Riegel's Handbook of Industrial Chemistry

EIGHTH EDITION

Edited by
James A. Kent

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Preface

As always, the aim of this book is to present an up-to-date account of the many facets of as broad a cross section of the chemical process industry as is reasonable in a single volume of this size. Since the last edition, which was published in 1974, the industry has continued to demonstrate that is is still in a period of dynamic change and that while some segments are more mature than others, none can be described as static. Indeed, developments in some areas of the industry can only be described as revolutionary and exciting. This edition brings together the contributions of thirty-four experts from industry, academe, and government. Many of these are probably known to the reader for their numerous contributions to scholarly literature. Through their excellent work, contents of the chapters from the previous edition have at the least been updated and revised. Several of the chapters, which now have new authors, have been completely redone, using new approaches and different perspectives.

The contributors have done an outstanding job, and credit for the quality of the individual chapters goes to them. Errors of omission or duplication, and shortcomings in organization of the material are mine.

Grateful acknowledgment is made to the editors of technical magazines and publishing houses for permission to reproduce illustrations and other material and to the many industrial concerns which contributed drawings and photographs.

Comments and criticism by readers will be welcome.

JAMES A. KENT
Birmingham, Michigan

Contents

1

Economic Aspects of the Chemical Industry

F. E. Bailey, Jr.*

Within the formal departments of science at the traditional university, chemistry has grown to have a unique status because of its close correspondence with an industry, the chemical industry, and a branch of engineering - chemical engineering. There is no biology industry, though drugs, pharmaceuticals, and agriculture are closely related disciplines. While there is no physics industry, there are the power generation and electronics industries. But, connected with chemistry, there is an industry. This unusual correspondence probably came about because in chemistry one makes things–chemicals–and the science and the use of chemicals more or less grew up together during the past century.

Since there is a chemical industry, which serves a major part of all industrialized economies, providing in the end synthetic drugs, fertilizers, clothing, building materials, paints, elastomers, etc., there is also a subject, "chemical economics," and it is this subject, the economics of the chemical industry, which is the concern of this chapter.

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DEFINITION OF THE CHEMICAL INDUSTRY

Early in this century, the chemical industry was considered to have two parts: the manufacture of inorganic chemicals and the manufacture of organic chemicals. Today, the Standard Industrial Classification (SIC Index) of the United States Bureau of the Census defines "Chemical and Allied Products" as comprising three general classes of products: "(1) basic chemicals such as acids, alkalis, salts, and organic chemicals; (2) chemicals to be used in further manufacture such as synthetic fibers, plastics materials, dry colors, and pigments; and (3) finished chemical products to be used for ultimate consumption as drugs, cosmetics, and soaps, or to be used as materials or supplies in other industries such as paints, fertilizers, and explosives."[1] An even broader description that is often considered is "chemical process industries," major segments of which include: chemical and allied products and petrochemicals; paper and pulp; petroleum refining; rubber and plastics; and stone, clay and glass products.

THE PLACE OF THE CHEMICAL INDUSTRY IN THE ECONOMY

The total value of manufacturer's sales and shipments in the United States in 1979 was about \$1.7 trillion. In comparison with this total, the value of sales and shipments of the chemical and allied products industry was about \$149 billion. For perspective, these chemical sales were equal to 60 percent of the total value of food and food products and about two-and-a-half times that of paper product shipments and sales and about the same sales value as that of all primary metals. In Table 1.1, these chemical sales to selected markets are indicated for 1971[1]. It is interesting to note that "Chemicals and Allied Products" is the industry's own best customer, reflecting the sale of reactive chemical intermediates used in the manufacture of more complex chemical products.

To further gauge the place of chemicals in the economy of the United States, comparisons in growth can be made with the *gross national product* (GNP). The gross national product, an index of the size of the economy, is the sum for any one year of a nation's output in terms of expenditures for goods and services by consumers, government, business, and foreign interests; that is, it is the total of personal consumption, government purchases, gross private domestic investment, and net export of goods and services. For 1979, the gross national product of the United States was over two-and-a-quarter trillion dollars (Fig. 1.1). In terms of current dollars (reflecting both real growth and inflation) the United States' GNP doubled between 1950 and 1960 (\$286 billion to \$506 billion) and essentially doubled again by 1970 (\$982 billion). These figures indicate average growth rates for the GNP of about 7.2 percent per year of which about four percent represents real growth in output of goods and services and the remainder, inflation factors.

