicals and Allied Products Industry.....	115
31. Top Ten Chemicals Produced by Chemical Industry,1981	116
32. Energy-intensive Processes in Chemical Manufacturing	119
33. Comparison of 1981 and 1972 Energy Consumption in the Chemicals industry ...	122
34. Operational and Design ProblemsinEnergy-intensive Equipment	125
35. Operational and Design Problems in Heat-Transfer Equipment	126
36. Funding Sources and Funding Uses of Cash Flow of Fifteen Largest Chemical Companies	128
37. Types of Energy Efficiency-Improving Projects Undertaken by Chemical Manufacturing Association Companies	129
38. Chemical industry Projects To Be Analyzed for Internal Rate of Return (IRR) Values	0 131
39. Historical and Assumed Growth Rates in SIC 28	132
40. Reference Case Energy Use Projection, by Fuel 1980-2000	132
41. Reference Case Energy Use Projection, by End Use: 1985-2000	132
42. Reference Case Energy Use Projection, by Process Heat Fuel 1985-2000	132
43. Reference Case Energy Use Projection, Steam and Power Fuel 1985-2000	132
44. Effects of Policy Options on IRR Values of Chemical Industry Projects..	134
45. Effect of Lower interest Rates on IRR Values of Chemical industry projects.	136

FIGURES

<i>Figure No.</i>	<i>Page</i>
28. Structure of Organic Chemicals Industry	117
29. Capital Spent in the Chemicals industry, 1971-81	118
30. Comparison of Chemicals Industry Energy Use and Production Output, 1972 and 1981..	122
31. Chemicals industry Energy Intensity Projection, 1970-2000	132
32. Chemical Industry Projections of Fuel Use and Energy Savings by Policy Options, 1990 and 2000...	133

INDUSTRY OVERVIEW

Of the **four industries chosen for study for this report**, the chemicals industry is by far the most complex. First, it produces several thousand products, in contrast to steel, paper, and petroleum refining corporations, which produce a relatively limited set of commodity products in large quantities. Second, it is more diverse—i. e., it has more capital investment choices and a less cohesive market. Within its SIC 28 classification are eight three-digit subcategories, as shown in table 30. Finally, the chemicals industry has the distinction of using the most energy of the four industries.¹ The 1980 *Annual Survey of Manufactures* shows its energy use to be 2.7 Quads, that is, 22 percent of all energy purchased by the industrial sector.

Industry Structure

More than 100 companies in the chemicals industry report **energy use data. Interestingly, over**

¹ U.S. Department of Commerce, Bureau of the Census, 1980 *Annual Survey of Manufactures: Fuels and Electric Energy Consumed*, M80(AS)-4, 1, Washington, D. C., 1982.

Table 30.—Definition of SIC 28—The Chemicals and Allied Products Industry

This major group includes establishments that produce basic chemicals and establishments that manufacture products by predominantly chemical processes. Establishments classified in this major group manufacture three general classes of products: 1) basic chemicals, such as acids, alkalies, salts, and organic chemicals; 2) chemical products to be used in further manufacture, such as synthetic fibers, plastics materials, dry colors, and pigments; and 3) finished chemical products for use by other industries, for example, paints, fertilizers, and explosives.

SIC 28 is broken down into the following eight subgroups:

SIC	Title
281	Industrial inorganic chemicals
282	Plastics and manmade fibers
283	Drugs
284	Soap, detergent, and cleaning preparations
285	Paints and varnishes
286	Industrial organic chemicals
287	Agricultural chemicals
288	Miscellaneous chemical products

SOURCE Office of Management and Budget, *Standard Industrial Classification Manual, 1972*.

half of the top 50 chemical producers are not primarily chemicals companies. Many are petroleum producers and refiners, such as Exxon and Mobil. Others produce chemicals only as part of their business enterprise; e.g., Eastman Kodak, Borden, and B. F. Goodrich.

OTA undertook an analysis of a number of smaller firms that produce chemical products, to determine if they exist in a different environment and behave differently than do larger firms.³ In general, they do not. Small chemical firms tend to be the developers of new products, rather than new processes. They appear to gain competitive advantage not by producing standard products at lower cost, but by conducting research and development (R&D) that produces new products or new formulations for existing products.

Product Mix

The top 10 chemicals produced by chemical companies are shown in table 31. **Many of the top 25 chemicals produced by chemical companies** are used in agriculture, which accounts for their large production volume; among these are sulfuric acid, ammonia, and phosphoric acid. Other chemicals are used as feedstocks in the production of rubber and plastic materials, such as polyethylene and synthetic fabrics. Within SIC 286 alone, products such as plastics, synthetic rubber, nylon, and antifreeze are produced from just three material feedstocks (see fig. 28).

In the past, chemicals production depended on the large-scale production of acetylene manufactured from coal and on the development of a number of processes and products using **acetylene** as a feedstock. Acetone and acetaldehyde, originally made from acetylene, were used as raw materials for pharmaceuticals, synthetic rubber,

² *Chemical and Engineering News*, "Facts and Figures for the Chemical Industry," June 14, 1982.

³ Technology and Economics, Inc., *The Impact of Selected Federal Policies on the Energy Use Patterns of Smaller Industrial Corporations*, final report, OTA contract No. 233-4680.0, August 1982.

Table 31.—Top Ten Chemicals Produced by Chemical Industry, 1981

Rank	Name	1981 production (lb x 10 ¹)	1981 production value (\$ x 10 ¹)	1971-81 annual growth rate (%)	Produced from	Major end use
1.	Sulfuric acid (H ₂ SO ₄)	81.35	\$3,250	3.4%	Sulfur dioxide from sulfur or smelter gases: reacted with water.	Fertilizers—700/0; chemical manufacture—150/0; metals recovery and petroleum refining.
2.	Ammonia (N H ₃)	38.07	2,500	2.7	Catalytic reaction of nitrogen (from air) and hydrogen (from natural gas).	Fertilizers—80%; plastics and textile fibers—10 ⁰ /0; explosives—5%.
3.	Nitrogen (N ₂)	37.31	550	11.2	Separated by distillation from air at cryogenic temperatures.	Inert blanketing atmospheres: chemical processing—14%; electronics—15%; metals—5%; freezing agent—21%; aerospace—8 ⁰ A.
4.	Lime (CaO)	35.99	800	-0.4	Limestone (CaCO ₃) heated to remove CO ₂ , then hydrated to make Ca(OH) ₂ ; CaO.	Metallurgy (in steel flux) —45%; chemical manufacture—10 ⁰ /0; potable water treatment—10%; sewage and pollution control—50/0; pulp and paper manufacture—5%.
5.	Oxygen (O ₂)	34.93	525	2.9	Separated from air at cryogenic temperatures.	Primary metal manufacture—300/0; health services—130/0; metal fabricating—330/0.
6.	Ethylene (H ₂ C=CH ₂)	28.87	7,000	4.6	Thermal and catalytic cracking of hydrocarbons.	Fabricated plastics—650/0; anti-freeze—10 ⁰ /0; fibers—50/0; solvents—50/0.
7.	Caustic soda (NaOH)	21.30	2,500	1.0	Electrolysis of salt brine.	Chemical manufacture—500/0; pulp and paper—150/0; aluminum—50/0; petroleum refining—50/0; soap and detergents—5 ⁰ /0.
8.	Chlorine (Cl ₂)	21.12	1,500	1.2	Electrolysis of salt brine. Recovery from hydrochloric acid, coproduction in making metals, caustic potash, or potassium nitrate.	Chemical manufacture—500/0; plastics—15 ⁰ /0; solvents—150/0.
9.	Phosphoric acid (NH ₃ PO ₄)	19.83	4,000	5.2	Reaction of phosphate rock and sulfuric acid: burning elemental phosphorus and subsequent reaction with water.	Fertilizers—850/0; animal feed—5%.
10.	Nitric acid (HNO ₃)	18.08	2,300	1.7	Reaction of ammonia with air, or sulfuric acid with sodium nitrate.	As ammonium nitrate fertilizers—950/0.

SOURCE. Chemical and Engineering News, June 14, 1982, p. 40

textiles, and the like. Now petroleum refining is used to produce a large number of petrochemical feedstocks.⁴ For the majority of modern organic materials, acetylene has been replaced as a feedstock by other intermediates, notably ethylene and propylene, which are derived from ethane and propane, now readily available from petrochemical sources. Acetaldehyde, now also declining in importance, is currently made from ethylene rather than from acetylene. Ethanol, once derived entirely from fermentation (before 1930), is now manufactured commercially by hydration from ethylene. Acrylonitrile is now made

