Survey of Industrial Chemistry

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Preface

This book arose from a need for a basic text dealing with industrial chemistry for use in a one-semester, three-credit senior level course taught at the University of Wisconsin-Eau Claire. The course was added in 1981 as a requirement for our B.S. degree in Chemistry-Business and is strongly recommended as an elective in our other chemistry majors, including our A.C.S.-accredited program. There are some good extensive texts and valuable reference works dealing with applied chemistry. What was needed for our course, and what I believe will be useful for similar courses, is a basic text of introductory material, sufficient to cover all important areas of the chemical industry, yet limited in scope so as to be a reasonable goal to complete in 40–45 hours of lecture.

Industrial chemistry means different things to different people. Most will agree that the phrase includes the practical, applied chemistry that bridges the gap between basic research and development and at least two other disciplines, chemical engineering and chemical marketing. The present text attempts to lessen the lack of knowledge that most graduates have in both of these areas. It probably emphasizes the business more than the engineering aspects for most subjects, which is understandable for the student clientele served by our course. But some attempt is made to instill in chemists an appreciation for both the manufacturing and economic problems facing the chemical industry on a day-to-day basis.

In developing such a book the toughest job is always deciding what to include. As a guide I have taken an economic approach and justify topics on how important they are in terms of value added to the chemical industry's contribution to the gross national product. The *Annual Survey of Manufacturers* gives this information, and the percentage contribution for the subjects included in the text toward the total value added for Chemicals and Allied Products (SIC 28) is given in the following table.

SIC Code	*Name*	*Percent*
281	Industrial Inorganic Chemicals	12
286	Industrial Organic Chemicals	20
2821	Plastics	6
2823-4	Fibers	6
2822	Synthetic Rubber	1
2851	Paints, Varnish, Lacquer, Enamels	5
2891	Adhesives and Sealants	1
2873-5	Fertilizers	4
2879	Pesticides and Agricultural Chemicals	4
283	Drugs	19
2841	Soaps and Other Detergents	6
		84%

Thus all important areas of the chemical industry and about 84% of the total industry have been included, as well as information on other industries separate from Chemicals and Allied Products that do contain interesting chemistry and do employ many chemists. Examples include Paper and Allied Products (SIC 26), Petroleum Refining (SIC 29), and Rubber and Miscellaneous Plastic Products (SIC 30).

Granted there are many areas of applied chemistry that contribute to the other 16% of the industry. Practice has shown that in our course these cannot be covered in any great detail because of time limitations. However, the requirement of having students write on one of these other subjects and study three extra topics (see Appendix) to enable them to pass a short quiz gives students some choice in material to be covered and further completes their study of the most important divisions of the chemical industry.

Perhaps the most challenging part of teaching this course and of writing a good text is to keep the important economic data current. In some cases this is done easily; in others it is not so easy. Rather than having to revise this material yearly or even monthly with changing economic times, I have made recourse to some references to periodic updates that students can consult for the latest data. Examples of these series include "Key Chemicals and Polymers" (KC) in *Chemical and Engineering News* and "Chemical Profiles" (CP) in *Chemical Marketing Reporter*. It is virtually impossible for a text to remain economically accurate and complete for more than a year or two, and the present text is no exception. In presenting this material I use numerous transparencies (over 800 have now been developed) to which up-to-date numbers for each year can easily be added when necessary. The material is also supplemented with over 200 color slides of various chemical plants, manufacturing sites, and research labs which have been visited in the last few years.

To attempt to thank everyone who has helped me expand my knowledge of this subject would be an impossible task, but certain organizations deserve a special mention. A University of Wisconsin System Undergraduate

Teaching Improvement Grant allowed me to plan the course initially during one summer. University of Wisconsin-Eau Claire Faculty Development Grants enabled me to visit chemical plants throughout the United States to get first-hand experience in manufacturing. They also funded some release time for one semester to write a portion of this book. A number of companies must be mentioned for letting me visit their facilities, talk with their personnel, and obtain pictures for use in class: Air Products and Chemicals, Allied Chemical Corporation, Amoco Chemicals Corporation, Amoco Oil Co., E.I. duPont de Nemours and Co., Georgia-Pacific Corporation, Monsanto Agricultural Products Co., Monsanto Chemical Corporation, Occidental Chemical Corporation, and W. H. Brady Co. I also thank the Department of Chemistry at UW-Eau Claire for allowing me to develop and teach the course, and to the students I have had who have given me valuable feedback on the course and text. Finally, I wish to thank one individual, Dr. Harold Wittcoff, who first got me interested in teaching industrial chemistry when I audited his course during a sabbatical at the University of Minnesota.