TABLE 1.1 Chemical Industry Sales to Selected Markets in the United States, 1971

Market	*Percent of Sales*
Chemical and Allied Products	46%
Textile Mill Products (Including apparel industry)	16
Rubber and Plastic Products	11
Food and Farming	6
Paper and Allied Products	4
Petroleum Industry	3

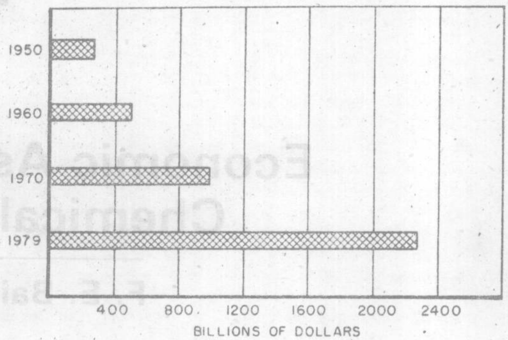


Fig. 1.1. The gross national product (GNP) of the United States in current dollars for the years 1950–1979.

In these terms, the chemical and allied products industry kept pace with the general economy. Sales in 1950 amounted to about \$15.4 billion and in 1960, \$26.3 billion. In 1970, sales amounted to about \$50 billion - essentially doubling in dollar value each decade, producing an industry annual growth rate of 7–8 percent per year.

In the decade of the 1970's, however, inflation became an enormous factor in the economy. In 1979, the GNP of the United States in current dollars was \$2369 billion. While a number of factors have been identified as the basis for inflation, the principal factors in the chemical industry have been the cost of energy (power and heat) and the cost of raw materials (petroleum and natural gas). It is instructive, then, to put the GNP in terms of constant dollars, so as to be an index of the "volume" of goods and services produced. In Figure 1.2, the GNP is expressed in terms of 1972 dollars in which case the GNP in 1970 is \$1075.3 billion and in 1979, \$1431.6 billion. In terms of either of these indices, GNP in current or constant dollars, the chemical industry grew in the 1970's at a pace faster than that of the overall economy. Chemical and allied products sales in 1979 in current dollars were about \$149 billion (Figure 1.3).

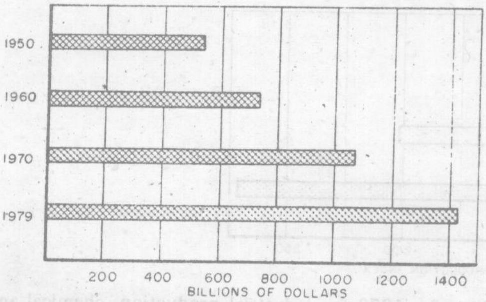


Fig. 1.2. The gross national product (GNP) of the United States for the years 1950–1979 in constant dollars (1972).

TABLE 1.2 1972–1977 Growth Rates in Value Added in the United States for Selected Parts of the Chemical Process Industries

Agricultural Chemicals	24.0%/year
Surface Active Agents	17.9
Plastics Materials	17.2
Adhesives and Sealants	14.5
Industrial Gases	12.4
Toilet Preparations	12.2
Chemical and Allied Products	12.0
Paints	11.8
Pharmaceutical Preparations (Human and veterinary)	8.9
Organic, Non-cellulosic fibers	8.0
Soaps and other Detergents	7.8
Cellulosic Fibers	6.7
Synthetic Rubber	3.2

These average growth rates for an entire industry cover a broad spectrum of rates of growth for various product classes. The historic growth of chemicals has been characterized by rapid development of new products which in time achieve the status of high volume, bulk-shipment products having an established place in the economy with correspondingly slower overall growth. Meanwhile, new materials are introduced which grow at a more rapid rate. The net result is an industry growing with the economy and an aggregate growth somewhat faster than GNP.

A spectrum of the chemical industry is examined in more detail in Table 1.2. The industry growth rate in the 1970's in value added was about 12 percent per year. The highest growth rates in value added tend to be in high technology areas with new products (Table 1.2). Agricultural chemicals is an area of both increased demand and high technology, reflecting the leadership of the United States in agricultural technology and production. On the other hand, synthetic rubber in the 1970's experienced a relatively low growth rate, reflecting the importance of the automobile tire (decline in sales growth) in this market as well as rapid inflation in raw material costs.

While growth in total dollar volume of the chemicals produced has kept pace or exceeded the growth of the total United States' economy, the actual production of chemicals has grown even faster. In terms of physical volume—the tons produced annually—the chemical process industries have grown faster than the industrial average represented by the Federal Reserve Board index of industrial production (1967 = 100). (Fig. 1-4.) Relative to 1967, the industrial production index in 1979 was 152.1, while that for chemical and allied products was 210.4 and plastic products was 270.5. These industry indices cover a broad spectrum of product classes (Table 1.3), ranging in growth from the huge increases in plastics, synthetic fibers,

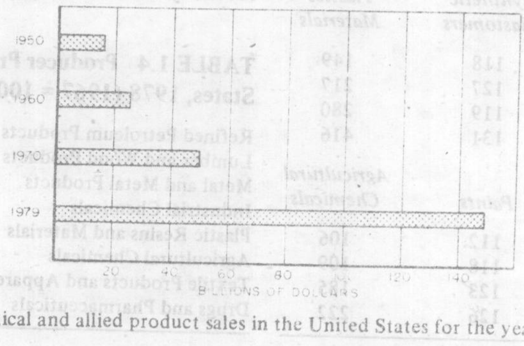


Fig. 1.3. Chemical and allied product sales in the United States for the years 1950–1979.