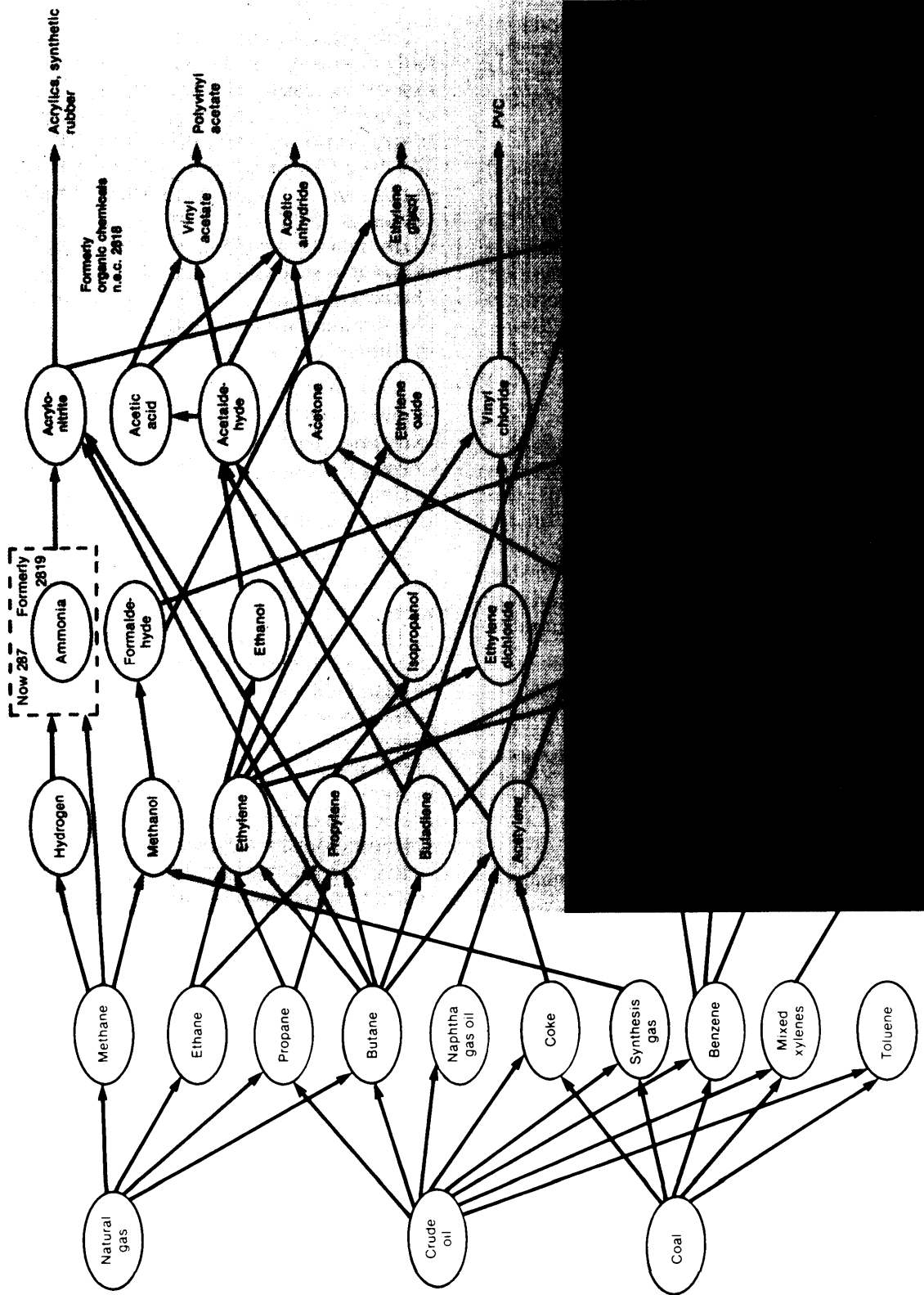
from propylene. Benzene and xylene, once largely obtained from coal tar, are now primarily derived from petroleum refining. Principally in response to demands for synthetic substitutes for naturally occurring industrial raw materials, especially those strategic materials whose access is controlled by foreign powers, the chemicals industry has developed new processes and technologies.

Economics of Chemicals Production

The overall economic health of the chemicals industry, compared to that of steel and petroleum refining, is good. As determined by a *Chemical*

⁴Mellon Institute, *Final Report on the Industrial Energy Productivity Project, Vol. 3, The Petroleum Refining Industry*, DOE contract No. DE-ACO1-79CS-40151, September 1982.

Figure 28.—Structure of Organic Chemicals Industry (SIC 286)



SOURCE: Mellon Institute, Final Report: The Industrial Energy Productivity Project, Volume 5, The Chemicals Industry, DOE contract No. DE-AC01-79CS-40151, September 1982.

and *Engineering News* survey,⁵ 1981 revenue was \$182 billion, with a net income of \$12.6 billion, or a 6.8-percent return, down slightly from the 1979 figure. Over the past decade, profit margins within the industry have averaged between 8 and 9 percent.

Their high profitability has allowed chemical companies to make investments in capital equipment and in research at levels much higher than those made by the other three industries studied by OTA. In 1981, the chemicals industry invested over \$13 billion in new plant and equipment, up from a 1980 level of \$12.6 billion.⁶ Figure 29 presents the capital investment trend for 1971-81.

Capital Investment

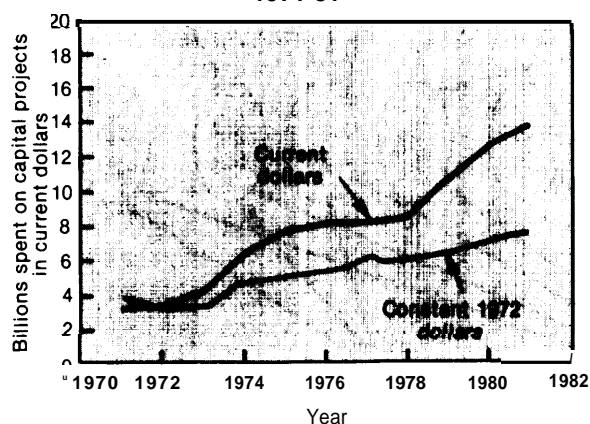
The chemicals industry spends approximately one-third as much money on research as on its entire inventory of capital projects. In 1981, this amount was estimated to be \$4.7 billion for R&D.⁷ For comparison, the proportion of funds spent on research, development, and demonstration (RD&D) by the other industries studied was 6 percent for steel, **4 percent** for petroleum refining, and 5.5 percent for paper.

⁵*Chemical and Engineering News*, "Facts and Figures for the Chemical Industry," June 14, 1982.

⁶U. S. Department of Commerce, Bureau of Economic Analysis, *1980 Annual Survey of Manufactures: Statistics for Industry Groups and Industries, A80(AS)-1*, 1982.

⁷*Chemical and Engineering News*, op. cit.

Figure 29.—Capital Spent in the Chemicals Industry, 1971-81



SOURCE: Bureau of Economics, Department of Commerce.

Imports and Exports

Both exports and imports increased substantially over the past decade. From **1971 to 1981, exports increased by 450 percent and imports increased by 513 percent.** The U.S. chemicals industry exported products in 1981 valued at \$21.19 billion, accounting for about 10 percent of the total U.S. exports that year. With imports valued at \$9.88 billion in 1981, a total positive trade balance resulted of over \$11 billion.⁸ Because of its extensive international trade, the U.S. chemicals industry is concerned about the implementation of tariffs and other barriers to trade in foreign countries.

In the next decade, it is predicted that the U.S. chemicals industry will export less organic chemicals and plastics and more of the specialized chemical products. It will also import more of the basic primary chemicals, process the chemicals in domestic plants, and export the final products.

U.S. producers of industrial organic chemicals are expected to have serious competition from foreign, state-owned petrochemicals complexes in Latin America and the Mideast. (However, state-operated organic chemicals plants in the Persian Gulf are not expected to be a major competitor in world markets in the near future.) Such plants, whose operations are based in part on political objectives such as job creation and foreign currency earnings, and not on the profit motive, are able to undercut the prices of U.S. suppliers. Domestic producers may thus be unable to compete in foreign markets. Unless substantial import restrictions are applied, they may have difficulty maintaining their domestic market.

producers of the two major chemicals (ammonia and phosphoric acid) used by the agricultural sector have completely different outlooks for the future in world trade. In 1985, the United States is expected to account for 25 percent of world phosphoric acid production.⁹ Exports, which have been high, should remain high for at least the next decade. Phosphate fertilizer production plants are clustered near the large sea-

⁸ibid.

⁹Mellon Institute, *Final Report on the Industrial Energy Productivity Project, Vol. 5: The Chemicals Industry*, DOE contract No. DE-AC01-79CS-401 51, September 1982.

ports in this country, reducing the necessity for more expensive rail transport. In fact, exports of phosphoric acid may be limited not by the world market competition, but by the availability of U.S. port facilities.

Ammonia producers will face a tightening foreign market in the next decade.¹⁰ Imports from

¹⁰Ibid.

relatively unreliable sources (e.g., Mexico and Russia) have increased substantially. **In 1970, ammonia imports amounted to only 3.5 percent of U.S. production. By 1978, imports were nearly 9 percent of total domestic production and have been increasing since.** This situation typifies some of the complex connections between the domestic and the international concerns of the chemicals industry.

ENERGY AND TECHNOLOGY

Production Processes

For the purposes of energy accounting, it is economical to classify the many unit operations that occur in the chemicals industry into a small number of groups. One way to identify these groups is on the basis of the equipment used to effect the chemical transformation. Table 32 presents the six most energy-intensive processes.

Table 32.—Energy-Intensive Processes in Chemical Manufacturing

Electrolysis.—Electrolysis includes all industrial electrolytic processes in which electricity is used in direct chemical conversion.

Fuel-heated reaction.—Processes that require some type of heat to force a chemical reaction to take place can be subdivided into low- and high-temperature operations. Energy sources include steam (except for high-temperature reaction), natural gas, residual oil, distillate oil, and even fluidized-bed coal combustion. Where precise temperature regulation is required, natural gas and distillate fuel oil are used.

Distillation.—Distillation processes include those that require physical separation of end products from both feedstocks and byproducts by evaporation and condensation.

Refrigeration.—Refrigeration includes processes that compress and expand a refrigerant, such as ammonia or a fluorocarbon, for the purpose of cooling feed stocks or products below ambient temperatures.

Evaporation.—Evaporation includes those processes that use passive-evaporation cooling. In general, the evaporated water is lost to the atmosphere, and the heat energy is unrecoverable.

