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Economic Aspects of the Chemical Industry

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Within the formal disciplines of science at traditional universities, through the years, chemistry has grown to have a unique status because of its close correspondence with an industry and with a branch of engineering—the chemical industry and chemical engineering. There is no biology industry, but aspects of biology have closely related disciplines such as fish raising and other aquaculture, animal cloning and other facets of agriculture, ethical drugs of pharmaceutical manufacture, genomics, water quality and conservation, and the like. Although there is no physics industry, there are power generation, electricity, computers, optics, magnetic media, and electronics that exist as industries. However, in the case of chemistry, there is a named industry. This unusual correspondence no doubt came about because in the chemical industry one makes things from raw materials—chemicals—and the science, manufacture, and use of chemicals grew up together during the past century or so. In addition, the chemical industry is global in nature.

Since there is a chemical industry that serves a major portion of all industrialized economies, providing in the end synthetic drugs, polymers and plastics, fertilizers, textiles, building materials, paints and coatings, colorants and pigments, elastomers, and so on, there is also a subject, "chemical economics," and it is this subject, the economics of the chemical industry, that is the concern of this chapter. Of course, the chemical industry does not exist alone, rather it interacts with many aspects of the global economy.

DEFINITION OF THE CHEMICAL INDUSTRY

Early in the twentieth century, the chemical industry was considered to have two parts: the discovery, synthesis, and manufacture of inorganic and organic chemicals. Later, and until about 1997, the Standard Industrial Classification (SIC) of the U.S. Bureau of the

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Census defined "Chemical and Allied Products" as comprising three general classes of products: (1) basic inorganic chemicals such as acids, alkalis, and salts and basic organic chemicals; (2) chemicals to be used in further manufacture such as synthetic fibers, plastic materials, dry colors, pigments; and (3) finished chemical products to be used for ultimate consumer consumption as architectural paints, cosmetics, drugs, and soaps or to be used as materials or supplies in other industries such as industrial paints and coatings, adhesives, fertilizers, and explosives.[1] The SIC system was a series of four-digit number codes that attempted to classify all business by product and service type for the purpose of collection, tabulation, and analyses of data. It used a mixture of market-based and production-based categories.

In 1997, the SIC classification was replaced by the "North American Industry Classification System" (NAICS).[2] The system is a major revision based on six-digit numerical codes, and it allows for new or relatively new industries to be included in what is termed "Chemical Manufacturing." It also reorganizes all categories on a production/process-oriented basis. Further, NAICS establishes a common numerical code among Canada, Mexico, and the United States that is compatible with the two-digit level of the United Nations' "International Standard Industrial Classification of All Economic Activities" (ISIC).

The NAICS code for "Chemical Manufacturing" is "325" and there are 49 subclassifications with four- to six-digit codes. The four-digit codes, which are a description of the manufacturing segments included in chemical manufacturing, the value of shipments, and the number of employees in the manufacturing segment are listed in Table 2.1.[2] Each of these four-digit segments may have five-digit subclasses associated with them, and the five-digit subclasses in turn may have six-digit subclasses associated with them. This hierarchy is exemplified for Manufacturing Segment 3251, which is titled "Basic Chemical Manufacturing," and one of its sub components, Code 32519, in Table 2.2.

While it may seem that Code 325199, "All Other Basic Organic Chemical Manufacturing," is too general in nature for its size, one needs to consider that by delving into the makeup of this component, about 150 individual compounds or groups of compounds are found. These contain a diverse group of chemicals including manufacturing of acetic acid and anhydride, calcium citrate, cream of tartar, ethylene glycol ethers,

TABLE 2.1 Chemical Manufacturing, NAICS Code 325, and Its Four-Digit Area Components. Shipment Value and Employees are from 1997 U.S. Economic Census[2]

NAICS Code[a]	*Description of Area*	*Shipments Value ($1000)*	*Percentage of Total*	*Employees*
325	Chemical manufacturing	419,617,444	100	884,321
3251	Basic chemical manufacturing	115,134,992	27.44	202,486
3252	Resin, synthetic rubber, artificial and synthetic fibers, and filament manufacturing	63,639,476	15.17	114,792
3253	Pesticide, fertilizer, and other agricultural chemical manufacturing	24,266,513	5.78	37,206
3254	Pharmaceutical and medicine manufacturing	93,298,847	22.23	203,026
3255	Paint, coating, and adhesive manufacturing	26,594,550	6.34	75,100
3256	Soap, cleaning compound, and toilet preparation manufacturing	57,507,318	13.7	126,895
3259	Other chemical product manufacturing	39,175,748	9.34	124,816

[a] Codes 3257 and 3258 were not used.

TABLE 2.2 Basic Chemical Manufacturing, NAICS Code 3251, and its Five-Digit Components and Other Basic Organic Chemical Manufacturing, Code 32519, and Its Six-Digit Components. Shipment Value and Employees are from 1997 U.S. Economic Census[2]

NAICS Code[a]	*Description of Area*	*Shipments Value ($1000)*	*Percentage of Total*	*Employees*
NAICS Code 3251 and Its Components				
3251	Basic chemical manufacturing	115,134,992	100.00	202,486
32511	Petrochemical manufacturing	20,534,750	17.84	10,943
32512	Industrial gas manufacturing	5,231,468	4.54	12,492
32513	Dye and pigment manufacturing	6,427,357	5.58	17,289
32518	Other basic inorganic chemical manufacturing	20,716,361	17.99	60,056
32519	Other basic organic chemical manufacturing	62,225,056	54.05	101,706
NAICS Code 32519 and Its Components				
32519	Other basic organic chemical manufacturing	62,225,056	100.00	101,706
325191	Gum and wood chemical manufacturing	815,201	1.31	2,267
325192	Cyclic crude and intermediate manufacturing	6,571,093	10.56	8,183
325193	Ethyl alcohol manufacturing	1,287,273	2.07	1,890
325199	All other basic organic chemical manufacturing	53,551,489	86.06	89,366

[a] Codes 325194 through 325198 were not used.

ethylene oxide, solid organic fuel propellants, hexyl and isopropyl alcohols, perfume materials, peroxides, silicone, sodium alginate, sugar substitutes, tear gas, synthetic vanillin, vinyl acetate, and so on. All these compounds have the code number 325199. Compounds with the code number 325211, "Plastic Material and Resin Manufacturing" are about 80 in number and may be exemplified by acrylic and methacrylic polymers; cellulose derivatives such as acetates, nitrates, xanthates, and the like; phenolics, polyesters, polyolefins, polystyrene, poly(vinyl halide)s, polyurethanes, and, again, and so on.

The new NAICS has broadened the definition of the chemical industry, and it now is more encompassing than in the past. The broadening is reasonable, and it improves on the goals of collecting and tabulating data so that it is available for study and analysis. One might say the data could be timelier, but collecting, amassing, and breaking down the information so it is understandable is a difficult, time consuming task that is dependent on many people. The Internet is a major factor in making the data available to the general public almost as rapidly as it is compiled. The NAICS system is recognized and accepted by the North American countries, and the system appears to be global in nature by being at least partially in line with the United Nations' classifications. Those interested in markets and market areas and in their size including their relation to other markets will find the U.S. Census Bureau's web site pages well worth visiting.