PHILIP J. CHENIER

List of Important References and Their Abbreviations

There are a variety of useful sources for obtaining information on industrial chemistry. An attempt has been made to specify appropriate reading for each chapter or in some cases individual sections. Some are given in abbreviated form. These references, as well as some of the others the author has found useful, are given below with the abbreviations used.

Books

Abbreviation	*Reference*
B & K	Billmeyer, F. W. and Kelly, R. N., *Entering Industry: A Guide for Young Professionals*; John Wiley & Sons, New York, 1975, Chapters 1 and 2.
Kent	Kent, J. A., *Riegel's Handbook for Industrial Chemistry*, 8th ed. Van Nostrand Reinhold, New York, 1983.
KO	Kirk-Othmer's multivolume *Encyclopedia of Chemical Technology*, 3rd ed. Wiley-Interscience, New York, 1978–1984.
Kline	Curry, S., and Rich, S., *The Kline Guide to the Chemical Industry*, 4th ed. Charles H. Kline and Co., Fairfield, NH, 1980.
L & M	Lowenheim, F. A., and Moran, M. K., *Faith, Keyes, and Clark's Industrial Chemicals*, 4th ed. Wiley-Interscience, New York, 1975.
R & B	Reuben, B. G., and Burstall, M. L., *The Chemical Economy*; Longmans, London, 1973, pp. 121–136.
S & B	Shreve, R. N., and Brink, J. A., Jr., *Chemical Process Industries*, 4th ed. McGraw-Hill, New York, 1977.
S & C	Seymour, R. B., and Carraher, Jr., C. E., *Polymer Chemistry: An Introduction*. Marcel Dekker, New York, 1981.
T	Thompson, R. *The Modern Inorganic Chemicals Industry*. The Chemical Society, London, 1977.
W & R I	Wittcoff, H. A., and Reuben, B. G., *Industrial Organic Chemicals in Perspective. Part One: Raw Materials and Manufacture*. Wiley-Interscience, New York, 1980.

W & R II	Wittcoff, H. A., and Reuben, B. G., *Industrial Organic Chemicals in Perspective. Part Two: Technology, Formulation, and Use.* Wiley-Interscience, New York, 1980.
Wiseman	Wiseman, P., *Industrial Organic Chemistry*, Wiley-Interscience, New York, 1972.

Periodicals

Abbreviation	*Reference*
C & E News	*Chemical and Engineering News*, American Chemical Society. Contains many interesting articles each week and valuable annual series including "Facts and Figures for the Chemical Industry" each June, "Facts and Figures for Chemical R & D" each July, "Salary Survey" each July, "Employment Outlook" each October, and "Top Fifty Chemicals and Companies" each May.
KC	"Key Chemicals" series in *Chemical and Engineering News*.
KP	"Key Polymers" series in *Chemical and Engineering News*.
AS	"Annual Survey of Manufactures," U.S. Department of Commerce, Bureau of the Census, each year.
SA	"Statistical Abstract of the United States," U.S. Department of Commerce, Bureau of the Census, each year.
CMR	*Chemical Marketing Reporter*, Schnell Publishing Co., New York. Contains many interesting articles in each issue and up-to-date chemical prices.
CP	"Chemical Profiles," a weekly series in *Chemical Marketing Reporter*.

Other

Abbreviation	*Reference*
W	*Wittcoff, H., Industrial Organic Chemistry*, American Chemical Society Audio Course, 1979.
J	Jonnard, A., *Business Aspects of Chemistry*, American Chemical Society Audio Course, 1974.