Machine drive.—Many chemical industry processes use machine drive to pump, compress, or move feedstock and end product materials. Machine drive arises from electric motors, steam turbines, or gas turbines. A subcategory of machine drive processes—mixing and blending (especially in polymerization processes)—can be very energy intensive due to the high viscosity of the materials.

SOURCE—Adapted by OTA from Robert Ayres, *Final Report on Future Energy Consumption by Industrial Chemicals Industry*, DOE contract No DE-AC01-79CS40151, Oct 7, 1981.

As an example of how these unit processes are used to produce particular chemicals, consider the production of ethylene and ammonia.^{11 12} Both are produced in large quantities, 27 million and 38 million lb, respectively in 1980. Both consume large amounts of energy. Together, they illustrate how a typical chemical commodity is produced, when the energy is consumed, and what particular opportunities exist to use energy more efficiently.

Ethylene is used as an intermediate in the production of plastics, rubber, and synthetic fibers, which are, in turn, used in industrial and consumer products. With its byproducts and derivatives, ethylene is a cornerstone in the petrochemical industry. It is produced by the reaction of steam and hydrocarbon feedstock, followed by thermal cracking. The resulting product mixture is cryogenically cooled to -150°F and compressed to 450 to 600 psi, after which the ethylene is distilled from its feedstock and byproduct materials. The combination of heated reaction, compression, and cryogenic cooling make ethylene production very energy-intensive.

Ammonia is used as a major agricultural fertilizer, either directly or in combination with nitric acid as ammonium nitrate. It is synthesized by the reversible reaction of nitrogen and hydrogen, a reaction carried out under elevated pressures of between 80 and 1,000 atmospheres, depend-

¹¹S. D. Lyon, "Development of the Modern Ammonia Industry," 10th Brotherton Memorial Lecture, *Chemistry and Industry*, vol. 6, September 1975.

¹²L. L. Gaines and S. Y. Chen, *Energy and Material Flows in the Production of Olefins and Their Derivatives*, Argonne National Laboratories AN/LCNSV-9, August 1980.



Photo credit: PPG Industries, Inc

Major plant for the production of ethylene glycols is being readied for late 1983 operation at PPG Industries' Beaumont, Tex., complex. Pittsburgh-based PPG is a supplier of glycol for making polyester fibers, photo film, and plastic bottles

ing on the specifics of the process, and in elevated temperatures of 750° to 1,000° F. Nitrogen used in ammonia production comes from the atmosphere. Hydrogen comes from the partial oxidation and steam reforming of natural gas (i.e., producing carbon monoxide and hydrogen by partially burning natural gas hydrocarbon feedstock). The resulting product mixture must be cryogenically cooled and partially distilled to remove argon, urethane, and unreacted nitrogen byproducts. This production process is similar to that used in ethylene production in that high-temperature reaction is followed by low-temperature purification processes.

Energy Use

According to 1977 *Census of Manufactures* data for the chemicals industry, nearly 57 percent of the energy from purchased fuels and electricity came from natural gas, over 16 percent from electricity, 11 percent from coal, and 11 percent from fuel oil.¹³ Within the Industrial inorganic Chemicals subgroup, the fuel energy breakdown in 1976 was roughly as follows: natural gas, 40 percent; electricity, 40 percent; coal,

¹³U.S. Department of Commerce, Bureau of Census, *1977 Census of Manufacturers, Statistics for Industry Groups and Industries, Volume II: Industry Statistics, Part 2 SIC Major Groups 27-34, 1977.*

12 percent; and fuel oil, 8 percent. In the event of fuel shortages, manufacturers indicated that only 38 percent of natural gas needs could be met by substitute fuels (mainly fuel oil), and less than 60 percent of fuel oil needs could be met by substitute fuels (mainly natural gas).

Within the Industrial Organic Chemicals subgroup, the fuel energy breakdown in 1976 was roughly as follows: natural gas, **70 percent; coal, 8 percent; and electricity, 7 percent.** Fuel oil usage was not shown for this industry. Manufacturers indicated that only 27 percent of natural gas needs could be met quickly by substitute fuels; 32 percent of coal needs could be met by other fuels (mainly natural gas).

Many of the generating processes in the chemicals industry are energy-intensive. Generation of the number two chemical, ammonia, is one example. Most of the energy in that process is used to generate hydrogen, as well as to break the extraordinarily tight nitrogen triple bonds.

In another example, sodium hydroxide (NaOH) and chlorine (Cl₂) are produced by passing a strong electric current through an aqueous brine solution, again a very energy-intensive process. **In contrast, sulfuric acid is made via** processes which, when summed, are energy producing.

Output from the chemicals industry, as measured by the Federal Reserve Board index, rose **50 percent from 1972 to 1981**.¹⁴ **Energy use fell 4.6 percent in 1980 to below the 1972 level. The decrease (1972-81) could be seen as even larger if electricity were counted at net heat value (3,412 Btu/kWh) because part of the decrease is masked by a fairly sharp (30 percent) increase in the use of purchased electricity. The major savings from 1972 to 1981 occurred in the use of natural gas, which was down by 244 trillion Btu from 1972 to 1979 and by another 75 trillion Btu from 1979 to 1980. Use of coal and purchased steam were down slightly, while use of residual fuel oil and "other gases" was up moderately.**

One trend that has strongly affected fuel use patterns was the switch from oil to coal as a fuel for steam generation. After 1965, use of coal

declined sharply so that in 1973, coal provided 22 percent of boiler fuel. Since then, this trend has reversed; and in 1981, coal provided almost half of the fossil fuel used for steam generation.¹⁵ Some companies have forecast their use of coal for steam to increase to 70 or 75 percent by the turn of the century. Vendors state that with new packaged boiler designs (including economizers) thermal efficiencies as high as 83 percent can be obtained from coal-fired boilers—efficiencies are significantly better than with older technology. Some custom-designed units can exceed even these efficiencies by optimizing systems for particular plants.

Energy Conservation

Over the last decade, the chemicals industry has increased the efficiency of nearly all its energy-consuming processes. The efficiency of processes using natural gas, distillate oil, and residual oil has increased dramatically, while the efficiency of those processes using electricity has not changed. According to the Chemical Manufacturers Association (CMA) aggregate trade association reports, the 110 chemicals industry firms reporting in 1981 had improved their energy efficiency 24.2 percent per unit of product compared to their 1972 production (see fig. 30 and table 33).

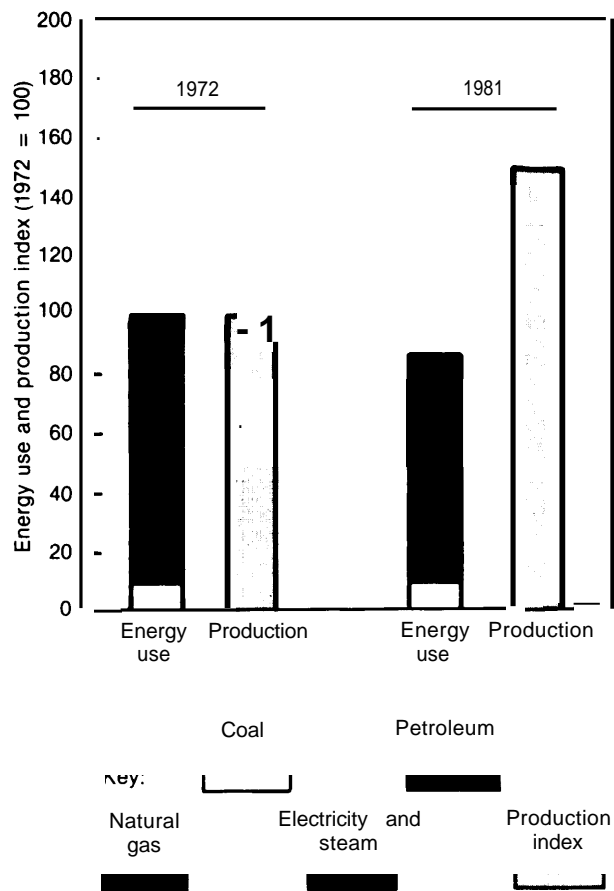
Most improvement resulted from reduced petroleum product use; distillate fuel oil and residual fuel use dropped from a combined 211 billion to 122 billion Btu. Moreover, since 1976 there has been a 5-percent decrease in Btu consumed, most of it occurring in decreased premium fuel consumption. Du Pont, for example, improved its energy efficiency dramatically in the 1970's and early 1980's to the point where in 1981 it used only 97 percent of the energy used in 1972, while units of production—measured in constant dollar sales of product—increased by 36 percent.¹⁶ Du Pont's achievement may be slightly better than that of the chemicals industry as a whole but is probably fairly representative.

¹⁵U.S. Department of Commerce, Bureau of the Census, *Annual Survey of Manufactures: Fuels and Electric Energy Consumed*, A(72)AS-4.1 through A80(AS)-4.1.

¹⁶James Borden, Economics and Policy Manager, Energy and Materials Department, E. I. du Pont de Nemours, Inc., Wilmington, Del.

¹⁴Federal Reserve Board, *Industrial Production*, Publication LC77-93930, December 1977.

Figure 30.—Comparison of Chemicals Industry Energy Use and Production Output, 1972 and 1981



SOURCE: Chemical Manufacturing Association and Federal Reserve Board.

OTA analysis indicates that among the factors that have brought about this energy efficiency improvement are the following:¹⁷

Much of the energy savings have come from improvements in energy management techniques. This is especially true in the area of steam generation and distribution. Among the specific items identified by OTA are improved maintenance of steam lines, thermostat setbacks, and lighting.