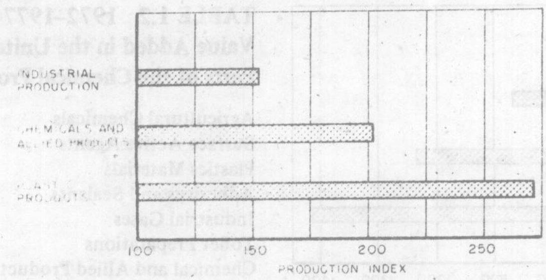


Fig. 1.4. United States Federal Reserve production indices for 1979 for industrial production, chemical and allied products and plastics products (1967 = 100).

and agricultural chemicals to the modest growth in elastomers and paints.

If the amount in tons produced by the chemical industry has grown faster than average industrial production, while the total dollar sales have grown at a rate closer to that of the economy, the relative unit price of chemical products might be expected to have been less subject to inflation. In Table 1.4, the producer price indices in the United States for a number of industries are given for 1978 relative to 1967. Relative to the economy, the price indices for chemicals products have held about even, reflecting primarily increases in raw material costs. The two most disruptive factors

TABLE 1.3 Production Indices for Selected Parts of the Chemical Process Industries (1967 = 100)

Year	*All Chemicals*	*Basic Inorganics*	*Basic Organics*
1969	118	98	125
1972	144	107	155
1976	171	124	190
1979	210	134	233
Year	*Synthetic Fibers*	*Synthetic Elastomers*	*Plastics Materials*
1969	140	118	149
1972	189	127	217
1976	214	119	280
1979	271	131	416
Year	*Soaps and Toiletries*	*Paints*	*Agricultural Chemicals*
1969	111	112	106
1972	130	118	109
1976	143	123	185
1979	172	126	222

in the economy of the United States in the 1970's, the cost of energy and the cost of petroleum and natural gas, have been offset in the chemical industry to a considerable degree through chemical process improvements and energy conservation. The chemical industry actually consumed three percent less total energy in operations in 1978 than in 1972[2]. (Fig. 1.5.)

CHARACTERISTICS OF THE CHEMICAL INDUSTRY

Investment Trends

The chemical industry tends to be a high investment business. Capital spending by the chemical and allied products industry in the United States has been a sizable percentage of that spent for all manufacturing, some ten percent (Table 1.5). The amount spent for all chemical process industries has been, of course, even larger. For perspective, annual expenditures for new plant and equipment in the United States for chemical and allied products industry in recent years has averaged about two-and-one-

TABLE 1.4 Producer Price Indices—United States, 1978 (1967 = 100)

Refined Petroleum Products	321
Lumber and Wood Products	276
Metal and Metal Products	227
Industrial Chemicals	226
Plastic Resins and Materials	200
Agricultural Chemicals	198
Textile Products and Apparel	160
Drugs and Pharmaceuticals	148

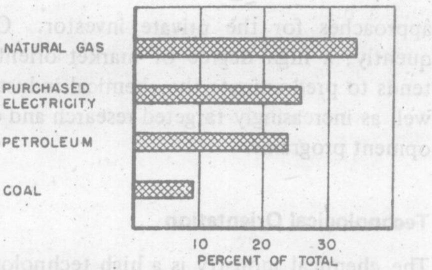


Fig. 1.5. Sources of energy used in chemical industry in the United States in 1978 as a percent of the total used by the industry.

half times that for iron and steel and about half of the invested in the petroleum industry. For the past decade a significant part of these capital investments have been made in pollution control projects.

Much of the capital investment in the chemical industry is spent for facilities to produce major chemicals (Table 1.6) in truly enormous quantities. The volume produced has been reflected in the size of plants being built to achieve the required economies of scale. That such economies are achieved is seen in the more modest increases in the chemical producers' price indices relative to the inflation levels in the general economy. (Economy of scale refers to the relative cost of building a larger plant. A rule of thumb is that the relative cost of building a smaller or a larger plant is the ratio of the productivities of the two plants being considered, raised to the 0.6 power. In other words, the unit cost of producing a chemical decreases markedly as the size of the plant producing it is increased, providing that the plant can be operated near capacity.)

Today, a typical base petrochemicals plant will consume the equivalent of 30,000 barrels per day of naphtha to produce about one billion pounds of ethylene a year, plus 2.5 billion pounds of coproducts. To be economically feasible, for example, vinyl chloride and styrene monomer plants must be scaled in the billion pound-a-year range.