Contents

1

Introduction to the Chemical Industry: An Overview

THE NATIONAL ECONOMY

Before beginning a detailed discussion of the chemical industry, we should have a basic appreciation for the main sectors of a developed economy so that we may understand the role that this industry plays in the overall picture. Table 1.1 gives the major subdivisions of the U.S. economy along with their official designation or Standard Industrial Classification (SIC) by the U.S. Bureau of Census. A similar classification system is used in Western Europe, Japan, and other complex societies. These sectors are separate but interdependent. For example, manufacturing draws on mining to buy iron ore for steel manufacture. The manufacturing sector also converts steel to machinery to sell back to mining for its operations.

TABLE 1.1 U.S. Gross National Product by Industry, 1984

Industry	SIC	Value Added ($ billion)
Agriculture, forestry, and fisheries	01–09	91.1
Mining	10–14	118.5
Construction	15–17	148.0
Manufacturing	20–39	775.7
Transportation, communication and electric, gas, and sanitary services	40–49	342.2
Wholesale and retail trade	50–59	601.8
Finance, insurance, and real estate	60–67	598.1
Other services, including medicine, education, social services, and entertainment	70–97	529.4
Governmental and government enterprises	98	421.9
Other	99	36.2
	GNP =	$3,662.8

Source: SA.

The third column gives an estimate of the size of these various sectors in terms of value added in billions of dollars. The value added is simply the difference between the output (goods and services) and the input (labor, land, and capital) of the industry. The total value added, $3,662.8 billion in 1984, is the gross national product (GNP) for the entire economy.

Note that manufacturing is the largest sector in terms of value added and amounts to about 21% or almost one fourth the GNP. The chemical industry is a part of this manufacturing sector.

DEFINITION AND DIVISIONS OF THE CHEMICAL INDUSTRY

Chemical Process Industries

Just what exactly do we mean when we refer to "the chemical industry"? This is a general term that may mean different things to different people. A very broad interpretation of this phrase might, according to certain Standard Industrial Classifications, refer to the "chemical process industries" that are divided into the following areas: chemicals and allied products; paper and allied products; petroleum refining and related industries; rubber and miscellaneous plastic products; and stone, clay, and glass products. These are some of the subdivisions of manufacturing dealing heavily in chemicals and chemical products, as listed in Table 1.2. However, this broader interpretation for the chemical industry is not commonly used.

Chemicals and Allied Products

Most people, when referring to the chemical industry, really have in mind one specific division of manufacturing which is classified as chemicals and allied products. Note that it is the fourth largest division of manufacturing in terms of manufacturers' shipments, which is the usual dollar amount quoted in the manufacturing sector to estimate division size. In 1983 this industry had shipments totaling $183.2 billion, or about 8.9% of all manufacturing. Unless specified otherwise, when we use the term *chemical industry* we mean this division, Chemicals and Allied Products (SIC 28).

What does the Chemicals and Allied Products segment include? This is summarized in Table 1.3 in terms of both shipments and value added. Note that organic chemicals is the largest subdivision in percentage for shipments and drugs is the largest for value added. Although there is a similarity for both methods of subdivisions, there are differences for fine chemicals such as drugs. These are high-priced products with specialized markets. Their manufacture requires less capital but is more labor intensive. Their contribution to value added therefore is much larger than that for shipments.

TABLE 1.2 U.S. Chemicals and Allied Products Industry Versus Other Manufacturing Industries, 1983