Significant energy savings have resulted from improvements in the operating practices of fueled reactors and fired heaters. Many of these improvements have come through the use of computerized burner controls, which is a part of the overall trend in many industrial processes toward computer control with feedback optimization.

Improvements in energy efficiency over the past 8 years have not, for the most part, resulted from major process substitution. There are some exceptions including the continued phasing out of synthetic soda ash production in favor of extraction from natural sodium sesquicarbonate, and the continued substitution of the wet process for phosphoric acid production for the electric arc furnace. Overall, though, the chemical manufacturing processes that were placed in the

¹⁷Adapted from Mellon Institute, *Final Report on the Industrial Energy Project, Vol. 5: The Chemicals Industry*, DOE contract No. DE-AC01-79CS-401 51, September 1982, pp. 14-17.

Table 33.—Comparison of 1981 and 1972 Energy Consumption in the Chemicals Industry

Energy source	1981 consumption (billion Btu)	1972 consumption (billion Btu)
Electricity	930,519.7	773,004.7
Natural gas	1,272,211.9	1,680,160.5
Propane	1,415.1	3,130.1
LPG	33,234.5	1,580.5
Bituminous coal	316,848.6	327,086.5
Anthracite coal	1,409.9	5,210.8
Coke	5,854.6	7,456.0
Gasoline	905.3	745.4
Distillate fuel oil	17,644.6	32,777.0
Residual fuel oil	104,227.3	178,746.1
Petroleum coke	5,118.1	—
Purchased steam	97,868.8	127,143.4
Other gases	346,224.2	358,256.5
Other liquids	44,691.2	50,120.7
Other solids	19,170.9	18,206.9
Total energy consumption	3,167,334.7	3,563,625.1

SOURCE: "Energy Efficiency Improvement and Recovered Materials Utilization Report," prepared for DOE by the Chemical Manufacturing Association, June 1, 1982.

early 1970's have **been supplanted by few new** processes that account for any sizable portion of the chemicals industry's energy efficiency improvement,

New and larger plants have saved energy without changing overall process characteristics found in older plants. Very dramatic results can often be achieved without process change when the various energy-saving options are put together in a new plant, as compared to using the same options by retrofitting an older plant. The fact that newer plants are usually larger contributes to this

record of improvement. Consider the following examples in energy efficiency improvements from plants throughout the world:

Ammonia (Haber-Bosch Process)

Year	Energy used per ton produced (10 ⁶ Btu)
1917,	800
1923-50	700
1965,	450
1972	400
1978	354

Source S D Lyon, "Development of the Modern Ammonia Industry." 10th Brotherton Memorial Lecture, *Chemistry and Industry*, vol. 6, September 1975, IR&T, *Industrial Energy Study of the Industrial Chemicals Group*, Vol 1, Executive Summary vol. 2, Data Base, IRT-352-R, Arlington, Va. 1974

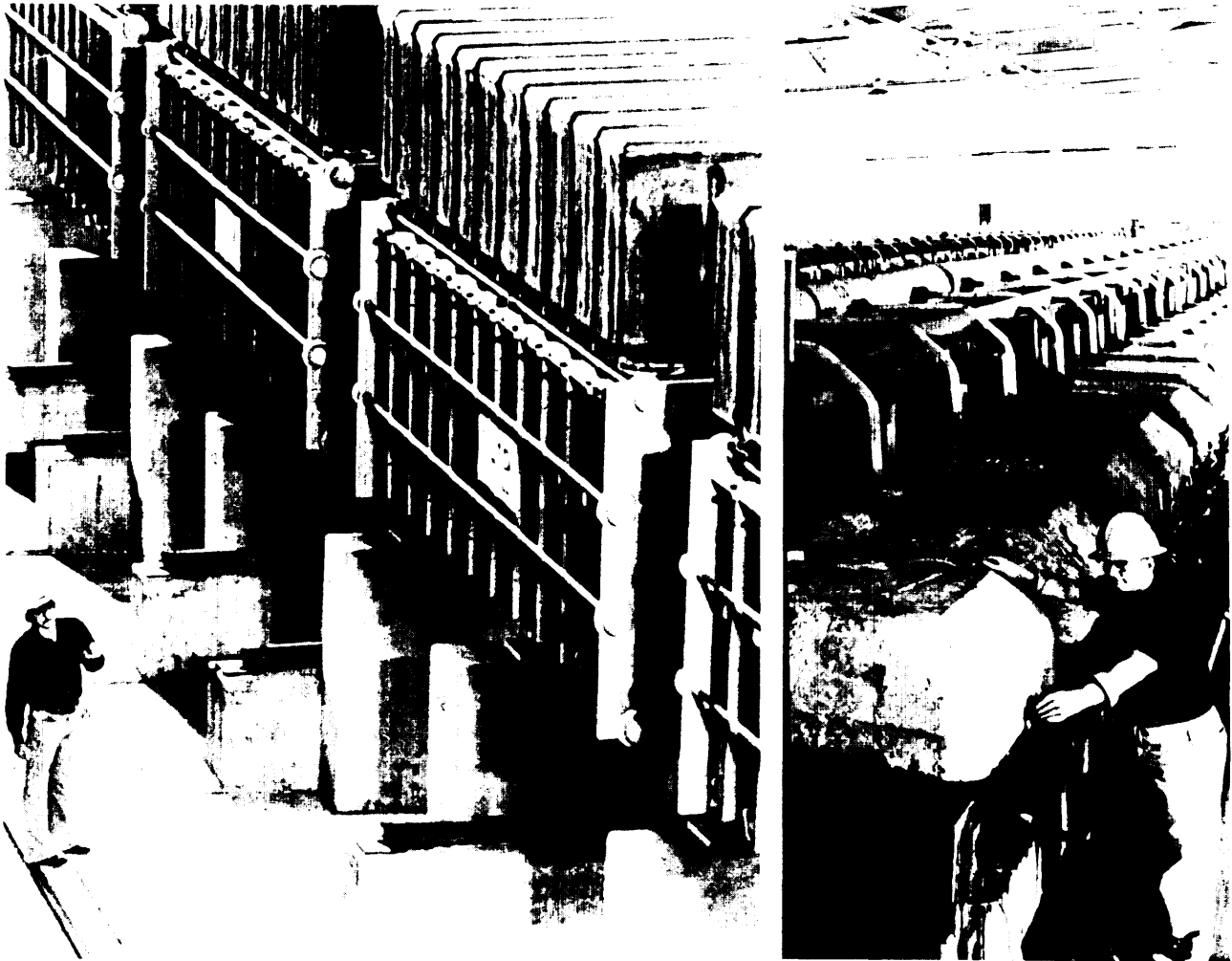


Photo credit: PPG Industries, Inc.

Bigger and better.—A workman inspects new giant-sized chlorine production units (left) similar to those that will replace outmoded units (right) at PPG Industries' Lake Charles, La., chemicals complex. New production units using PPG-developed technology will reduce by about 25 percent the amount of energy required to produce chlorine and caustic soda. Chlorine is used in making plastics and solvents, and in water purification. Caustic soda is used in chemical processing and making pulp and paper

Chlorine Cells (Diaphragm)

Year	Electricity used per ton produced (10 ³ kWh/ton)	
	1916	1947-73
1916	4,000	3,000
1947-73	3,000	2,200
1980	2,200	

Source The Conference Board, "Energy Consumption in Manufacturing" (Cambridge, Mass Ballinger Publishing Co., 1974), Mellon Institute, *Final Report Industrial Energy Productivity Project, vol 5 The Chemicals Industry, September 1982*

Cyclohexane (Institute Francais du Petroles Process)

Year	Energy used per ton produced	
	Steam (10 ³ lbs)	Electricity (kWh)
1963	568	23.76
1965	358	15.00
1971	403	9.63

Source The Conference Board "Energy Consumption in Manufacturing" (Cambridge, Mass Ballinger Publishing Co., 1974)

The recovery of heat from exothermic or energy-producing reactions has improved. The use of heat exchangers and heat economizing is more widespread now than in 1972.

Significant improvements have been made in the design of distillation columns for physical separation. Improvements in physical separation can have salutary effects for a chemical firm. First, they can reduce fuel requirements. Second, they can often decrease feedstock requirements.

While use of premium petroleum fuels has decreased since 1972, use of electricity has increased markedly. The ammonia subsector probably accounts for part of the recent increase in purchased electricity. After 1965, most new ammonia plants incorporated single-train, centrifugal compressors, which are more economical (though less efficient) than reciprocal compressors for capacities above 600 tons per day. After 1970, there was also a brief trend toward higher compression (5,000 psi compared to 2,000 psi in earlier plants) to increase the capacity of the synthesis loop and reduce refrigeration equipment requirements. In both cases, lower capital costs were achieved at the expense of higher energy costs.

Recently, increased fuel prices (and natural gas shortages) have resulted in reversals of some of the above trends. Substantial investments in heat recovery equipment and expander turbines (to regain energy from ammonia as its pressure is reduced) have been made in response to higher

energy prices in effect since 1973. Other types of add-on units have been developed—e.g., cryogenic processes to recover hydrogen and nitrogen for recycle to the synthesis loop. In addition, most of the low-cost, high-return, housekeeping investments have been made.

Changing Feedstock Availability

A major concern of the primary chemical producers is the availability of feedstock materials. Certainly, the industry's susceptibility to a curtailment of feedstock supply was made evident during the 1973 oil embargo. The United States imports an ever-increasing amount of both organic and inorganic raw materials as it depletes its domestic resources. The chemicals industry must rely on relatively unstable countries for its supply of feedstocks.