Along with these very large plants and the associated enormous investment, most of the chemical industry is characterized by high investment versus low labor components in cost of manufacture. The National Industrial Conference Board statistics list the chemical industry as one of the highest in terms of capital investment per production worker. The investment per worker in a base petrochemicals olefins plant may well exceed a quarter of a million dollars. Once again, however, such an index covers a spectrum of operations, and for a profitable chemical specialties manufacturer the investment may be of the order of 25,000 dollars per worker. Employment in selected parts of the chemical industry is given in Table 1.7.

TABLE 1.5 Capital Spending by Industries in the United States (Billion of Dollars), 1979

All United States Corporations	180
All Manufacturing	80
Chemical Process Industries	30
Chemical and Allied Products	8
Industrial Chemicals	6.5

Capital Spending by Industries in the United States on Pollution Control Projects (Billions of Dollars), 1979

All Manufacturing	4.0
Chemical Process Industries	2.3
Chemical and Allied Products	.5

TABLE 1.6 Production of Selected Chemicals and Plastics in the United States, 1979 (Billions of Pounds)

Organic Chemicals	*Billion Pounds*
Ethylene	29.2
Propylene	14.3
Styrene (monomer)	7.5
Phenol (synthetic)	3.0
Inorganic Chemicals	
Chlorine	24.2
Ammonia	36.2
Sulfuric Acid	84.0
Plastics	
Low density polyethylene	8.8
High density polyethylene	5.0
Polypropylene	3.8
Polystyrene (all types)	6.2
Poly (vinyl chloride)	6.1
Phenolics	1.8
Synthetic Rubber	2.5

TABLE 1.7 Employment in Selected Parts of the Chemical Industry in 1979

Chemical Industry	*Thousands of Workers*
Chemical and Allied Products	1100
Plastics Materials	220
Drugs	190
Inorganic Chemicals	170
Organic Chemicals	170
Petroleum Products	200
Rubber and Plastic Products	770

Commercial Development and Competition Factors

In an earlier period in the development of the chemical industry, chemical companies were generally production oriented, exploiting a process to produce a chemical and then selling it into rapidly expanding markets. Plant sizes and investments required to participate were small fractions of those of today. Raw materials were often purchased to produce chemical intermediates for sale. Smaller plants operating in smaller manufacturing complexes did not present the obvious problems of environmental pollution about which we have become more aware during the past decade. A new investment in chemical production today includes a significant proportion to abate and control environmental intrusion.

As the industry has grown, there has been a strong tendency toward integration both forward and back. Petroleum producers have found opportunities based on their raw materials position to move into chemical manufacturing. Chemical companies, on the other hand, have moved to assure their access to low-cost raw materials. Similarly, producers of plastic materials have moved forward to produce fabricated products, such as films, fibers, and consumer items, while fabricators have installed equipment to handle and formulate the plastic materials in order to provide a supply at the lowest possible cost.

With ever higher investment and increasing cross-industry competition, increasingly greater sophistication has been required of marketing analysis and selection of investment. The enormity of the investment required today to participate successfully does not permit multiple approaches for the private investor. Consequently, a high degree of market orientation tends to predominate the chemical industry, as well as increasingly targeted research and development programs.

Technological Orientation

The chemical industry is a high technology industry, albeit now more marketing oriented and competitive than in its earlier period of development. This orientation is seen in the number of scientists and engineers employed in Research and Development relative to other industries (Table 1.8). In general, the chemical industry is among the largest employers of scientists and engineers, and it invests a sizable percentage of the total United States business investment in R&D (Table 1.9).

The contemporary scientist and engineer engaged in research and development in the chemical industry represents individually a high investment occupation. Since the mid-1950's, chemistry has become increasingly an instrumental science. The instruments now routinely used are both highly sophisticated and costly. A major research project would not be undertaken without access to a variety of spectrophotometers, spectrometers, and chromatographs, as well as the needed physical chemical instruments for structure determinations and reaction kinetics. Pilot plants are highly automated and instrumented. Both the basic researcher and pilot plant engineer require access to computer facilities. In 1978, the average cost to maintain an operating R&D scientist or engineer in the chemical industry was $74,000 per year. Impressive as these statistics may be in representing the business investment in chemicals R&D in the United States, R&D

TABLE 1.8 Scientists and Engineers in Research and Development in the United States, 1979 (Thousands)

Aircraft and Missiles	86
Electrical Equipment and Communications	90
Machinery	64
Chemical and Allied Products	52
Motor Vehicles and other Transportation	34
Petroleum Refining	17

TABLE 1.9 United States' Business Investment in Research and Development, 1979

	Billions of Dollars
All Business	37.7
Chemical and Allied Products	4.1
Industrial Chemicals	2.1

spending in the chemicals industry as a percent of sales has declined from about four percent in 1970 to about 2.5 percent in 1980 (Fig. 1.6). This decline has become a concern in that reinvestment in R&D, particularly in West Germany and Japan, has remained at a higher level as measured by this index.