THE PLACE OF THE CHEMICAL INDUSTRY IN THE ECONOMY

Because the chemical industry is a major sector of any advanced national economy, a forecast of trends in the chemical industry must fall within certain general guidelines that are established by the national economy. A forecast for the chemical industry in the United States must be within the general boundaries set for the overall societal, financial, environmental, governmental, and economic forecasts for the country. However, such forecasts should be carefully considered for they may or may not accurately predict the future.

It had been said that it was clear for many years that certain demographic and societal issues would have a dominant effect on the U.S. economy of the 1990s. In the previous edition of this Handbook, it was pointed out that there was an expectation that from the late 1980s through the year 2000 there would be a decline in the growth of the work force in the United States. This was predicated on the number of women within the usual childbearing age group of 18–35 and by family-size decisions that were made in the 1960s. Shortages of chemists, chemical engineers, and other scientists were predicted for the 1990s. Supposedly, such predictions can be made from census data that was obtained in the prior two or three decades. There is a direct relation between the growth of the workforce and the growth of Gross Domestic Product (GDP). Although this was the prediction, it is not what happened.

During the 1990s and through the start of the twenty-first century, due to events put in motion during the late 1980s, the United States and many world economies experienced unprecedented growth. During this time unemployment decreased and reached very low percentages on an absolute and a historical level. This factor was coupled with significant productivity increases throughout the economy. The productivity increases resulted from a better-trained workforce, from new tools such as computers and allied software, and from just plain harder, more conscientious working during regular and overtime hours. An important factor during this period of growth was that the productivity increases were obtained without inflation raising its ugly head. Company mergers and the spinning off or the selling off of business segments to stockholders or to allied businesses played an important role through these years. These actions resulted in new stand-alone businesses that were operated by new owners and managers when the units were spun off. The mergers or unit-sales resulted in a restructuring or downsizing as duplicated efforts were eliminated. Productivity increased because of these actions, and many workers were displaced. But, the man power hungry economy quickly absorbed for the most part these displaced workers. The hunger for manpower was partially, but importantly, related to the electronic, computer, telecommunications, and related industries that provided many jobs in previously non-existent sectors. Chemicals were used in various ways in these new growth areas—as, for example, wire coatings, solder masks, conformal coatings, optical fiber coatings and marking materials, magnetic tape coatings, and so on.

Mergers and acquisitions certainly played a role in shaping today's chemical manufacturing industry. Included among the notable mergers are the Pfizer Inc. merger with Warner Lambert Company. The Dow Chemical Company acquisition of Union Carbide Corporation, Exxon merging with Mobil, and many others in the United States. Larger companies acquire smaller companies to expand business through new or expanded opportunities, diversify, reduce research and development expenditures, improve negotiations with suppliers and customers, and improve operating efficiency. For example, in the water industry, Aqua America, Inc., the largest United States-based, publicly traded water company, acquired 29 small companies in 2004 in line with their growth target of 25 to 30 acquisitions per year. In 2005, diversified 3M Company acquired CUNO, Inc., a water filtration products company, to capitalize on the global need for water purification, a market that is growing at more than 8 percent per year. Great Lakes Chemical Corp. and Crompton Corp. merged to form a new company known as Chemtura Corp., a company that is focused on the future's specialty chemical needs. In the paint and coating segment of the chemical business, major changes have taken place through mergers and acquisitions. In 1990, the five largest producers had 37 percent of the market and the ten largest producers had 52 percent. By 2003, the top five had 51 percent and the top ten had 74 percent of the market.[3] Included in the acquisitions are Akzo Nobel's purchases of Courtalds and Ferro's powder coating business; Dow acquired Celanese's Taxas acrylic monomers plant and output will be used for superabsorbants and paint emulsions; Sherwin William's acquisitions of Duron, Krylon, Pratt & Lambert, Paint Sundry Brands (a manufacturer of high quality paint brushes), and Thompson Miniwax; and Valspar's purchase of Lilly Inc. and Samuel Cabot Inc.

In Great Britain, Glaxxo Holdings PLC first merged with Wellcome to form Glaxo Wellcome, this combination then merged with Smith Kline to form GlaxoSmithKline PLC. Malvern Instruments Ltd. In the United Kingdom and Perkin Elmer of the United States agreed to a collaborative sales agreement that will offer customers material characterization instruments of both companies: rheology, thermal analysis, and rheometers. Degussa AG acquired Cytec Industries holdings in CYRO Industries to consolidate its position as a leading global supplier of methyl methacrylates. In The Netherlands, Arnhem, Akzo Nobel's Coatings business, acquired Swiss Lack, Switzerland's leading paint company. Larger, improved efficiency companies resulted. One result of such national and international mergers and acquisitions is a shrinking of *Chemical and Engineering News'* top 100 companies to the top 75 companies.[4]

The electronics/computer industry grew rapidly during the past decade or so, and new company names appeared during this time period. Its growth was spurred by the productivity increase even as it was a participant in causing the increased productivity. Computers began to be used to control processes and training personnel with the skills to run such computer-operated processes was high on many companies' lists of important projects. A decade or so ago, computers were available in companies on a limited basis. Today, there is a computer on essentially every desk and portable computers to carry out work during trips, and the like. The "dot com" companies started their appearance through the Internet, and they grew rapidly. Later, when business turned down, many of these companies disappeared—they merged with or were purchased by other companies. However, overall prosperity reigned during this time period, and, as it did, the chemical manufacturing industry, which was allied with a broad variety of these industries, also prospered.

At the turn of the twenty-first century, it was becoming apparent that the economy was at a high point and could be expanding too rapidly. Inflation was still low, and there was even talk that deflation might come into play. They latter did not happen. Price-to-earnings ratios were very high for many companies, and it did not appear that future growth would expand sufficiently to accommodate such high price-to-earnings ratios and large additions to the work force. The national economy, which certainly includes chemical manufacturing, entered a recession in March 2000. However, the economy grew in the first three months of 2001 indicating that the economic recovery could be beginning. The improvement was led by new automobile purchases and increased government spending. The fourth quarter of 2001 was small and considered by some as flat, but it built on the preceding quarter and in early 2002 there was a belief that the economic recovery has begun.

The events of September 11, 2001, changed many aspects of our lives with chemical manufacturing included. The terrorist attacks rocked many markets on a short-term basis, but before long the markets stabilized, but did not really grow in the recent past. Overall, in the first half of 2002 the world economy remained in a recession. However, because of the constant threat of terrorism, national corporate spending will increase as military, security, and other government expenses increase and transportation costs and its allied security measures come into play. Chemical manufacturing of basic chemical, polymer, and pharmaceuticals are expected to increase. Yet, there are no expected productivity increases as was seen in the 1990s associated with the increased spending.[5] In early 2002, the Chairman of the Federal Reserve predicted that the recovery was apparent, but would be a mild recovery.[6]

As can be seen from the previous discussion, economic forecasts are subject to all of the uncertainties and unpredictabilities of national, international, and societal events. With this in mind, at the present time the forecast for the ensuing part of this decade is for improved growth in national chemical manufacturing with growth and the profit picture beginning an upturn in the second or third quarter of 2002. (Note that in the 1980s, it was not predicted that the 1990s would show strong growth, yet strong growth did take place.) At present the concerns with global terrorism, low interest rates, high but constant productivity, oil and gas prices, and other factors are components of a mixture that will dictate the future. None of these factors will remain constant. Rather, they will change individually at times and with some factors in concert at other times. These variations along with the size of the workforce and its attitude will dictate the future for chemical manufacturing and the global economy.