To reduce their susceptibility to potential feedstock supply curtailments, chemical companies are increasing their flexibility in the type of raw materials they require. Olefin plants, for example, are shifting away from natural gas, ethane, and propane toward the liquid feeds (naphtha, gas oil, and eventually crude oil). Since plants that process liquid feeds are more complex, because of the initial gasification process required they are equipped to shift feedstock mixes with relative ease, although the plants are still constrained to the same general area of operations.

Shortages of natural gas in the United States have caused some feedstock shifts that are not justified on energy efficiency grounds. Most notably, natural gas is no longer the major feedstock for the production of hydrogen and acetylene. Naphtha and heavy gas oil are now the major sources of cracking feedstock, and by 1990 it would not be surprising if crude oil were cracked directly. Increased demand for byproducts such as propylene and butadiene is one of the driving forces behind this shift. The cost and scarcity of natural gas, the major feedstock for ammonia, have removed domestic producers of ammonia from the world market and made it difficult for them to compete with ammonia imports from Russia and Mexico. As a result, domestic firms have invested in researching methods for producing ammonia from coal.

Changing Feedstock Requirements

Chemical companies can reduce their total feedstock requirements by increasing conversion efficiencies. * This reduction can be done by carefully monitoring present production processes or by switching to new, more efficient production processes. Substantial increases in useful product-to-feedstock ratios can be achieved by improving product separation techniques. By carefully controlling the distillation process, a manufacturer may reduce both his feedstock and his fuel requirements. Ethylene plants have increased their production without increasing their feedstock requirements, simply by routing the by-product, propylene, through the ethylene production process.

Changing Processes

New processes that maximize conversion fractions or minimize the length of production chains have also become important in the past several years. For example, the accepted procedure for the production of acetaldehyde was from ethane, to ethylene, to ethanol, and finally to acetaldehyde. By 1980, most of the production of acetaldehyde was directly from ethylene, resulting in a 15-percent improvement in the acetaldehyde-to-ethane ratio.

*Conversion efficiency is the percentage of feedstock material that is successfully converted into a desired product.

In examining the processes for efficiently making industrial chemicals, four generalized rules become apparent:

1. High-energy feedstocks (typically hydrocarbons) lead to highly efficient (i.e., minimum number of process steps) processes for making a given chemical.
2. High-yield reactions that require only one pass through a reaction chamber or vessel are the most highly efficient means of chemical synthesis because they minimize feedstock and separation energy.
3. Energy efficiency is maximized when the need for product separations is minimized.
4. High conversion reactions recycle **energy and minimize recovery.**

In the course of the workshop meetings and case study visits carried out as part of this analysis, a number of energy-related problems were found to be generic throughout the chemicals industry—i. e., the problems were not specific to a particular chemical production facility. In tables 34 and 35, these problems are listed, along with the typical approaches that have been used **to circumvent or eliminate them.**

Table 34 describes the problems associated with the three largest energy-consuming activities in the chemicals industry—furnace operation, vapor compression, and distillation. A number of the problems involve careful attention to

Table 34.—Operational and Design Problems in Energy-Intensive Equipment

Common problems	Measures to overcome problems
Furnace combustion	
Improper air/fuel ratio	Provide instrumentation to measure oxygen content in flue gas (automatic controls)
Leaks in furnace stacks	Maintenance repair
Vapor compression	
Leaky compressor bypass valves	Maintenance repair
Excess capacity in motor or turbine	Replace with equipment matched to need
Improper suction pressure	Replace with equipment matched to need
Increasing clearance to lower output	Reduce compressor speed to lower output
Use of less expensive and less efficient turbines and compressors	Replace with high-efficiency equipment
Distillation	
Erratic control of columns	Provide automatic control
Excessive reflux, resulting in excessive component separation	Produce minimum quality material
Improper feed tray	Change process operation
Nonoptimum distillation scheme	Consider energy-saving possibilities such as multifeeds, side product draw, or cascade distillation schemes

SOURCE Office of Technology Assessment.

Table 35.—Operational and Design Problems in Heat-Transfer Equipment

Common problems	Measures to overcome problems
Steam traps Faulty operation Leaking traps Mismatch between steam line pressure and trap operating range	Monitor Maintenance repair Use proper application and sizing
Steam tracing Leaks Unnecessarily high steam temperature	Maintenance repair Substitute another fluid for steam
Heat exchangers Fouling Higher than necessary temperature separation between fluid streams	Maintenance repair Design for low-temperature differences by increasing heat-transfer surface area

SOURCE: Office of Technology Assessment.

maintenance and repair; others involve a more precise matching between the pieces of equipment used in a process— i.e., matching electric motors or gas turbines to mechanical drive requirements.

Table 35 describes the general problems found by OTA to be associated with heat-transfer equipment. Again, many of the solutions involve maintenance and more precise equipment matching.

Energy Conservation Through Technology

In considering the chemicals industry as a whole, OTA finds that there are three main areas for improving energy use: physical separation, energy recovery, and product integration.

Physical Separation Technologies

Dramatic improvements in energy use can result from changes in the physical principles embodied in certain unit operations, especially in physical separation.¹⁸ By far, the most widespread technique of chemical separation used today for mixtures of liquids is distillation. This is an energy-intensive process, especially as practiced in the former days of cheap fuel. Already, incremental improvements in the process, retrofitted to existing installations, have achieved significant (e.g., 25 percent) savings in many plants. Further improvements of comparable magnitude can be expected during the next few years through redesign and add-on units, though generally at higher

costs. Steam distillation columns provide opportunities for heat recovery in larger, integrated systems.

Alternative approaches to liquid separation include vacuum distillation, freeze crystallization, and liquid-liquid (solvent) extraction. Dramatic increases in the cost effectiveness of turbocompressors and advances in vacuum pumps and cryogenic technology since the 1950's have vastly increased the relative attractiveness of both vacuum distillation and crystallization relative to steam distillation. However, the most promising technique seems to be liquid-liquid extraction, a process using a solvent with high affinity for one component of the mixture but immiscible with the remaining components. With this technique, separation involves two steps: decanting and closed-loop evaporation/condensation of the solvent. One company has already used the technique in a synthetic fiber plant, saving an estimated 40,000 bbl of oil equivalent annually. Other applications are being actively considered.

Dehydration ("drying") using steam heat is another energy-intensive separation operation that can be dramatically improved in many cases. A technique of squeeze-drying wet solids or fabrics (prior to steam drying) can be adapted from technologies already developed in the paper industry. Separation (prior to disposal by incineration) of oily wastes or oil-soluble contaminants from water mixtures can be accomplished by using specially treated cellulose* that has an affinity for oil. The oil-soaked cellulose can subse-

¹⁸Ibid., p. A-92.

*A technique developed for oil-spill containment.

quently be burned, or squeeze-dried and then recycled.

Technologies for Energy Recovery and Conservation

This category includes both heat recovery per se and improved utilization of energy embodied in high-pressure gases or steam.¹⁹ For example, expansion turbines that recover kinetic energy from ammonia as it comes off the high-pressure synthesis loop are being increasingly used.

A variety of engineering schemes are available to recover waste heat from boilers and exothermic reactors. A "bare burner" boiler, operating with excess air to ensure complete fuel combustion, will typically produce stack gases at **600° F with 6.2 percent oxygen, a stack gas heat loss of 19 percent, and an overall thermal efficiency of 78 percent. Modest improvements in efficiency could be achieved by more precise monitoring of stack temperatures, fuel and air intake, and closed-loop process control.** More significant improvements could result from using the heat of the stack gases either to preheat intake air or intake water via an "economizer." Overall efficiency of 85 percent, with stack gas temperatures reduced to **350°F**, is readily achievable by either technique.

Many older plants used steam-driven vacuum jets instead of electric- or turbine-driven vacuum pumps because of lower capital costs. However, in a typical application, the vacuum pump is up to four times more efficient. For example, **80,000 Btu per hour are typically** used for the electric pump versus 300,000 Btu per hour for the steam jet. Most existing steam jet-driven vacuum systems will probably be replaced by 1990, **except in those situations of low pressure and low flow** where they will continue to have an economic advantage.

Production Integration Technologies

Integration is a strategy for justifying energy and waste recovery that would not otherwise be economically justified.²⁰ The simplest example is cogeneration of electricity and steam. Most firms

in the chemicals industry have several applications of cogeneration under active consideration—in some cases, based on the use of process wastes as fuel. One company, perhaps further along than most, produced 25 percent of its 1980 electricity requirements from onsite cogeneration, a proportion expected to increase to 40 percent by 1985.

Cogeneration opportunities exist to produce electricity or mechanical shaft power as a byproduct of existing steam systems. For instance, in one plant an existing steam boiler produced 300- and 40-psi steam (as needed in the plant). By modifying the boiler to produce steam at 800 psi and 800° F, and interposing a turbogenerator (with exhausts at 300 and 40 psi), enough electricity to supply the plant was generated. Since, utility electricity normally requires 10,000 Btu to produce 1 kWh of electricity, and this operation used 4,200 Btu to produce 1 kWh of electricity, there was a net energy savings of 5,800 Btu/kWh. Many applications such as this will doubtlessly be found in the 1980's.

Potential savings from production integration extend far beyond the case of cogeneration, however. Production of intermediates, such as ethylene and butadiene, is increasingly being integrated into petroleum refining complexes. This trend will be accelerated by the shift toward heavier cracking feedstocks such as heavy gas oil or fuel oil because of the greater importance of coproduct ion.