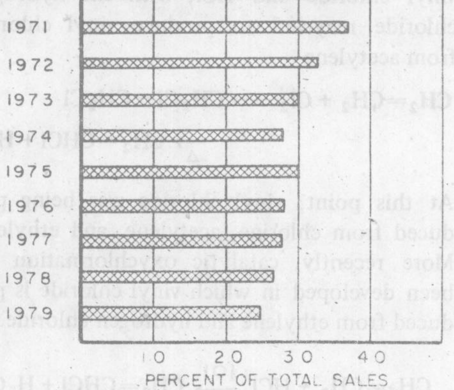


Fig. 1.6. R and D spending by the 14 largest chemical companies in the United States as a percent of total sales for the years 1970–1979.

Obsolescence and Dependence on Research

The high technology level that characterizes the chemical industry, and which is reflected in heavy investments in R&D, generally concerns discovery and development of new products and improvement in the manufacture of known products. The first area is the more conspicuous: the pharmaceutical for a specific disease; the narrow spectrum, transient pesticide; the new, super-performance, composite system for an internal combustion engine; or the new composite sails on the 1980 entries in the America's Cup races. The second area, however, makes viable the circumstances outlined earlier under which increasing investments can be made to produce larger quantities of materials. The development of a new, lower cost process for a commercial product can permit development of a profitable opportunity, or spell disaster for a company with existing investment in a now obsolete plant. Major reductions in manufacturing cost can be achieved, for example, by reducing the number of reaction steps required, changing to a lower cost or more available raw material, or eliminating coproducts or costly separations. The ability of a process scheme to contain or avoid a pollutant can be a deciding factor in continuance of a manufacturing operation. Examples of the above factors will make clear the economic consequences.

Acetic acid production in the United States has increased eightfold in the last 30 years. From the 1930's, acetic acid was produced by a three-step synthesis from ethylene: acid hydrolysis to ethanol, then catalytic dehydrogenation to acetaldehyde, then direct liquid-phase oxidation to acetic acid and acetic anhydride as coproducts.

$$CH_2{=}CH_2 \xrightarrow[H_2O]{H_2SO_4} C_2H_5OH \xrightarrow[Cu/Cr]{}$$

$$CH_3CHO \xrightarrow[\substack{Co\\(liq)}]{O} \begin{matrix} CH_3C(=O) \\ \quad\;\; O \\ CH_3C(=O) \end{matrix} + CH_3C(=O)OH$$

In the 40's, a major process change was introduced—direct oxidation of butane to acetic acid and coproducts (such as methylethylketone).

$$C_4H_{10} \xrightarrow{O_2} CH_3C(=O)OH + CH_3{-}\underset{\|}{C}{-}C_2H_5 \;(C{=}O) + \text{etc.}$$

Fewer steps in synthesis were reflected in lower cost and investment. In 1969, another advance was announced, synthesis of acetic acid from methanol and carbon monoxide with essentially no coproducts[3,4].

$$CH_3OH + CO \xrightarrow[Rh]{I^-} CH_3C(=O)OH$$

Lack of coproducts reduces costs and investment in distillation and other separations systems, very attractive process features in an industry where the principally accepted measure of business quality is return on investment.

Acetic anhydride is needed as a process intermediate in acetylations. To obtain acetic anhydride from acetic acid, acetic acid is first pyrolized to ketene which then reacts with recovered acetic to yield the anhydride.

$$CH_3C(=O)OH \xrightarrow[\Delta]{} CH_2{=}C{=}O$$

$$CH_2{=}C{=}O + CH_3C(=O)OH \longrightarrow (CH_3C(=O))_2O$$

In 1980, the Tennessee Eastman unit of Eastman Kodak announced that it would begin construction of a plant to make acetic anhydride from coal[5,6]. This decision reflected the changing of the raw materials base of much of the chemical industry due to such factors as the rising cost of natural gas and of petroleum and the large coal reserves of the United States.

In the new process, Eastman will make synthesis gas (carbon monoxide and hydrogen) from coal and then from synthesis gas, methanol. Up to now, methanol has been chiefly produced from natural gas methane.

$$CO + 2H_2 \longrightarrow CH_3OH$$

Methanol can then react with acetic acid to make methyl acetate

$$CH_3OH + CH_3C(=O)OH \longrightarrow CH_3{-}O{-}C(=O){-}CH_3$$

Acetic anhydride is then obtained from the catalytic carbonylation of methyl acetate with carbon monoxide[4]

$$CH_3{-}O{-}C(=O){-}CH_3 + CO \longrightarrow (CH_3{-}C(=O))_2O$$

The attractiveness of this process is twofold: (1) the raw materials base of synthesis gas from coal and (2) the avoidance of the energy consuming manufacture of ketene by pyrolyzing acetic acid.