Against this brief discussion of the general demographic, societal, and economic factors that govern forecasting economic prospects, a general picture of the economy of the United States can be given by the GDP and chemical and allied products portion of GDP as described in Table 2.3.

This reasoning is a way to highlight the sensitivity and place chemical manufacturing has in the national economy, which is becoming more and more entangled with the countries of the North American Free Trade Agreement (NAFTA) and with the global economy. Thus the chemical manufacturing industry is worldwide and interconnected in many ways. These factors play important roles in the importance of imported raw materials such as petroleum products and the cost of labor. Businesses or parts of businesses can be transported across the southern U.S. border to take advantage of more favorable labor costs. Through this, successful partnerships have been forged and welded together between border countries. As mentioned earlier, other partnerships are developing through purchase of assets in other countries by the United States and by other countries in the United States. Today, the United States is entrenched in the age of a global economy and all it ramifications.

TABLE 2.3 U.S. Economy and Chemical Manufacturing[7]

Year	*U.S. Gross Domestic Product (GDP) Current Dollars, Billions*	*Chemicals and Allied Products Portion of GDP, Current Dollars, Billions*
1987	4,742.5	83.8
1990	5,803.2	109.9
1995	7,400.5	150.8
1996	7,813.2	153.6
1997	8,318.4	164.8
1998	8,781.5	164.8
1999	9,268.6	175.1
2000	9,872.9	191.1

The United States imports and exports a wide variety of raw materials and chemical products. Major U.S.-based chemical companies have manufacturing and sales facilities abroad and a large number or foreign-based companies have similar facilities in the United States. The U.S. economy is dependent on the balance of trade, that is, on the difference between the dollar value of exports and imports. A negative trade balance means that dollars spent abroad to import goods and services exceed the value of goods and services exported. In effect such an imbalance increases the cost of goods and services purchased in the United States and results in a net inflationary effect. To a large extent during the 1980s, this potential inflationary effect was offset by foreign investment in the United States. In the 1990s and through the early years of the twenty-first century, foreign investment in the United States has increased, productivity has increased without major wage increases, and interest rates were managed with the net result that inflation remained low.

In foreign trade, the chemical industry of the United States has consistently performed in an outstanding manner. While the overall balance of trade has been negative, the chemical industry has been one of the truly strong sectors in the economy of the United States, Table 2.4. Year after year, the trade balance of chemicals has been positive and thus has had

TABLE 2.4 U.S. Balance of Trade[8]

	Total Trade Balance[a] (Billions of Dollars)			*Chemical Trade[b] (Billions of Dollars)*		
Year	*Export*	*Import*	*Balance*	*Export*	*Import*	*Balance*
1987	250.2	409.8	−159.6	26[c]	16	+10
1990	389.3	498.3	−109.0	39[c]	22	+17
1995	575.8	749.6	−173.8	32.18	20.59	11.59
1996	612.1	803.3	−191.2	31.4	21.81	9.59
1997	678.4	876.5	−198.1	34.6	23.5	11.10
1998	670.4	917.1	−246.7	33.32	23.38	9.94
1999	684.6	1,030.0	−345.4	34.09	23.82	10.27
2000	772.2	1,224.4	−452.2	38.42	27.12	11.30

[a]International Trade Accounts (ITA); [b]Chemicals-Fertilizer, -Organic, -Inorganic, and -Other; [c]Amounts for 1987 and 1990 are taken from Bailey and Koleske.[9]

a positive impact on the national economy. When the total world export market for chemicals is considered, that is the sum of all the chemicals exported by all the world's national economies, the U.S. chemical manufacturing industry has held a significant market share, about 15 percent, for the past three decades.

The export and import values for chemical segments described in Table 2.4, chemical-fertilizer, chemical-organic, chemical-inorganic, and chemical-other, are detailed in Table 2.5. The magnitude of the individual items varies from year to year, but overall, the balance is favorable and these four segments of chemical manufacturing are usually positive values. It should be pointed out that various items (plastic materials, pharmaceuticals, etc.) that make up chemical manufacturing have been excluded, but this was done without bias. The four items used in Tables 2.4 and 2.5 are directly related to what has been traditionally known as the "chemical industry." The less favorable Total Trade Balance of the United States is principally due to imports of manufactured good and petroleum products.

TABLE 2.5 Chemical Export/Import Segments for Year 2000

Chemical Segment	*Exports (Billions of Dollars)*	*Imports (Billions of Dollars)*	*Balance (Billions of Dollars)*
Fertilizer	4.098	3.388	+0.710
Inorganic	4.180	4.414	−0.234
Organic	16.505	13.779	+2.726
Other	13.636	5.525	+8.111

To support the U.S. chemical manufacturing economy (Code 325) in 1997 (see Table 2.1), there was a workforce of more than 884,000 of which about one-fourth were employed in basic chemical manufacturing (Code 3251) and about one fourth were employed in pharmaceutical and medicine manufacturing (Code 3254). The next largest area of employment, about 14 percent of the workforce, was the soap, cleaning compound, and toilet preparation manufacturing component (Code 3256), which was closely followed by the polymer manufacturing area (Code 3252) at 13 percent. In such comparisons, one might argue that the paint, coating, and adhesive manufacturing component (Code 3255), with about 8.5 percent of the employment figure, should be included with polymer manufacturing. The remainder of the workforce is employed in the agricultural chemical and other chemical manufacturing components. The value of the chemical manufacturing business produced by this workforce was $419,617,444,000 in 1997. To maintain market share and grow this huge business, the companies in chemical manufacturing invest to various degrees in research and development efforts, which are carried out by scientists within the organizations. The percentage of sales varies with the particular component, and the pharmaceutical firms will spend much more than say a fertilizer manufacturer. The average for many chemical companies varies from about 3 to 5 percent of sales. In the 1999–97 period, about seven billion dollars were spend annually on research and development by the chemical industry.

CHARACTERISTICS OF THE CHEMICAL INDUSTRY

Investment Trends

The U.S. chemical industry is the world's largest and it accounts for about one fourth of global chemical production. The industry, which is a part of the non-durable goods manufacturing industry, is a high capital 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. In 1999, non-durable goods manufacturers spent about $80 billion on capital goods. This was a decrease of about 7 percent from that of 1998, which was approximately $85 billion. Most of this decline can be attributed to decreased spending by the basic chemical industry. In 1996 and 1997, capital expenditures in the chemical industry were about $15.5 and $16.4, respectively. During the late 1980s and 1990s, a significant portion of these capital expenditures was made for pollution control and other environmentally related efforts.

Much of the capital investment in the chemical industry is spent for facilities to produce major chemicals in enormous quantities. The huge volume of the chemicals produced and consumed is reflected in the size of plants being built to achieve the required economies of scale, which in turn allow for competitive pricing. The fact that such economies are achieved is seen in the relatively modest increases in chemical producers' price indices relative to the inflation levels in the general economy. The competitive nature of the chemical business also plays a role in this matter of price. (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 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 markedly decreases as the size of the plant producing it is increased, providing the plant can be operated near capacity.)