Integration of the production of ethylene, propylene, and a wide range of petrochemicals from a naphtha-based (aromatics-based) scheme is a strong possibility by 1990. Another option would be to integrate ethylene and acetylene production with ammonia and/or methanol. Ethylene/acetylene coproduction will become increasingly attractive as distillate prices rise and heavier feedstocks are used, and will undoubtedly result in some downstream process switching as acetylene again becomes competitive with ethylene as a feedstock for acrylates, vinyl acetate, and vinyl chloride.

In the United States, at least, there is considerable interest in redeveloping coal-based chemical technologies via synthesis gas. Synthesis

¹⁹ *Ibid.*, p. A-94.

²⁰ *Ibid.*, p. A-97.

gas is currently produced mainly by steam reforming natural gas in the presence of a catalyst to yield a mixture of carbon monoxide and hydrogen (CO-H₂). This process is the basis of most commercial methanol production. In recent years, there has been a good deal of interest (supported by the Department of Energy (DOE)) in coal gasification by a similar technique, resulting in ammonia and/or methanol, the obvious first-stage chemical products. Interest in methanol is

amplified by the possibility that it may be a viable coal-based alternative to gasoline motor fuel. For these reasons a number of large-scale methanol synthesis processes are under active development. It is quite likely that methanol will grow in importance as a chemical intermediate and that a significant fraction of its 1990 production (perhaps 5 to 10 percent) will be derived from coal.

INVESTMENT CHOICES FOR THE CHEMICALS INDUSTRY

Given traditional means of accounting for corporate funds, major corporations in the chemicals industry can finance investments by either internally or externally generated funds. Within the internal category, there is net income, depreciation, deferred taxes, or advanced tax credits. From external sources, there are long-term debt and, in some cases, equity stock sources. The first part of table 36 presents data for 1979, 1980, and 1981 on the funding sources for the 15 largest chemical companies in the United States. The second part of the table shows how the 15 largest chemical companies have allocated their moneys over the past 3 years. As shown, these major corporations devoted over 50 percent of their cash flow to capital expenditures in 1980.

CMA, in reporting energy conservation improvements under DOE's Industrial Energy Reporting Program, listed the aggregate number of energy-related projects undertaken by those 110 companies participating in the CMA report. Table 37 lists the generic categories of these projects. The diversification of the projects in the list reflects the diversity of the industry itself.

It is unlikely that the trends in energy usage in the chemical industry since 1973 will simply continue. Although, it is implicitly assumed that continued rising energy costs will remain the primary force driving energy conservation, it can be assumed that the reductions that have been achieved to date are a result of implementing the

Table 36.—Funding Sources and Funding Uses of Cash Flow of Fifteen Largest Chemical Companies

	1979		1980		1981	
	\$ millions	% of total	\$ millions	% of total	\$ millions	% of total
Sources of funds						
Net income	\$ 3,801	36.30/o	\$3,981	33.20/o	\$4,358	18.20/o
Depreciation and depletion	3,602	34.4	3,818	31.8	4,267	17.9
Deferred taxes	427	4.1	679	5.7	1,012	4.2
Other internal sources	1,093	10.5	815	6.8	1,833	7.7
Long-term debt	1,210	11.6	2,079	17.3	7,493	31.4
Stock	322	3.1	630	5.2	4,931	20.6
Total	\$10,454	100.0 %o	\$12,002	100.00/o	\$23,894	100.00/o
Allocation of funds						
Dividends	\$ 1,474	14.1 %	\$ 1,603	13.4%	\$ 1,845	7.7%
Capital expenditures	5,633	53.9	7,027	58.5	8,344	34.9
Additions to working capital	1,075	10.3	1,057	8.8	3,759	15.7
Reduction of long-term debt	1,042	10.0	1,119	9.3	1,493	6.3
Other applications	1,230	11.7	1,196	10.0	8,453	35.4
Total	\$10,454	100.0 %o	\$12,002	100.0 %o	\$23,894	100.00/o

SOURCE: *Chemical and Engineering News*, June 14, 1982, p. 43.

Table 37.—Types of Energy Efficiency-improving Projects Undertaken by Chemical Manufacturing Association Companies

New process units and technologies

• **25 companies** reported new energy efficiency-improving projects, such as replacing infrared dryers with microwave units; improving chlorine cell energy use; installing new, low-density, polyethylene production facilities; and converting high-pressure methanol manufacturing facilities to low-pressure facilities.

Improvements in existing processes

- **70 companies** reported capital projects that replaced existing equipment or added process control to existing equipment.
- **10 companies** reported projects that changed materials usage and thereby improved energy use.
- **75 companies** reported changes in plant operations that improved energy use.
- **30 companies** reported projects that improved product yield, thereby decreasing the amount of energy used per unit of production.

Housekeeping and retrofit improvements

- **64 companies** reported energy-efficiency improve merits from improved maintenance.
- **59 companies** improved their waste heat recovery.
- **70 companies** invested in improvements in power and steam operations.
- **36 companies** improved plant heating, ventilation, and air conditioning.
- **38 companies** reported improvements in energy recovered from waste materials.
- **71 companies** improved their process pipe insulation.

SOURCE "Energy Efficiency Improvement and Recovered Materials Utilization Report," prepared for DOE by the Chemical Manufacturing Association, June 1, 1982

shorter payback, more apparent, and easier to obtain energy conservation opportunities. The industry had to seek a new balance between factors of production, capital, labor, and energy. Each future reduction in **energy use will make the next increment more difficult or expensive to obtain. Moreover, a certain minimum amount of energy must be used and cannot be reduced for a given amount of industrywide output.**

The major trends within the chemicals industry appear to be as follows:

- Continued improvement in equipment efficiency and operational management.
- Improved methods of physical separation.
- More capital-intensive energy conservation and recovery projects.
- More production integration (including co-generation) to combine exothermic and endothermic reactions and utilize byproducts and waste products efficiently.
- More use of heavy gas oils and coal as feedstocks and synthesis gas in production of ammonia and methanol.
- New processes driven primarily by feedstock costs and availability.

OTA finds that there is still room for improved energy housekeeping and improved process control in many plants. Du Pont, unusual among chemical companies in that it does most of its own plant design and engineering, set up a consulting service in 1973 to sell energy conservation engineering services to other firms in the industry. Its consultants claim to be able to reduce the average client's energy bill by 20 percent, 40 percent of which can typically be achieved without major capital investment.

Moreover, equipment suppliers are constantly introducing incremental improvements—e. g., in sensors and microprocessor controls and in motor, pump, and turbine efficiencies. These changes, together with efficiencies of larger scale, would result in 10 to 20 percent better performance for most new plants in 1990 as compared to 1980, even if plant layouts were unchanged.

IMPACTS OF POLICY OPTIONS ON THE CHEMICALS INDUSTRY

In order to analyze the impacts of legislative options on the chemicals industry, OTA first made certain assumptions about economic growth rates and energy price trends that might occur between now and 2000. The assumptions, presented in tables 2 and 3 of chapter 1, were based on energy price projections of the Energy

Information Agency (EIA) that indicated that distillate fuel prices will remain relatively stable through the 1980's and then rise at a rate of 2 to 3 percent above inflation by **2000**.

In addition, OTA assumed that the following five specific trends would occur in the chemicals industry.

- Ethylene feedstocks will switch from gaseous feeds (ethane and propane) to liquid feeds (naphtha and gas oil).
- More chlorine will be produced from the diaphragm cell and less from the mercury cell.
- Ammonia and methanol production from coal via synthesis gas will become more prevalent, especially after 1990.
- Acetylene production will move toward the crude oil, submerged-flame **process**.
- **Less phosphoric acid will be produced** in electric arc furnaces.

While some of these trends were drawn purely on economic grounds, some are the result of the increasingly cautious attitude toward the use of limited feedstock resources by the industry. For example, by moving toward liquid feeds, an olefin plant will increase its feedstock flexibility because liquid feedstocks require additional vaporizing equipment, and this equipment can be used for a variety of liquid feeds.

Investment Strategy

There is some concern that small chemical firms will respond differently to policy options than will large firms. As part of the OTA analysis, case study visits were made to two small (gross revenue less than \$250 million per year) chemical companies. OTA found no difference between these firms and the larger ones in terms of their energy conservation decision making.

Smaller chemical companies do tend, however, to be motivated by a desire to produce products that have a distinct market differentiation. Whereas large firms tend to rely on high volumes and have relatively high break-even points, smaller firms seek a temporary monopoly or advantageous competitive position in some special area. For these smaller firms, it is more important to spend money differentiating their products than to minimize the cost of standard products.

Ultimately, smaller firms in the chemicals industry can be expected to respond rationally to a Government policy. OTA analysis indicates that a small firm will not take advantage of an initiative simply because it is there, unless it contributes toward the firm's objectives and coincides with its outlook for the economy.

In order to project the impacts of four legislative options, OTA used three types of analytical information. First were the observations of case study corporations and workshop participants. Their experiences and perceptions are presented in the opening paragraphs of the subsection dealing with each legislative option. Next, OTA considered a series of eight capital projects, along with their predicted energy efficiency improvements and costs. These projects were used to illustrate the changes in internal rate of return (IRR) percentages as each legislative option was applied to the series. Some of these projects were generic to all manufacturing establishments, such as replacement of older electric motors with more efficient ones or installation of process control computer facilities. Other projects were specific to the chemicals industry, for example, installation of a heat exchanger in an ammonium nitrate production plant. Table 38 presents brief descriptions of these eight projects along with a summary of the economic and energy assumptions used to calculate individual IRR percentages. Third, OTA used the Industrial Sector Technology Use Model (ISTUM). The analysis begins with the reference case.