The increase in the production of vinyl chloride, the principal monomer for poly(vinyl chloride) plastics, which are used in vinyl flooring, phonograph records, shower curtains, rain coats, car seat upholstery, house siding, pipe, and so on, is even more spectacular. Production in the United States has increased from 250 million pounds in 1950 (when it was declared by many industry economic forecasters to be a mature chemical commodity) to over one billion pounds in 1960, to about 3.5 billion pounds in 1970, and to over seven billion pounds in 1980.

During the early development period of vinyl resins in the 1930's, vinyl chloride was produced via catalytic addition of hydrogen chloride to acetylene.

$$CH{\equiv}CH + HCl \xrightarrow[HgCl]{} CH_2{=}CHCl$$

Later, a so-called "balanced" process was introduced in which, by addition of chlorine to ethylene, ethylene dichloride was produced. Ethylene dichloride could then be cracked to vinyl chloride and HCl, with the hydrogen chloride recycled to produce vinyl chloride from acetylene

$$CH_2{=}CH_2 + Cl_2 \longrightarrow CH_2Cl{-}CH_2Cl \xrightarrow[\Delta]{} CH_2{=}CHCl + HCl$$

At this point, vinyl chloride was being produced from chlorine, acetylene, and ethylene. More recently, catalytic oxychlorination has been developed in which vinyl chloride is produced from ethylene and hydrogen chloride.[7]

$$CH_2{=}CH_2 + HCl \xrightarrow[Cu]{[O]} CH_2{=}CHCl + H_2O$$

The hydrogen chloride can be obtained via cracking of ethylene dichloride. The oxychlorination process freed vinyl chloride from the economics of the more costly raw material, acetylene (Deliberate acetylene manufacture is energy intensive. Less expensive byproduct acetylene from gas cracking has not been available in sufficient supply for the large, near billion pound-per-year vinyl chloride units).

During the long period of development of poly(vinyl chloride) into one of the major plastics materials, several basic processes for making PVC evolved. In all of these processes, vinyl chloride was handled as a liquid under pressure. Other than the relative ease with which vinyl chloride could be polymerized by free radical initiators, the monomer, vinyl chloride, was regarded as an innocuous, relatively inert chemical. A number of producers of PVC resins were caught by total surprise in the 1970's when it was found that long-term (20 years) exposure to vinyl chloride monomer could cause rare forms of tumors[8].

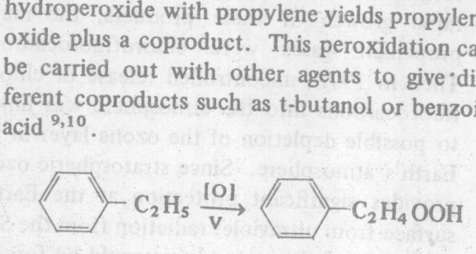
During the 1960's, vinyl chloride sold in the United States for five to six cents per pound. In the presence of traces of air (oxygen), vinyl chloride could form low concentrations of peroxide which could collect in compressors and on occasion decompose to blow out compressor seals. Rather than recover and compress the inexpensive monomer for recycle from stripping and drying operations at the end of the polymerization process, some manufacturers vented it to the atmosphere. After discovery that vinyl chloride was a carcinogen, venting was not permissible. Containment and recovery were mandatory. Some older processes and manufacturing facilities could not be economically modified to incorporate monomer containment, so operations were discontinued. This case is but one example of the impact of the need for environmental controls on manufacturing processes and operations.

Propylene oxide is another basic chemical, used in manufacturing intermediates for urethane foams (used in cushioning and insulation) and brake and hydraulic fluids. The volume of propylene oxide produced has increased from 310 million pounds in 1960 to two-and-a-quarter billion pounds in 1979. The classical industrial synthesis has been the reaction of chlorine with propylene to produce the chlorohydrin followed by dehydrochlorination with caustic to produce the epoxide, propylene oxide, plus salt. In this case, both the chlorine and the caustic used to effect this synthesis are discarded as a valueless salt byproduct.

$$CH_3CH{=}CH_2 + Cl_2 + H_2O \longrightarrow CH_3CH(OH)CH_2Cl$$

$$CH_3CH(OH)CH_2Cl \xrightarrow[\text{Caustic}]{} CH_3\overset{O}{CH{-}CH_2} + \text{Salt}$$

A more economic process has been commercialized. In one version, a hydroperoxide is produced by catalytic air oxidation of a hydrocarbon such as ethylbenzene. Reaction of this hydroperoxide with propylene yields propylene oxide plus a coproduct. This peroxidation can be carried out with other agents to give different coproducts such as t-butanol or benzoic acid [9,10].