	SIC	Industry	Value Added* ($ billion)	Shipments ($ billion)
	20	Food and Kindred Products	93.4	287.0
	21	Tobacco Products	9.8	16.3
	22	Textile Mill Products	21.3	53.4
	23	Apparel, Other Textile Products	27.3	55.4
	24	Lumber and Wood Products	19.5	51.3
	25	Furniture and Fixtures	14.3	26.5
→	26	Paper and Allied Products	35.6	84.6
	27	Printing and Publishing	60.1	92.8
→	28	Chemicals and Allied Products	86.5	183.2
→	29	Petroleum and Coal Products	21.0	192.6
→	30	Rubber and Misc. Plastic Products	29.8	60.3
	31	Leather and Leather Products	4.9	9.8
→	32	Stone, Clay and Glass Products	25.3	48.7
	33	Primary Metal Industries	36.0	108.5
	34	Fabricated Metal Products	61.3	122.1
	35	Machinery, Except Electric	94.8	179.0
	36	Electric, Electronic Equipment	92.5	159.2
	37	Transportation Equipment	99.6	244.1
	38	Instruments, Related Products	35.3	53.6
	39	Miscellaneous Manufacturing	13.7	26.4
		Total	882.0	2,054.9

Source: AS.

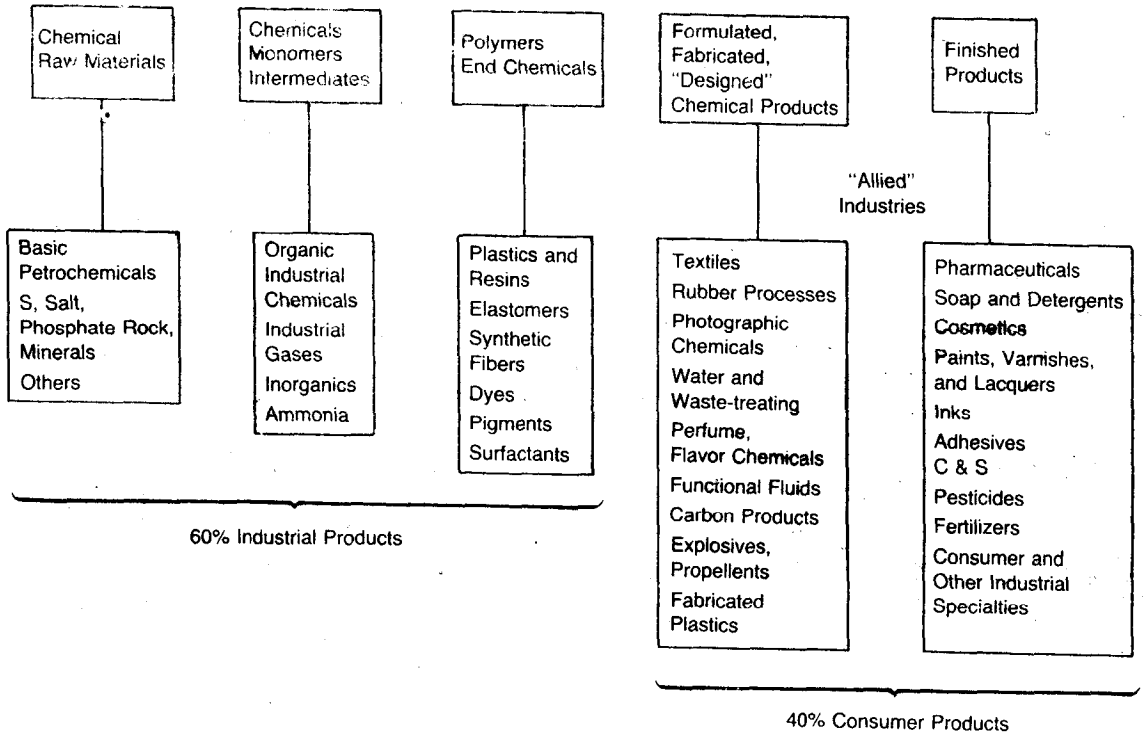
*Value added = (shipments + services rendered) − (cost of materials, supplies, containers, fuel, purchased electricity, and contract work). Value added avoids the duplication in shipments resulting from the use of products by other sections of the industry. It is the best measure of the relative economic importance of different segments of the industry.