Along with these very large plants and the associated enormous investments, most of the chemical industry is characterized by high investment versus low labor components in the cost of manufacture. The National Industrial Conference Board statistics list the chemical industry as having one of the highest capital investments per production worker. The investment per worker in a base petrochemicals olefins plant may be in the neighborhood a half-million dollars. A profitable chemical specialties manufacturer may have capital investments as low as 10 percent of such values per employee. Of course, sales per employee are also important and large. From Table 2.1, it can be seen that annual sales per employee in the overall chemical manufacturing area (Code 325) are about $475,000. Such ratios vary with the market segment and depend on the labor intensity needed within the segment. For example, the number is about $569,000 for basic chemical manufacturing (Code 3251), $652,000 for agriculture chemicals (Code 3253), $459,541 pharmaceuticals (Code 3254), $354,000 coating chemicals (Code 3255), and so on. Note that number for pharmaceutical sales per employee is quite close to the overall chemical manufacturing sales per employee. The average hourly pay of production workers in the chemical industry was $18.15 in 2000.

Commercial Development and Competition Factors

During the earlier period of the chemical industry's development, chemical companies were generally production oriented, wherein they would exploit a process to produce a chemical and then sell it into rapidly expanding markets. The investments and plant sizes required for participation were a small fraction of that required to participate today. Raw materials were often purchased to produce chemical intermediates for sale. Small-sized units operating in small manufacturing facilities do not present the obvious problems of environmental pollution, a factor about which everyone has become more aware in the past two or three decades. A new investment in chemical production facilities today must include a sizable proportion of the total outlay for pollution abatement and control of environmental intrusion. The chemical industry spends about $5 billion annually on pollution abatement.

As the chemical industry has grown, there has been a strong tendency toward both forward and backward integration. Petroleum producers have found opportunities based on their raw materials—natural gas, condensates, and oil—to move into chemical refining. Chemical companies, on the other hand, have moved to assure their access to low-cost raw materials through contract purchases and hedging contracts. Similarly, producers of basic plastic materials have forward integrated to produce compounder materials and fabricated products such as consumer items, fibers, and films. At the same time, fabricators have installed equipment to handle and formulate or compound the basic plastic materials and thus provide a ready, constant supply at the lowest possible cost. With the global economy in place and relative ease of moving around the world, large investments are now made in far-off countries such as Malaysia and Saudi Arabia, for example, to be near raw material supplies and to meet large market needs.

With ever-larger investment costs and increasing cross-industry competition, markedly greater sophistication has been required of marketing analysis coupled with cost analysis when selections of investment opportunities are made. The enormity of investment capital required in today's marketplace to successfully participate does not permit multiple approaches for the private investor. Consequently, a high degree of market orientation tends to predominate in the chemical industry along with increasingly targeted and pinpointed research and development programs. In 2000, the industry spent about $31 billion on such research and development efforts.[10]

A major trend in industrial chemistry has been an emphasis on improved processes for the production of major chemicals such as ethylene, propylene, vinyl chloride, styrene, alkylene oxides, methanol, terephthalates, and so on. The necessity for higher efficiency, lower cost processes has been accentuated by the relatively slow growth rates of major industrial chemicals over the past two decades or so. The fertilizer portion of the agricultural chemicals market as described in Table 2.6 is an example of the slow growth.

How well has the chemical industry developed? At the beginning of the twenty-first century the United States accounted for 27 percent of the world's chemical production, making it the world's largest chemical producer.[10] In 2000, chemical shipments reached $460 billion, and, at this level, it provides about 1.2 percent of the national GDP and almost 12 percent of the manufacturing GDP. As such, it is the largest factor in the manufacturing segment of the economy. The chemical industry continues to grow, and it attained an all-time high in profits by netting $44 billion. Globally, chemicals are almost a $1.5 trillion dollar business.

With its large size, the chemical industry is a large user of energy, and it consumed about 7 percent of all domestic energy and about 25 percent of all energy used in manufacturing. In 1985, the industry used 3,567 trillion Btu, in

TABLE 2.6 Annual Production of Inorganic Chemicals Used in the Fertilizer Industry (Note Break in Years between 1996 and 1993)[8]

	Production Amount (Billions of Pounds)		
Chemical	*1997*	*1996*	*1993*
Ammonia	34.68	35.85	34.39
Ammonium Nitrate	17.21	17.00	16.56
Ammonium Sulfate	5.42	5.32	4.87
Nitric Acid	18.87	18.41	16.51
Phosphoric Acid	26.32	26.42	23.03
Sulfuric Acid	96.04	95.54	79.68
Super Phosphates and others	20.86	21.09	17.6
Urea	15.33	17.10	16.66

1991 usage increased to 5,051 trillion Btu, and in 1994 it had increased still further to 5,328 trillion Btu.[11] The energy is used to supply heat and power for plant operations and as a raw material for petrochemicals, plastics, and fibers production. Feedstocks represent a little less than half of the total usage, a number that varies from year to year.

Thus, the chemical industry is a key component in the U.S. economy. It converts raw materials such as gas, oil, condensates, water, metals, and minerals into more than 70,000 products that are used in a variety of ways. In some fashion, this industry impacts the daily lives of everyone. Industrial customers for chemicals are many, but some of the major ones are apparel, plastic and rubber products, petroleum refining, textiles, pulp and paper, primary metal, and the like.

Information technology and E-commerce have become increasingly important assets to the chemical industry. Spending on information technology reached $10.2 billion in 2000 and this represented a 75 percent increase over such expenditures of 1990.[10] Selling via the Internet or E-commerce resulted in sales of $7.2 billion in 2000. Projections indicate that this type of business will grow rapidly and are expected to reach $150 billion by 2006. This means about one third of shipments will be via E-commerce transactions in five years.

Technological Orientation

The chemical industry is a high technology industry, albeit now is more marketing oriented and competitive than in its earlier period of development. Chemists and materials scientists held about 92,000 jobs in 2000. Over half of these are employed in manufacturing companies and most of these companies are in the chemical manufacturing industry, that is in firms that produce synthetic materials, plastics, drugs, soaps and cleaners, paints, industrial organic and inorganic chemicals, and other chemicals.[12(a)] Other chemists and chemical engineers are found in various government Departments and Agencies, in teaching, and in research, development, and testing firms. The latter firms are becoming more and more a growth area in the chemical industry. A bachelor's degree in chemistry or a related discipline is the minimum education requirement for these technical positions. To work and grow in research positions, a Ph.D. is required. There will be strong demand for those people who have a masters or Ph.D. in the future with job growth concentrated in the pharmaceutical companies and in research, development, and testing services firms.

The contemporary scientist or engineer engaged in research and development in the chemical industry is a highly trained individual who is a part of a high-investment occupation. Since about the mid 1950s, much of chemistry has become increasingly an instrumental science, and the instruments routinely used by investigators are highly sophisticated, reliable, and costly. In the laboratory, a scientist has available mass, infrared, visible, and ultraviolet spectrometers; various chromatographs; physical and chemical property determination devices such as those used for molecular structure, size, and conformation determinations; and others used for reaction kinetic studies. Pilot plants and many production facilities are highly instrumented and automated. The basic scientist doing research, laboratory workers, pilot plant and process development chemical engineers, and plant production workers require at a minimum access to excellent computer facilities. All engineers and scientists require computers to analyze the massive amounts of data that are generated and to aid in the design of manufacturing processes and equipment.