When the economics are balanced, a significant cost reduction is achieved by eliminating the coproduct, salt, which is of low value and presents a disposal problem. Further, a process can be designed to produce a coproduct which can be used or sold as a chemical intermediate.

If a company is in the business of making and selling products such as acetic acid, vinyl chloride, propylene oxide, or other chemicals and has plans to stay in business and to expand its facilities to serve growing markets, it must have at least economically competitive processes. Today, this means being competitive with new processes in the United States, Western Europe, Japan, and the Soviet Union—for the chemical industry is a world-wide industry. Further, the processes which are operative must be environmentally compatible—all toxic or carcinogenic by-products or waste must be contained and disposed of harmlessly. Even a relatively innocuous by-product such as salt must be disposed of so as not to intrude on the environment.

The profound effect of environmental concerns on the manufacture of a chemical is reflected in the history of aerosol pressurized products. These products are familiar to the consumer as the aerosol spray can containing hair spray, deodorant, desert cream topping, or insect spray (Table 1.10). The market for these products grew enormously in the 1960's, with rapid consumer acceptance of these convenience, packaged products[11,12].

The aerosol spray product is a pressurized formulation with a propellant gas. During the rapid growth of these products, the major propellant gases were chlorofluorocarbons. Then in 1973, uncontrolled release of chlorofluorocarbons into the atmosphere was linked to possible depletion of the ozone layer in the Earth's atmosphere. Since stratospheric ozone provides significant protection at the Earth's surface from ultraviolet radiation from the Sun, depletion of the ozone layer could be forecast to lead to skin cancers, reduced seafood and grain crops, and alteration of the carbon dioxide level in the atmosphere.

The most easily controlled source of chlorofluorocarbon discharge into the environment—aerosol propellants—was removed from the marketplace. These products have been removed from the marketplace and replaced by formulations in which the propellant gas is

TABLE 1.10 Aerosol, Pressurized Product Sales in the United States in 1978

Use	*Percent of Sales*
Personal Products and Toiletries	33%
Household Products	28
Coatings and Finishes	14
Automotive	7
Food Products	6
Insect Sprays	6
Industrialized Products	5
Animal Products	1
Miscellaneous	0.5

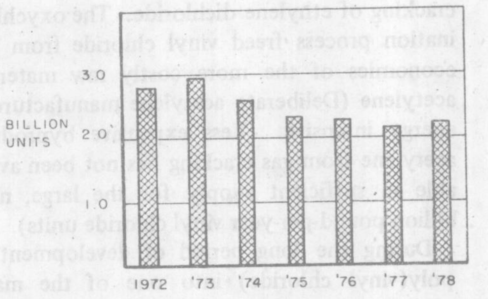


Fig. 1.7. Billion units of aerosol-pressurized products sold in the United States for the years 1972–1978. The year 1973 marked the announcement of the potential effect of chlorofluorocarbons on the stratospheric ozone layer.

hydrocarbon or carbon dioxide. The consumers, however, have registered their concern by switching away altogether from aerosol products. This consumer concern was noted in the rapid decline is sales of these products from 1973 until 1977 (Fig. 1.7). Since then, consumers have begun to return to the convenience products as an understanding of the new propellant systems has been accepted. Meanwhile, one of the fastest growing chemical product markets of the 1960's, the fluorocarbon propellant gases, has abruptly ended. However, typical of such situations in the chemical industry, replacement systems have been rapidly developed.

WORLD-WIDE CHEMICAL INDUSTRY

The major chemical producers in the United States have developed very significant overseas business through trade and investment (Table 1.11). In companies such as DuPont, Union Carbide, and Monsanto, foreign assets and sales amount to about 25 to 30 percent of total business, while Dow Chemical derives an even higher proportion from overseas investment[2]. The major chemical companies truly do business on a world-wide basis, as with the established and familiar pattern in the petroleum industry. As United States producers have expanded abroad, competitors based in the large economies of Western Europe and Japan have developed comparably in size with those in the United States. These chemical companies compete in exports to developing areas

TABLE 1.11 1979 Overseas Business of United States Chemical Producers

Producer	*Foreign Assets as a Percent of Total Assets*	*Foreign Sales as a Percent of Total Sales*
DuPont	26.0%	31.7%
Dow Chemical	52.6	50.5
Union Carbide	28.6	30.3
Monsanto	30.7	33.1
Celanese	19.9	21.1
W. R. Grace	23.1	29.9
Allied Chemical	25.8	25.5

and in United States domestic markets by both trade and investment.