TABLE 1.3 Divisions of U.S. Chemical and Allied Products Industry, 1983

SIC	Industry	Value Added ($ billions)	Percent	Shipments ($ billions)	Percent
281	Industrial Inorganic Chemicals	9.205	10.6	17.758	9.7
282	Plastic Materials, Synthetics	12.395	14.3	32.993	18.0
283	Drugs	19.367	22.4	27.410	15.0
284	Soaps, Cleaners, Toilet Goods	15.503	17.9	27.035	14.8
285	Paints and Allied Products	4.706	5.4	10.195	5.6
286	Industrial Organic Chemicals	14.513	16.8	41.264	22.5
287	Agricultural Chemicals	5.108	5.9	13.726	7.5
289	Misc. Chemical Products	5.675	6.6	12.826	7.0
	Total	86.472		183.206	

Source: AS.

TABLE 1.4 The Chemical Business is 30 Businesses



Source: J.

Diversity and Complexity in the Chemical Industry

The chemical industry is actually a set of related industries with many diverse functions and products. Table 1.4 lists some of these different areas and at the same time emphasizes that certain raw materials are used to prepare key chemicals, monomers, and intermediates that may be sold independently or used directly in additional steps to give various polymers and end chemicals. These in turn can be formulated and fabricated into chemical products, which can sometimes be modified into finished products. Hence the term *chemicals and allied products* accurately emphasizes this diversity as well as the flow of materials and products from raw sources to finished formulations. Although the division is approximate, about 60% of the chemical industry manufactures industrial products that are further modified, whereas 40% of their products are sold directly to the consumer. Chemistry may not be a household word, but it should be.

Further proof of diversity in the chemical industry is apparent in other statistics. There are over 12,000 manufacturing plants in operation in the United States. Over 55,000 chemicals are commercially produced, but only 10% of these account for over 99.9% of production and are made in excess of 1 million lb/yr in the United States. Although the top four companies in

TABLE 1.5 Brief History of Chemical Industry Products

Pre-1900:	Lye, sulfuric acid	
	Pigments, inks, dyes, and paints	
	Explosives	
	"Natural" soaps, fertilizers	
	Drugs	
1920s-30s:	Rayon and nylon	Plastics and resins
	Medicinal chemicals, solvents	Rubber chemicals
	Photographic chemicals	Adhesives
	Industrial gases	Ammonia and urea
	Petrochemicals	Functional fluids (e.g., hydraulic)
1940s:	Pesticides	
	Detergents	
	Synthetic rubber	
	Plastic packaging	
1950s:	Engineering plastics	
	Additives	
	Process improvements (lower costs)	
	New products but *no new types* of products	
1960s:	Foreign investment—both ways	
	Performance and property improvements	
	Lower prices	
	Pollution	
1970s:	Energy problems	
	High raw materials cost	

Source: J.

TABLE 1.6 U.S. Shipments

$ Billions	1984	1983	1982	1981	1980	1979	1978
All manufacturing industries	$2273.3	$2047.4	$1910.1	$1994.6	$1851.0	$1727.2	$1523.4
Chemicals and allied products	211.3	190.2	172.8	175.1	161.6	147.7	129.8

Source: C & E News, "Facts and Figures."

the chemical industry have about 25% of the sales in the industry, the top ten have only 35% of all sales. This percentage is small compared to other industries like automobiles, airplanes, tires, and glass, where 80–99% of sales are taken by the top eight companies or less. Diversity has increased in the last few years. Before 1940 chemical companies sold nothing but chemicals. Although some are primarily chemical, others have diversified so that it is common to have chemicals account for only half of the company's sales. Many corporations such as the petroleum companies have chemical sales with a very low percentage of total sales.

History of the Chemical Industry

Table 1.5 gives a brief summary of the important discoveries that have occurred in the history of the chemical industry. You should be somewhat familiar with the general historical development and refinement that has taken place in this barely century old industry.

SIZE AND CURRENT ECONOMICS OF THE CHEMICAL INDUSTRY

Shipments and Production

How big is the chemical industry? This is a difficult question to answer. What should be the best determining factor? One good measure of size is dollar value of shipments reported. Table 1.6 shows that this industry had 1984 shipments of $211.3 billion compared to all manufacturing at $2273.3 billion, about 9.3% of all manufacturing.

1982 was a bad year and the dollar volume of shipments fell for the first time in over a decade for both chemicals and all manufacturing, but 1983 and 1984 were good years again. Over the decade an average increase in chemicals of 10% per year is still healthy and better than 8% for all manufacturing.