Employment of chemists and chemical engineers is expected to grow at about a 10–20 percent rate between 2000 and 2010.[12(a)] Predictions indicate that job growth will be concentrated in drug manufacturing and in research, development, and testing services companies. Demands will be for new and better pharmaceuticals, personal care products, and specialty chemicals designed to solve specific problems or applications. Demand will be high for personnel who have a Ph.D. degree and the opportunities will be in biotechnology and pharmaceutical firms. An aging, better informed population will want products that treat aging skin, that are milder on the body, new and innovative drugs, reliable medical devices, and so on. The population in general will be interested in chemical processes that are more benign in nature to produce all types of products and thus in an industry that is more friendly to the environment.

In the year 2000, the median salary of chemists was $50,080.[12(a)] The lowest 10 percent earned less than $29,620, and the highest 10 percent earned more than $88,030. The middle 50 percent earned between $37,480 and $68,240. It is interesting to point out that the median annual salary of chemists employed in the Federal Government was $65,950 or about 30 percent higher than the overall median. In 2001, chemists in nonsupervisory, supervisory, and managerial positions in the Federal Government averaged $70,435.[12(a)] As is the usual case, chemical engineer salaries were higher than those of chemists by about 10–25 percent.[12b] Median experienced and starting salaries for the various degrees can be found in Table 2.7.

In 2003, median starting salaries for industrial chemists were $32,000 (B.S.), $44,500 (M.S.), and $63,000 (Ph.D.).[12c] The Ph.D. starting salary actually dropped from $67,000 in 2002 due to Ph.D.s' finding academic employment. In 2003, 35.3 percent of new Ph.D. graduates went into academic positions compared with 20.5 percent in 2002. A 2005 salary survey of chemical industry professionals with a Bachelor's degree in chemical engineering with 22 years of experience in the chemical industry (pharmaceuticals, organic chemicals, construction, and consulting) indicated that the average salary was $85,234.[12d] the 1205 nationwide respondents were male, had an average age of 47, and rated their overall job satisfaction as "satisfied." During 2004, about 85 percent of the participants received a raise and about 65 percent also received a cash bonus. Health insurance costs increased with many companies requiring employees to pay a larger portion of the insurance costs. The satisfaction portion of the survey indicated that challenging work was the most important factor (44 percent of responses) and other factors such a salary and benefits (17.5 percent), job security (13.5 percent), advancement opportunities (7.4 percent), recognition (12.6 percent), and other (5.1 percent) were secondary in nature.

TABLE 2.7 Chemist[12(a)] and Chemical Engineer[12(b)] Salaries in 2000

	Year 2000	
Degree	*Overall Median Salary*	*Inexperienced Median Starting Salary*
Chemists		
Bachelor	$55,000	$33,500
Master	$65,000	$44,100
Ph.D.	$82,200	$64,500
Chemical Engineers		
Bachelor	[a]	$51,073
Master	[a]	$57,221
Ph.D.	[a]	$75,521

[a] The median annual salary for all chemical engineers was $65,960. The salary of the middle 50% ranged between $53,440 and $80,840. The salary of the lowest 10% was less than $45,200 and of the highest 10% was greater than $93,430.

Historical

How did the chemical manufacturing industry get its beginning? To get this answer, we need to go back to the latter part of the eighteenth century.[13] The availability of alkali or soda ash (sodium carbonate) for the growing manufacture of glass, soap and textiles in France was becoming a major concern. At that time, the chemical was obtained from plant materials, principally from wood ashes that were leached with hot water to obtain potash and from marine plants such as *barilla*, which grows mainly along the Spanish Mediterranean coast and in the Canary Islands. Other plant sources existed. The main exporter of soda ash was Great Britain with whom France was at odds and there was concern about the chemical's availability. In 1783, the French Academy of Sciences was offered a handsome prize by Louis XVI to develop a simple process for "decomposing" sea salt on a large scale and securing alkali from it. Eight years later Nicholas Leblanc, a 49-year-old French physician, devised a scheme to commercially obtain soda ash from sea salt. The process became known as the Leblanc process, and this process is considered the basis for development of the first chemical industry. For almost a century, this process was the most important method known for producing chemicals. Basically, Leblanc's process involved reacting sodium chloride with sulfuric acid to produce sodium sulfate. The product was then reacted with calcium carbonate and carbon to form a "black ash" that contained sodium carbonate and other compounds. The "black ash" was extracted with water followed by an evaporation process to obtain soda ash.

Leblanc's process had many disadvantages; it was complicated, was dirty and polluting, and was materials and fuel inefficient. This set other scientists to working on development of a new process. In about 1872, Ernst Solvay developed what became known as the Solvay process, and this resulted in establishment of the French firm Solvay & Cie. By 1890 the Solvay process dominated the world's alkali production.[14] Leblanc's process was obsolete.

Obsolescence and Dependence on Research

The high technology level that characterizes the chemical industry, and which is reflected in heavy research and development investments, generally concerns discovery and development of new products as well as improvements in the manufacture of known products. New product discovery and development may be typified by a new pharmaceutical product for a specific disease, by a stealth aircraft and all its special polymer and composite needs, by development of a new non-polluting technology for a known process, a uniform molecular weight polymer designed and made by nanotechnology, and so on. Improvements in the manufacture of known products might be typified by producing a modified form of a pharmaceutical that is easier to dissolve, by a new or modified higher efficiency catalyst for a known process, by toughening a brittle plastic material, by improving the strength of a composite, and so on. The development of a new, lower cost process for a commercial product can permit development of a profitable opportunity or it can spell disaster for a company with existing investment in a plant made obsolete by the competitor's new process as in the preceding soda ash example.

Major reductions in manufacturing cost can be achieved, for example, by reducing the number of reaction steps required in a process, by changing to a lower cost or more available raw material, or by eliminating byproducts and co-products, costly separation, and environmental intrusions. The ability of a process scheme to contain or avoid a pollutant can be a deciding factor in continuance of a manufacturing operation. At times new regulations, such as the Clean Air Act (CAA), or shortages can spawn new ideas and technologies if the people involved are astute and react positively to the new, developing environment. The brief discussion of Leblanc's process being replaced by Solvay's process for soda ash is an example of how economic consequences can change if a competitor finds a process better than the one being practiced. The following detailed examples will make the matter even more clear.

Acetic Acid. Acetic acid production in the United States has increased by large numbers in the last half century, since the monomer has many uses such as to make polymers for chewing gum, to use as a comonomer in industrial and trade coatings and paint, and so on. In the 1930s, a three-step synthesis process from ethylene through acid hydrolysis to ethanol followed by catalytic dehydrogenation of acetaldehyde and then a direct liquid-phase oxidation to acetic acid and acetic anhydride as co-products was used to produce acetic acid

$$CH_2{=}CH_2 \xrightarrow{H_2SO_4/H_2O} C_2H_5OH$$

$$C_2H_5OH \xrightarrow{Cu/Cr} CH_3CHO$$

$$CH_3CHO \xrightarrow{[O],\,Co} CH_3COOH + (CH_3CO)_2{=}O$$

Then, in the 1940s, a major process change was introduced. In this new process, butane was directly oxidized to acetic acid and co-products such as methylethylketone.

$$C_4H_{10} \xrightarrow{[O]} CH_3COOH + CH_3COC_2H_5 + \text{others}$$

The novel synthesis required fewer process steps, and this resulted in lower costs and investment. In 1969, another advance was announced—the synthesis of acetic acid from methanol and carbon monoxide with essentially no by-products or co-products.[15,16]

$$CH_3OH + CO \xrightarrow{I/Rh} CH_3COOH$$

The use of readily available raw materials and absence of co-products reduces production costs and investment needed for distillation and other separation systems. Such simplification results in a very attractive process in an industry where the principally accepted measure of business quality is return-on-investment.