For the overall economy of the United States, the United States chemical exports are a very important factor. This importance is emphasized if the United States balance of trade is examined (Table 1.12). In 1969, the United States enjoyed a favorable balance of trade of over one billion dollars. If just the balance of trade in chemical products were counted, the 1969 "chemical balance of trade" was over two billion dollars. At that time the preponderance of chemical trade was with Western Europe.

In the decade from 1969 to 1979, the dollar value of United States trade has increased fivefold; however, principally due to oil imports and a fifteenfold increase in the price of imported oil, the United States' trade balance in

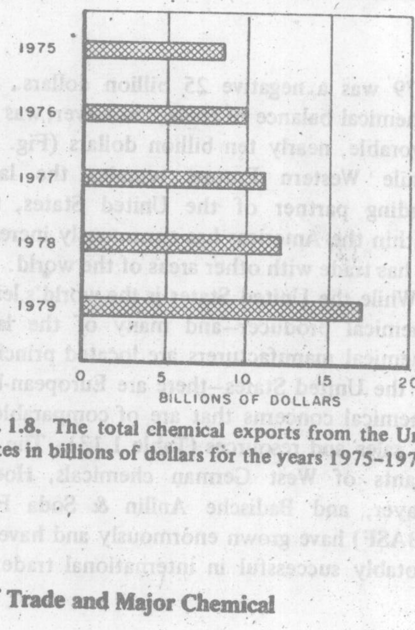


Fig. 1.8. The total chemical exports from the United States in billions of dollars for the years 1975–1979.

TABLE 1.12 United States Balance of Trade and Major Chemical Trading Areas (Millions of Dollars)

	1979	*1969*
Total Chemical Exports	$17,306	$3,383
Total Chemical Imports	7,485	1,232
Chemical Trade Balance	+9,821	+2,151
All Export Trade	$181,639	$37,314
All Import Trade	206,327	36,052
Official Balance of Trade	−24,688	+1,262
Chemical Trade	*Exports to (1979)*	*Imports from (1979)*
Western Europe	$5,585	$3,449
Canada	1,991	2,362
Japan	1,652	616
Latin America	3,814	405
All Other Areas	4,264	653

TABLE 1.13 World's Largest Chemical Companies

Company	Country		Total Sales Millions of Dollars in 1969	1979
Hoechst	Germany		$2,550	$15,870
Bayer	Germany		2,550	15,079
BASF	Germany		2,430	15,018
DuPont	United States		3,655	12,572
ICI	United Kingdom		3,250	11,389
Dow Chemical	United States		1,876	9,255
Union Carbide	United States		2,933	9,177
Montedison Group	Italy	(Montecatini)	2,620	8,224
Rhone-Poulenc	France		1,840	7,940
Monsanto	United States		1,939	6,193
Exxon (Chemical Sales Only)	United States		1,004	5,807
Celanese	United States		1,250	3,010

1979 was a negative 25 billion dollars. The "chemical balance of trade," however, was very favorable, nearly ten billion dollars (Fig. 1.8). While Western Europe remains the largest trading partner of the United States, trade within the Americas has enormously increased, as has trade with other areas of the world.

While the United States is the world's leading chemical producer—and many of the largest chemical manufacturers are located principally in the United States—there are European-based chemical concerns that are of comparable size in sales and resources (Table 1.13). The three giants of West German chemicals, Hoechst, Bayer, and Badische Anilin & Soda Fabrik (BASF) have grown enormously and have been notably successful in international trade. All three operate in the United States through subsidiaries.

In recent years, the Japanese chemical industry has also grown to rank with the world's giants (Table 1.14). The industry development in Japan has been carefully guided by the Ministry of International Trade and Industry. Capital demands have been met by cooperation within the industry through joint ventures involving the most basic processes to produce, for example, methanol, olefins, and ammonia. The basic plants in Japan are "world-scale," that is, approximately a billion pounds of annual capacity. The Japanese chemical industry is active both in export and also investment abroad as a means of introducing new technology on the world market.

The trend of "foreign" expansion in the chemical industry on a world-wide basis by companies based in Japan, Europe, and the United States can be expected to continue. The chemical giants are multinational in seeking raw materials and markets for the increasingly high technology products of the chemical industry. Operating from the strong investment and technological base in the United States, the chemical industry in the United States in one of the country's major assets in world trade.

TABLE 1.14 Major Japanese Chemical Producers

Company	1979 Sales (Millions of Dollars)
Mitsubishi Chemical	2,967
Sumitomo Chemical	2,716
Asahi Chemical	2,359
Toray Industries	2,094
Mitsui Toatsu	1,767
Teijin Ltd.	1,756
Showa Denko	1,706
Mitsubishi Petrochemical	1,558
Dainippon Ink and Chemical	1,416
Sekisui Chemical	1,300

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