The Reference Case

The reference case is based on the economic and legislative environment that exists for industry today and was presented previously in chapter 3. Given the chemical industry reference case, OTA assessment indicates that there will be little change in capital investment trends from that which has been observed in the past 5 years. Recent declines in energy prices may delay projects designed to facilitate fuel switching, especially those switching from distillate fuels to coal. Switching from natural gas energy sources will in all likelihood continue. It seems clear that improvements in energy efficiency will be dictated more at the direction of the economic business cycle, and by perception of opportunity of risk, than by policy.

The reference case incorporates the 1981 Economic Recovery Tax Act, with its special provisions for accelerated depreciation and safe harbor leasing.

Table 38.—Chemical Industry Projects To Be Analyzed for Internal Rate of Return (IRR) Values

1. **Inventory control**—A computerized system can keep track of product item availability, location, age, and the like. In addition, these systems can be used to forecast product demand on a seasonal basis. The overall effect is to lower inventory yet maintain the ability to ship products to customers with little or no delay. In typical installations, working capital costs are dramatically reduced.
Project life—5 years.
Capital and installation costs—\$560,000.
Energy savings—0 directly, but working capital could be reduced by \$1.2 million.
2. **Electric motors**.—The chemical industry uses electrical motors for everything from vapor recompression to mixing, pumping, and extruding. In this analysis, OTA has assumed that five aging electric motors will be replaced with newer, high-efficiency ones.
Project life—10 years.
Capital and installation costs—\$35,000.
Energy savings—\$16,000 per year at 4¢/kWh.
3. **Ammonia nitrate fertilizer plant cogeneration project**.—Installation of a turbogenerator unit to recover electrical power from a steam production facility. Superheated steam is produced at 600 psi and then passed through a mechanical turbine to generate electricity. The turbine exhaust, which is 175 psi steam, is then used for normal plant production.
Project life—10 years.
Capital and installation costs—\$231,000.
Energy savings—\$72,300 per year.
4. **Computerized process control**—The most common retrofit purchases being made for industrial systems are measuring gauges, controlling activators, and computer processors. The main accomplishment of such a process control system is to enhance the throughput and quality of a chemical production plant with only materials and small energy inputs.
Project life—7 years.
Capital and installation costs—\$500,000.
Energy savings—\$150,000 per year.
5. **Heat exchanger in nitric acid plant**.—Equipment installed to heat incoming plant gas streams with the exhaust gas from a 175 psi steam line.
Project life—10 years.
Capital and installation costs—\$155,000.
Energy savings—\$41,200 per year.
6. **Counterflow heat exchanger**.—A counterflow heat exchanger preheats air entering a kiln with the exhaust stack gases from the same kiln.
Project life—10 years.
Capital and installation costs—\$200,000.
Energy savings—\$53,000 per year.
7. **Waste heat boiler**.—Installation of a heat exchanger and waste heat boiler in an ammonia plant.
Project life—10 years.
Capital and installation costs—\$1,425,000.
Energy savings—\$351,000 per year.
8. **Ammonia plant cogeneration project**—installation of a turbogenerator unit to recover electrical power from a high-pressure, natural gas stream just before it enters the reformer burner.
Project life—10 years.
Capital and installation costs—\$816,000.
Energy savings—\$193,000 per year.

SOURCE: Office of Technology Assessment.

The gross output of the chemicals industry is anticipated to grow at a rate of approximately 4 percent per year between now and 2000. Consider data presented in table 39. Between 1969 and 1979, the industry grew at an annual rate of 5.8 percent. That growth rate will probably decline slightly as energy prices increase over the next 20 years. Under the energy price scenario of the reference case, OTA analysis projects, the fuel to be consumed and the energy service to be provided between now and 2000* (see tables 40 and 41).

Tables 42 and 43 show that process heat, which should decrease from 526 trillion to 379 trillion Btu, will shift from the proportions of 76 percent natural gas, 13 percent oil, and 11 percent electricity to those of 70 percent natural gas, 14 percent oil, and 15 percent electricity. In steam and power generation, natural gas will decrease from 70 percent of the 2,456 trillion Btu to 34 percent of the 3,180 trillion Btu predicted to be used in 2000.

Figure 31 shows that the energy intensity of the average product in the chemicals industry is projected to fall from its present value of 17.6 thousand Btu per pound of product to approximately 15 thousand Btu per pound by the end of the century. Figure 32 shows that fuel use is projected to grow only slightly from its present level of 6.8 Quads to just over 8 Quads by 2000, assuming the energy price and product growth rates built into the initial parameters of OTA's modeling efforts.

Projected Effects of Policy Options

The following sections describe the projected effects of the four policy options in comparison to changes in the chemicals industry energy use and product energy intensity in the reference case. Figure 32 presents a graphical overview of the impact of these policies.

Option 1: Removal of Accelerated Depreciation

Removal of accelerated depreciation is projected to have little impact on energy use in the

*It should be noted, once again, that energy demand projections are predicated on a set of exogenously determined energy prices and a fixed product output.

Table 39.—Historical and Assumed Growth Rates in SIC 28

	1969-80	1980-85	1985-90	1990-2000
All manufacturing FRB ^a growth rate	3.250/o	3.9 %/0	4.3 %/0	3.7 %/0
Chemical industry FRB ^a growth rate	3.9 %/0	5.0 %/0	5.00/0	4.60/o
Fuel price, gas (\$/MMBtu)	—	5.0	6.3	9.0
Fuel price, residuum (\$/MMBtu)	—	5.0	6.2	9.0
Fuel price, coal (\$/MMBtu)	—	2.2	2.3	2.4
Fuel price, electricity (\$/MMBtu)	—	13.8	13.7	13.8

^aFederal Reserve Board.

SOURCE: Office of Technology Assessment

**Table 40.—Reference Case Energy Use Projection, by Fuel: 1980-2000
(In million Btu)**

Year	Gas		oil		Coal Fuel	Purchased electricity	Total energy
	Fuel	Feedstock	Fuel	Feedstock			
1980	2,114	388	377	1,711	287	537	5,414
1985	2,085	371	369	2,002	462	558	5,847
	1,794	333	439	2,431	829	613	6,439
2000	1,201	246	518	3,268	1,636	702	7,571

^aAt 3,412 Btu/kWh.

SOURCE: Office of Technology Assessment.

**Table 41.—Reference Case Energy Use Projection, by End Use: 1985-2000
(In million Btu)**

Year	Process heat		Steam and power	Machine drive	Electrolysis	Feedstocks	Total
	Process heat	Steam					
1985	526	2,456	585	177	2,163	5,847	
1990	515	2,640	644	129	2,511	6,439	
2000	379	3,180	681	151	3,180	7,571	

SOURCE: Office of Technology Assessment.

**Table 42.—Reference Case Energy Use Projection,
by Process Heat Fuel: 1985=2000 (In percent)**

Year	Total	Gas	Oil	Coal	Electricity	Other ^a
1985	100	76	13	—	11	11
1990	100	79	10	1	10	—
2000	100	70	14	1	15	—

^aChemical byproducts and waste products used as fuels.

SOURCE: Office of Technology Assessment.

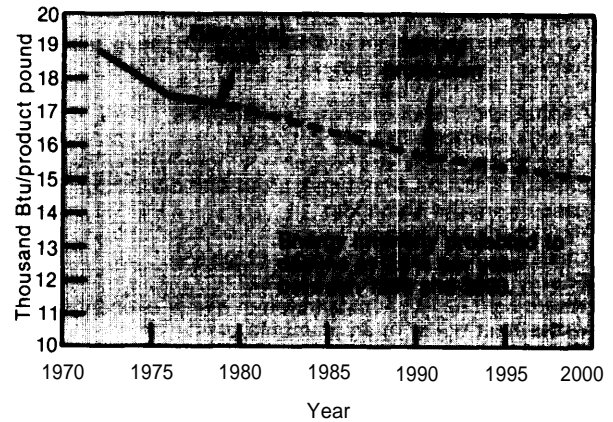
**Table 43.—Reference Case Energy Use Projection,
Steam and Power Fuel: 1985=2000 (in percent)**

Year	Gas	Oil	Coal	Other ^a
1985	70	8	18	4
1990	56	11	30	3
2000	34	14	50	2

^aChemical byproducts and waste products used as fuels.