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

$$CH_3COOH \xrightarrow{\text{Heat}} CH_2{=}C{=}O$$

$$CH_2{=}C{=}O + CH_3COOH \longrightarrow (CH_3CO)_2\text{–}O$$

In 1980, the Tennessee Eastman unit of Eastman Kodak announced that it would begin construction of a facility to make acetic anhydride from coal, which was readily available at reasonable cost.[17,18] This decision reflected a changing of the raw materials base of much of the chemical industry due to such factors as the rising cost of natural gas and petroleum and the large coal reserves of the United States.

In the new Eastman process, synthesis gas (carbon monoxide and hydrogen) is made from coal. Then, from the generated synthesis gas, methanol was prepared. (Prior to this time, methanol had been made from methane, i.e., natural gas.)

$$CO + 2H_2 \longrightarrow CH_3OH$$

Methanol was next reacted with acetic acid to form methyl acetate.

$$CH_3OH + CH_3COOH \longrightarrow CH_3COOCH_3 + H_2O$$

Acetic anhydride was then obtained by the catalytic carbonylation of methyl acetate with carbon monoxide.[16]

$$CH_3COOCH_3 + CO \longrightarrow CH_3CO\text{–}O\text{–}OCCH_3$$

There are two major points that make this process attractive. First, the raw material base of synthesis gas is coal. The second point is avoidance of the energy-consuming manufacture of ketene by pyrolyzing acetic acid.

Vinyl Chloride. The increase in the production of vinyl chloride, which is the principal monomer for poly(vinyl chloride) plastics and various vinyl copolymers that are used in vinyl flooring, shower curtains, car-seat upholstery, house siding, pipe, beverage can coatings, and so on, is an even more spectacular example. This polymer is used in multibillion pound quantities. It is an interesting sidelight to point out that the polymer has poor thermal stability, and its huge penetration into the marketplace is attributable to the development of highly efficient thermal stabilizers.

During the early monomer development in the 1930s, vinyl chloride was produced by means of a catalytic addition of hydrogen chloride to acetylene.[19]

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

Later, what was called a "balanced" process was introduced. In this process, chlorine was added to ethylene and ethylene dichloride was produced.

$$CH_2{=}CH_2 + Cl_2 \xrightarrow{[O]/Cu} CH_2ClCH_2Cl$$

The ethylene dichloride was then cracked to vinyl chloride and hydrochloric acid with the hydrochloric acid recycled to produce vinyl chloride from ethylene as shown above.

$$CH_2ClCH_2Cl \xrightarrow{\text{Heat}} CH_2{=}CHCl + HCl$$

At this point in time, vinyl chloride was being produced from chlorine, acetylene, and ethylene. After these processes, a catalytic oxychlorination has been developed in which vinyl chloride is produced from ethylene and hydrogen chloride in the presence of oxygen.[20,21]

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

If desired, the hydrochloric acid can be obtained via cracking of ethylene dichloride. The oxychlorination process freed vinyl chloride production from the economics of a more costly raw material, acetylene. Deliberate acetylene manufacture is energy intensive and relatively expensive. By-product acetylene from gas cracking is less expensive, but it has not been available in sufficient supply for the large, approximately billion-pound-per-year plus, vinyl chloride production units.

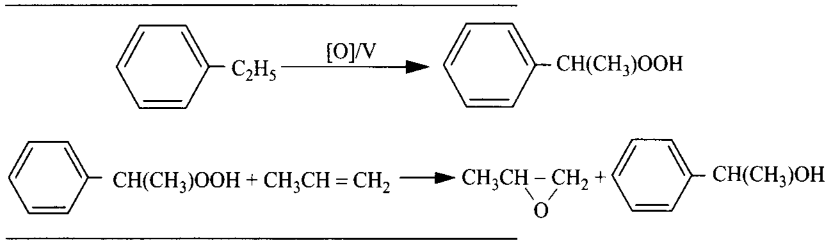
During the long development and commercialization of poly(vinyl chloride) into one of the major plastic materials, several basic processes of making the polymer evolved. In all of these processes, vinyl chloride was handled as a liquid under pressure. Other than the relative ease with which the monomer could be free radically polymerized, vinyl chloride was regarded as an innocuous, relatively inert chemical. During the 1960s, the monomer sold for five or six cents a pound. Because of the low cost, it was uneconomical to recover and compress the monomer for recycle during stripping and drying operations at the end of the process. The monomer was often vented into the atmosphere.

Then, in the 1970s, a number of poly(vinyl chloride) producers were completely surprised when it was found that long-term (20-year) exposure to vinyl chloride could cause rare forms of tumors.[22] After the discovery that vinyl chloride was a carcinogen, venting was not permissible. Containment and recovery of the monomer was mandatory. As a result, some older processes and manufacturing facilities could not be economically modified to incorporate containment, and as a result such operations were discontinued. This case is but one example of the impact that necessary and regulated environmental controls can have on manufacturing processes and operations.

Coatings Technology. Environmental regulation also had a major impact on the coatings industry. Before, around 1970, almost all (between 90 and 95%) industrial coatings were applied at low-solids (about 10–20%) contents from solvents. Many trade or house paints were also solvent based, since aqueous latex technology did not yet have its dominant position. Solvents were inexpensive and they did an excellent job of dissolving the high molecular weight polymers needed to obtain good performance characteristics. The high molecular weights used necessitated the large quantities of solvent to be used—about 4–9 lb of solvent were venting to the atmosphere for each pound of final coating film.

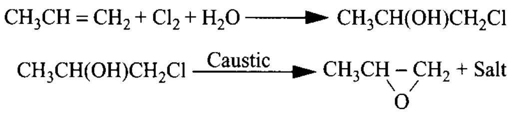
Then in the early 1970s, two factors affected the coatings industry. One of these was cartel oil pricing—both unexpected and quickly imposed. This was a factor that increased solvent cost and potentially its availability in needed quantities. At almost the same time, Government regulations requiring less solvent usage (the CAA) were imposed on the industry. Solvent cost was not a major problem—just raise prices, but many coatings are not inelastic commodities and there still was the threat of non-availability. The availability of oil to manufacture solvents was a totally different matter, and anyone who suffered through the gasoline shortages of this time knows well what effect oil availability can have on an economy. Also, government regulations were not just a temporary measure. Many of the regulations were difficult to meet and could not be met with the technology in hand.

Here a large industry (NAICS Code 3255) that represented about 6 percent of all chemical manufacturing was being asked to change the way they had been doing business for many, many years. Some companies responded well, but others thought solvents were too important to literally be taken out of such a large industry. Many companies innovated and came up with radiation—curable coatings, powder coatings, high-solids coatings, two-package coatings, and others. The new technologies did not take over the marketplace overnight, but with time, each found a niche and in so doing took away a portion of the original market. Today one does not find



low-solids, solvent-borne coatings in the market to any great extent. One does find companies that have changed the nature of their business favorably by innovating and changing, that have lost market share by taking a "wait and see" attitude, and that are new on the scene and growing. Thus, increased raw material pricing, shortages—real or created, and regulation can have a positive effect on the overall chemical economic picture.