TABLE 1.6 ***(Continued)***

				Percent Annual Change	
1977	**1976**	**1975**	**1974**	**1983–1984**	**1974–1984**
$1358.4	$1185.6	$1039.1	$1017.5	11%	8%
118.2	104.1	89.7	83.7	11	10

Table 1.7 gives 1980 shipments for important selected areas of the chemical industry as well as for estimating the 1985 values in constant dollars. This table acquaints us with the important divisions of Chemicals and Allied Products and demonstrates areas of predicted high growth, such as plastics and fertilizers, and unusual slower growth, such as dyes and surfactants, where health and pollution problems are apparent, and elastomers (rubber) for automobile tires, where energy problems are being felt. The short-term effects of the 1982 slowdown is shown in Fig. 1.1.

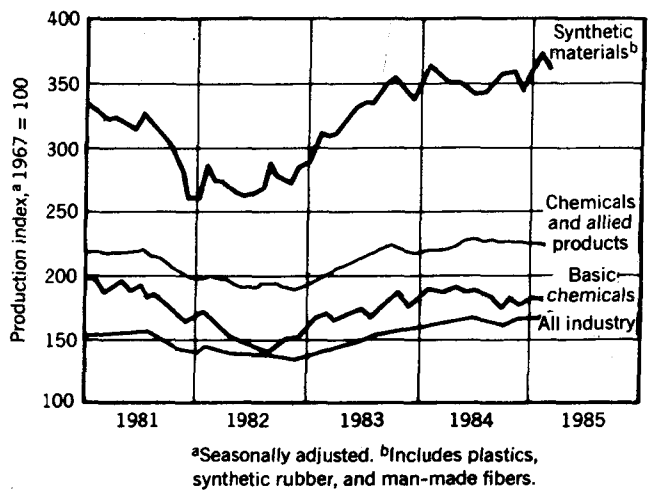


Figure 1.1 Chemical output. (*Source*: *C & E News*, "Facts and Figures.")

TABLE 1.7 Actual and Forecast Shipments of the U.S. Chemical Industry in Constant Dollars, 1980 and 1985 (million dollars)

	1980 ($)	1985 ($)	Average Annual Growth 1980–1985 (%)
Basic and intermediates			
Organic chemicals			
Petrochemicals	32,000	43,840	6.5
Gum and wood chemicals	630	730	3.0
Fatty acids	350	425	4.0
	32,980	44,995	6.4
Inorganics	11,290	12,900	2.8
Industrial gases	1,490	2,145	7.5
	45,760	60,040	5.6
Functional chemical products			
Polymers			
Plastics materials	20,600	32,960	9.8
Man-made fibers	9,535	13,065	6.5
Elastomers	3,175	3,685	3.0
	33,310	49,710	9.9
Agricultural chemicals			
Fertilizers	9,065	13,325	8.0
Pesticides[a]	4,150	5,315	5.0
	13,215	18,640	7.1
Medicinals	4,230	5,415	5.0
Adhesives, caulks, and sealants	2,420	3,315	6.5
Industrial and institutional cleaners	2,500	2,900	3.0
Chemical catalytic preparations[b]	580	690	3.5
Other	4,965	7,200	7.7
	61,220	87,870	7.5
Multipurpose additives			
Colors			
Inorganic pigments	1,800	2,110	3.2
Dyes	840	925	1.9
Organic pigments	465	550	3.4
	3,105	3,585	2.9
Surfactants[c]	1,290	1,485	2.9
Flavors and fragrances[c]	935	1,140	4.0
Carbon black	650	735	2.5
Other	3,290	4,475	6.3
	9,270	11,420	4.3
End-use additives[d]	5,640	7,385	5.5
Total	121,890	166,715	6.5

Source: Kline.

[a] Formulated pesticides only.

[b] Excludes commodity chemicals used as catalysts, the value of captive consumption and automotive catalysts.

[c] Excludes value of captive consumption.

[d] Includes only single-purpose end-use additives.