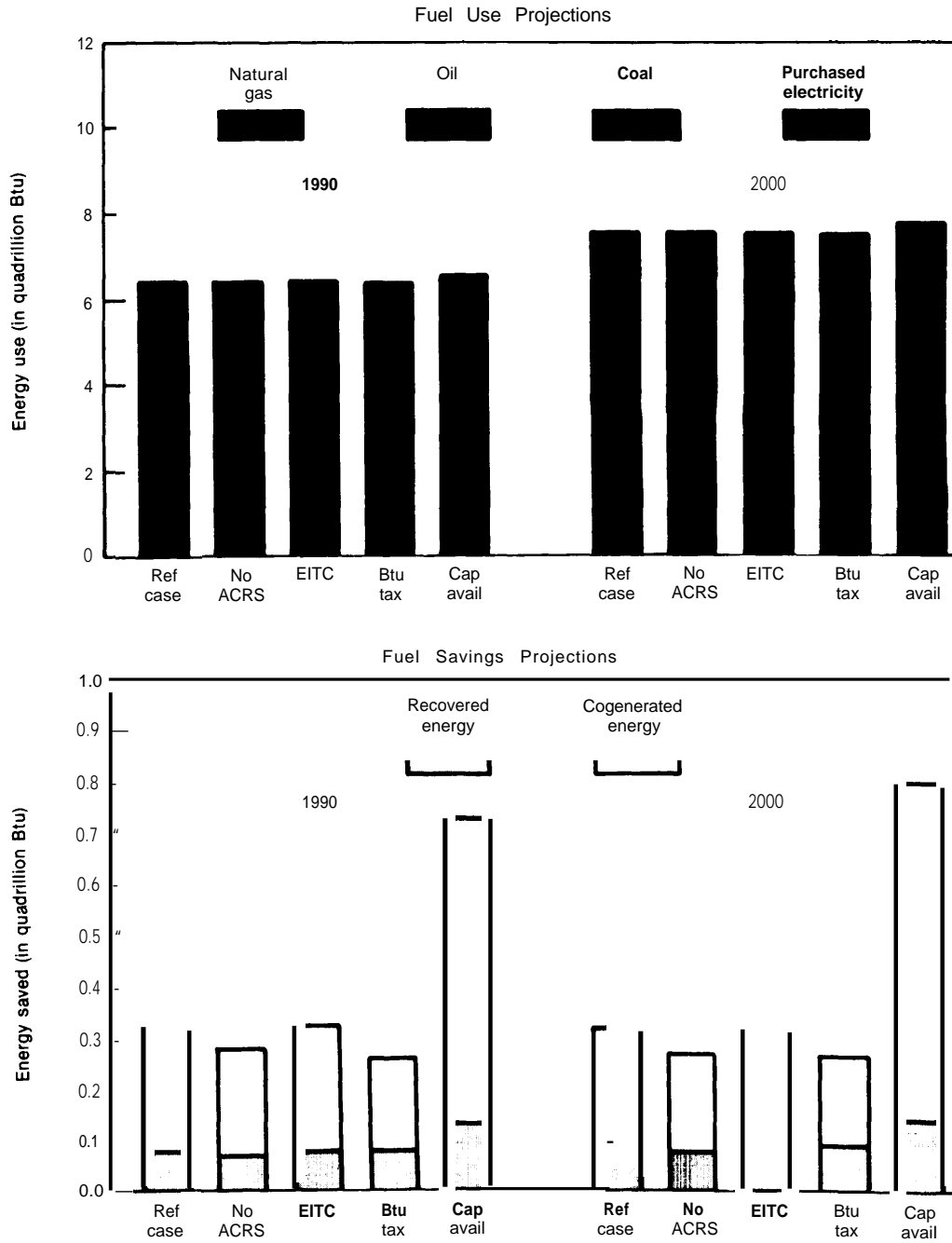
SOURCE: Office of Technology Assessment.

**Figure 31.—Chemicals Industry Energy Intensity
Projection, 1970-2000**



SOURCE: Office of Technology Assessment

Figure 32.—Chemical Industry Projections of Fuel Use and Energy Savings by Policy Options, 1990 and 2000



SOURCE: Office of Technology Assessment

chemicals industry, since the accelerated cost recovery system (ACRS) effects are so dependent on the general investment climate. OTA analysis indicates that the energy intensity decline with ACRS removal is coincident with the reference case energy intensity projection over the next 17 years. In addition, the fuel use projections are virtually identical for both the reference case and the removal of accelerated depreciation, as shown in figure 32.

Table 44 presents the IRR calculations of the eight chemical projects under both old depreciation and accelerated depreciation schedules. As shown, there is essentially no change between the two columns of calculations, nor is there any change in the relative rankings of each of the projects. In sum, energy use, compared to the reference case, is unaffected by removal of the ACRS depreciation schedule.

Option 2: Targeted Energy Investment Tax Credits

Targeted energy investment tax credits (EITCS) of the magnitude discussed in this report will likely have little effect on energy efficiency in the chemicals industry between now and 2000. Such incentives are perceived as having three functions. First, they are useful for increasing the IRR, thereby presumably elevating the desirability of a project that would not have met the hurdle-rate cut-off for consideration as part of a corporation's capital plan. OTA calculations show that a 10-percent EITC would change the IRR by 3 to 6 percentage points, depending on the length of

a project's lifetime. This change is not large enough to influence significantly the decision to implement a capital project. OTA **was** unable to find evidence of a chemicals project that was influenced by a 10-percent EITC.

Second, targeted tax credits increase general cash flow in an energy-intensive company. Logic would dictate that if an organization were to invest 25 percent of its funds in energy efficiency-improving capital stock, to the degree that more money is generated for investment through such a credit, 25 percent of that additional money would go to energy efficiency-improving equipment. At best, however, this is speculative. The case study firms and workshop panelists state that some energy would be saved with increased cash flow, but the amount saved is unquantifiable and very company-specific.

The third reason for justifying tax credits is to raise the awareness of corporate management that saving energy is important, not only for profitability, but also for the national interest. Although the effect of this rationale is unquantifiable, workshop panelists say it could be an important motivating influence to some organizations.

OTA analysis projects that a 10-percent EITC would produce no change in chemicals industry energy intensity from that projected in the reference case. Figure 32 shows that the fuel use patterns would be unchanged as well,

To illustrate the effect of a 10-percent EITC on the IRR, the eight chemical industry projects

Table 44.—Effects of Policy Options on IRR Values of Chemical Industry Projects

Project	Reference case	ACRS removed	10-percent EITC	Policy option \$1/MMBtu tax on natural gas and petroleum products
1. Inventory control	87	87	87	87 (No fuel)
2. Electric motors	43	43	48	51 (Electric)
3. Fertilizer plant cogeneration project	18	18	20	18 (Coal)
4. Computer process control	16	16	22	19 (Oil)
5. Nitric acid plant heat exchanger	15	15	18	21 (N. Gas)
6. Counterflow heat exchanger	15	15	18	19 (Oil)
7. Waste heat boiler	11	11	14	16 (N. Gas)
8. Ammonia plant cogeneration project	11	11	15	17 (Gas)

SOURCE: Office of Technology Assessment.

previously described were analyzed with and without the tax credit. In table 44, the IRR for each project is presented. As shown, only two projects—projects 4 and 8—changed their relative rankings. However, such changes are unlikely to cause projects 4 and 8 to be undertaken at the expense of projects 3 and 7. There might be other factors which the investment tax credit might supplement or bolster to cause the project to be undertaken, but the tax credit alone would not be so motivating.

Option 3: Tax on Premium Fuels

OTA's assessment of the impact of a fuel tax of \$1 -per-million-Btu fuel tax on natural gas and distillate fuels is that it would have a positive effect on improving energy efficiency but could have an overall negative effect on the U.S. chemicals industry with respect to foreign competition.

OTA's ISTUM analysis projects a premium fuels tax to have little effect on energy use in the chemicals sector. The energy intensity of chemicals industry products is projected to be within a percentage point of being identical to that of the reference case. However, as shown in figure 32, fuel use patterns are projected to shift slightly. A premium fuels tax would cause natural gas consumption to fall by approximately 10 percent, while coal would increase by a similar amount. [It is also noteworthy that a premium fuels tax would decrease cogeneration of electricity, since the most reliable and efficient fuel in cogeneration units is natural gas. OTA projects that cogeneration could fall by 25 percent under the premium fuels tax scenario.

If a premium fuels tax were to be levied, multinational chemical companies would probably build production facilities outside U.S. boundaries in order to take advantage of lower energy prices. The products would then be imported to the United States or shipped to other countries. In either case, this would adversely affect U.S. balance of payments, since chemical trade generated an \$11 billion positive flow in 1981.

The fuels tax would also change the IRR percentages, as indicated in table 44. The effect of the fuel tax on the eight sample projects would

be more pronounced than in the case of the EITC. The gain in the IRR was almost 6 percentage points for project 5, the nitric acid plant heat exchanger, for example. The overall effect on most of the projects was to increase the IRR overall by 4 to 6 points.

Option 4: Low Cost of Capital

At present, the availability of capital is *not* a major constraint in the chemicals industry. The chemicals industry has been profitable over the last 10 years, especially compared to the steel industry. High interest rates have not hurt chemical firms directly, although they have indirectly decreased the demand for chemical products in the housing and auto industry. Moreover, chemical companies have been able to borrow funds where needed. Although making funds available for general investment at lower interest rates does have an impact on the IRR, the energy, employment, and capital investment consequences are, at best, difficult to estimate.

Energy intensity is projected to fall in approximately the same fashion with the capital availability option as in the reference case, although the projected level is slightly higher than with the reference case. Figure 32 shows that with less expensive capital, chemicals industry firms would install more cogeneration capacity, and thereby decrease purchased electricity demand while increasing natural gas use. In a sense, this increase is an energy accounting artifact. Fuel use is being switched from public utilities to the industrial sector. As with all cogeneration, the effect on the energy economy is to make the United States more energy efficient with cogeneration, even though it looks less efficient for the chemicals industry.

In order to illustrate the effect of lower interest rates on IRR, OTA first assumed that the chemicals industry projects would be funded by debt financing. In the analysis, shown in table 45, those projects that were good investments at the outset continued to be good investments with the change in interest rates. While the IRR values changed slightly, none surpassed the others with a low cost of capital option.

Table 45.—Effect of Lower Interest Rates on IRR Values of Chemical Industry Projects^a

Project	Reference case IRR with 16% interest rate	IRR with policy options: interest rate of 8%
1. Inventory control	385	370
2. Electric motors	93	97
3. Computer process control	36	44
4. Nitric acid plant heat exchanger	35	39
5. Counterflow heat exchanger	33	38
6. Ammonia plant cogeneration project	27	31
7. Fertilizer plant cogeneration project	26	28
8. Waste heat boiler	24	27

^aAll projects are assumed to be two-thirds debt financed and one-third equity financed,
SOURCE: Office of Technology Assessment.