Propylene Oxide. Propylene oxide is another basic chemical used in manufacturing intermediates for urethane foams (cushioning and insulation), coatings, brake fluids, hydraulic fluids, quenchants, and many other end uses.[23] The classic industrial synthesis of this chemical has been the reaction of chlorine with propylene to produce the chlorohydrin followed by dehydrochlorination with caustic to produce the alkylene oxide, propylene oxide, plus salt.



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

$$CH_3CH(OH)CH_2Cl \xrightarrow{\text{Caustic}} \underset{\diagdown \, O \, \diagup}{CH_3CH - CH_2} + \text{Salt}$$

In this reaction sequence, both the chlorine and the caustic used to effect the synthesis are discarded as a valueless salt by-product.

A more economic process has been commercialized. In one version, the hydroperoxide is produced by catalytic air-oxidation of a hydrocarbon such as ethylbenzene (see top of page). Reaction of this hydroperoxide with propylene yields propylene oxide as a co-product.

This direct peroxidation scheme can be carried out with other agents to give different coproducts such as *t*-butanol or benzoic acid.[24,25] When the economics of the direct peroxidation system are balanced, a significant cost reduction in the preparation of propylene oxide is achieved by eliminating the co-product, salt, which is of low to nil value and thus it presents a disposal problem coupled with all of the related environmental ramifications. Note that in the previous reaction scheme the weight of salt is almost the same as the weight of the epoxide produced and thus great quantities of salt would be produced. In addition, the process can be designed to produce a co-product that can be used or sold as a chemical intermediate. For example, in the case of using isobutene as the starting hydrocarbon, the by-product is *t*-butanol, which can then be converted to methyl *t*-butyl ether, which is a gasoline additive.

Ramifications. If a company is in the business of making and selling products such as those used in the above examples, that is, acetic acid, vinyl chloride, and propylene oxide, as well as other chemicals and if it has plans to stay in business and to expand its facilities and workforce thereby serving growing markets, it must have at least economically competitive processes. Today, this means being competitive with not only any new process developed in the United States, but also with any new process technology developed in the global economy. Another need for market maintenance and growth is a management system that is forward-looking, keenly aware of potential competitive threats, and ready to change directions when needed. The same management team must maintain a highly skilled research, development, and engineering staff to provide the new products and processes as well as product and process innovations and thereby create and maintain the pipeline to future sales, growth, and profitability as existing

TABLE 2.8 Sales for the Top 10 Global Chemical Companies in 2000[26]

Company	*2000 Chemical Sales (Billions of Dollars)*	*Rank in 1999*
BASF	30.8	1
DuPont	28.4	2
Dow Chemical[a]	23.0	4
Exxon-Mobil	21.5	5
Bayer	19.3	3
Total Fina Elf	19.2	11
Degussa	15.6	9
Shell	15.2	7
ICI	11.8	6
British Petroleum	11.3	10

[a] Sales numbers were before the merger with Union Carbide Corp. Merger is expected to raise Dow Chemical to the No. 1 position.

products or processes become obsolete. Anticipation of market needs must be recognized by both the scientific and management components of a successful firm. In the year 2000 the top ten global companies in sales are listed in Table 2.8.[26]

The companies spending the most for research and development are given in chronological order in Table 2.9.[27]

Not noted above is the profound effect that environmental concerns have on new products and processes. It was mentioned earlier that the chemical manufacturing industry spends about five billion dollars annually on pollution and environmental control. Thus, the entire staff of an organization must be aware of these costs and have concerns for the environment when new products and processes are created.

THE FUTURE

What will this huge manufacturing giant called the chemical manufacturing industry look like five or ten years from now? That changes will be made is certain, and an ability to predict and anticipate those changes and to guide the industry or segments to certain changes will certainly bode well for the economic health of any particular company. It may be recalled that earlier in this chapter, it was mentioned that more and more sales of chemicals would be done via E-commerce on the Internet. If the projections are correct, there will be a compounded annual growth rate of 66 percent in chemical E-commerce—from $7.2 billion in 2000 to $150 billion in 2006. Such sales will be

TABLE 2.9 Research and Development Spending by Chemical and Pharmaceutical Companies[27]

	Spending in Millions of Dollars					*Spending as % of Sales*
	2000	*1999*	*1998*	*1997*	*1996*	*2000*
Chemical Companies						
Dupont	1,776	1,617	1,308	1,116	1,032	6.3
Dow Chemical	892	845	807	785	761	3.9
Rohm and Haas	259	236	207	200	187	3.8
Union Carbide	152	154	143	157	159	2.3
Eastman Chemical	149	187	185	191	184	2.8
Air Products and Chemicals	124	123	112	114	114	2.3
International Flavors	123	104	98	94	94	7.7
Pharmaceutical Companies						
Pfizer	4,435	4,036	3,305	2,536	2,166	15.0
Pharmacia	2,753	2,815	2,176	2,144	1.936	15.2
Merck	2,344	2,068	1,821	1,684	1,487	5.8
Ely Lilly	2,019	1,784	1,739	1,382	1,190	18.6
Bristol-Myers Squibb	1,939	1,843	1,577	1,385	1,276	10.6
American Home Product's	1,688	1,740	1,655	1,558	1,429	12.7

carried out through buyers and sellers of chemicals as they develop agreements on purchases; cost estimates including the carrier method—land, water, truck, train; custom matters such as documentation, regulatory fees and taxes; insurance; warehousing matters; and so on. This will have an economic effect on the industry.

The coating and paint industry has undergone huge changes in the past two decades, but there probably will be further change as the new technological areas are sorted out. In paint or trade sales, it would appear that aqueous latexes will dominate the industry for the foreseeable future. It would take a major breakthrough to dislodge them from their place. The industrial-coating industry and their customers must continue to sort through a number of new technologies—conventional solvent-based, high-solids, powder, radiation, water-borne, two-package, and others—in the future. In the past some technologies have been given emphasis at coating companies because they fit existing technology, but they are not necessarily the final winners. Powder coating has captured more than 10 percent of the industrial coating market, and it will probably grow in the future but perhaps not as rapidly as it did in the past decade. Radiation curing appears to be poised for rapid growth. It is on an upsweeping growth curve, and if new products, new end uses, and interest through meeting attendance is any measure, this technology will have a significant portion of the market five–ten years from now.

The opening of trade with China has resulted in several chemical company expansions in that country and nearby countries. In 2005, the two national chemical giants, Dow Chemical Company and Dupont Company have large-scale plans for investment in China. Dow is planning a large coal-to-methanol-to-olefins complex that includes chlor-alkali facilities that will take five to ten years for completion. Dupont has recently doubled its investment in China and plans to spend another $600 million BY 2010, a portion of which may go to build a titanium dioxide plant. Dupont employs about 5000 people on Mainland China and recently built a Research and Development center near Shanghai. In 2005, Dupont will also build a laboratory in Japan to facilitate worldwide technical approvals for automotive coatings and to support home-country assembly operations. The laboratory will be established by Dupont and operated in cooperation with Shinto Paint Company.

In the pharmaceutical area, there are many new compounds that will reach the marketplace in the near future. One in particular is insulin for diabetics that can be inhaled or taken orally rather than by injection. The former is in final testing stages and could be on the market in the very near future. The oral type many take longer. Either of these will be "blockbuster" drugs and will mean major sales, growth, and profit for the winning company or companies. The revolution that has taken place in automated drug synthesis and screening will continue and improve. Workers entering the industry or relocating will be expected to have knowledge of parallel and recombinational synthesis methods,[28] or they will be rapidly trained within the company in the area. Such screening methods and facilities can screen 200,000 drug candidates in a single day.[29] This technology is so useful that it will also creep into other areas of chemical manufacturing that can benefit by screening large numbers of candidate materials as, for example, the paint, coating, and adhesive area.

Interrelated with the pharmaceutical industry is the biotechnology area. Biotechnology products or products derived from biotechnology processes, are expected to account for 30 percent of the total chemicals market by 2010. Large national and international chemical companies are getting started and have a position in the biotechnology area. Examples of such companies are The Dow Chemical Company, DuPont Company, and Monsanto Company in the United States and Bayer AG, BASF AG, Alusuisse Lonza Group AG, and Degussa AG in Europe. Biotechnology offers both cost-effective and environmentally friendly technology and products. The technology will produce proteins and vitamins for animal feed; genetically modified vegetative plants that will resist drought, insects, and cold; new enzyme controlled processes for production of specific chemicals, new fibers for textiles that are derived from renewable raw materials and are biodegradable. Such agro-growth aspects will result in significant losses in other agrochemicals areas such as herbicides and insecticides as resistant, modified plants are developed.

Research, development, and testing will be carried out more and more at independent facilities according to Federal Government reports, and this function will be a significant growth area. This is related to the high cost of specialized investigative tools, which can be shared by a number of companies. Also important is the ability to temporarily hire highly skilled personnel to carry out testing and developmental efforts when they are needed rather than have them as permanent members of a firm's staff. The independent agencies are the ones who will be able to set up the combinational programs for some of the chemical manufacturing segments so set-up costs, in effect, are shared by a number of companies. These programs are expensive to develop and maintain. Many smaller firms would not be able to afford the technology unless some centralized, independent source was available to allow them to share the cost rather than the whole cost burden.

Composites have not been previously mentioned, but they form an important area that is sizable and that will grow in the future. These graphite- or glass-reinforced materials are useful in many markets that need strong, shaped articles including the aircraft/ aerospace, automotive, recreation, general industrial, and similar markets. In addition to strength, composites often offer weight savings plus the ability to rapidly produce complex-shaped, small to large articles.

Energy sources continue to be highly important. Oil prices have recently skyrocketed making gas-to-liquid technology by means of syngas technology take on a new importance.[30,31] At today's oil prices, gas-to-liquid is becoming quite attractive. Renewable energy sources such as hydropower, biomass, wind, and solar photovoltaics are also receiving a great deal more attention. Although such energy sources only accounted for about 8 percent of energy consumption early in the 21st century,[32] the field is rapidly growing. Major oil companies are investing in wind power generation to ensure their future growth. For example, Royal Dutch/Shell Transport is concert with The Netherlands power company Nuon N.V. recently announced that 36 three-megawatt wind turbines located about six to eleven miles (10–18 km) off the Dutch coast will be built and should be in commercial operation in 2006.[33] Wind and solar renewable energy have a combined compound annual growth rate of 30 percent on a global basis.[32] The same article indicated that $20.3 billion or about 16 to 17 percent of total world investment in power generation equipment was invested in developing renewable energy in 2003. In a general sense, renewable energy is becoming more affordable, and as fossil fuels become increasingly scarce and high priced, such sources, as well as replacement ethanol from grain, will take on more and more importance and will aid in providing a cleaner environment. The high price of oil also makes development of oil sands in Canada and elsewhere viable energy sources. Some plants are now on stream and production will be markedly increased by 2010 to 2012 as huge capital investments are made by companies such as Canadian Natural Resources, EnCana, and Suncor.

Nanotechnology has great promise for the chemical industry. This is an emerging technology whose aim is to place atoms and molecules in particular arrays, a technique termed "positional assembly," and to have this done repetitively through "self-replication."[34] This sounds more like science fiction than chemistry. But, nanotechnology already produces significant sales, and the sales are predicted to grow from a base of $200 million in 2002 to $25 billion by 2012.[35] This is an astounding 62 percent compounded growth rate for 10 years.

What is nanotechnology? Imagine having a machine that can go forward, backward, right, and left as well as up and down at various angles. Now imagine that this machine is very, very small—in fact, so small that it is approaching atomic dimensions and it is measured in terms of nanometers. A nanometer is 1×10^{-9} meters, and we certainly cannot see things this small. However, regardless of these difficulties, we want to build and control this machine—that is, have it do whatever we want it to do, which is to place atoms and molecules in particular arrays so we end up with a desired product. Still not satisfied, we want the machine to do this over and over and over again.

One might ask why we want to do this. We all know that everything is made up of atoms. Chemicals are everywhere and in everything. The difference in the carbon in coal and in diamonds is the way the atoms of carbon are arranged. Arrange the atoms properly and a worthless pile of carbon becomes a precious diamond. If we were able to arrange the atoms in air, dirt, and water into a desired configuration, it would be possible to make, for example, carrots, beets, potatoes, and so on. At present, the transformations are made by nature, using a gene system to combine the ingredients in the proper way. Properly align the atoms of a material that is to be used as a filler or reinforcing material, and one can envision super strong composite materials resulting. If one were to rearrange the atoms of sand and in so doing add a few trace elements, the end result could be a computer chip.[36] The goals of nanotechnology are to:

- Arrange every or almost every atom in a desired structure in its proper place,
- Make effectively any structure that can be atomically specified and that does not violate laws of chemistry and physics, and
- Have manufacturing costs that are basically energy and raw material costs.

The other concepts associated with nanotechnology are those described above, positional assembly and self-replication. Nanotechnology is currently being used for light-emitting polymer films, in computer applications, electrically conductive adhesives, and other areas.

These are but only a few of the potential areas for chemical manufacturing during the first decade of the twenty-first century. Most probably, many of the products and processes that will be in place in 2012 or so cannot even be imagined today.

New emerging markets for nano-based products include nanomemory products used in mobile communications and computers wherein it is expected the market will grow to \$8.6 billion by 2007 and \$65.7 billion by 2011; nanosensors for medical, homeland security, and aerospace applications wherein the market is expected to be \$446 million in 2007 and should grow to \$5.6 billion in 2011; nanoengineered display technology for roll-up displays using plastic electronics, other platforms, and carbon nanotubes for large-size, high-definition television sets should grow to \$1.6 billion in 2007 to about \$7.5 billion by 2011.[37] A very recent article[38] indicated the global market for nanophotonic devices is to reach \$9.33 billion by 2009; photonics is the technology of generating and controlling light and using it to conduct information. All in all, one finds nanotechnology being mentioned, discussed, and applied in application after application, technical, scientific meetings are being organized and held, and nanotechnology along with its architecture certainly will grow in importance in a wide variety of uses.[39]

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