Petrochemicals

THE RISE OF AN INDUSTRY

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Jacket. *Background:* Courtesy of Bayer AG at Leverkuesen, West Germany, which operates some of the most modern chemical plants, but has preserved many years of industrial architecture and design that reveal traces of its past.
Inset: Union Carbide and Shell Chemical, two companies that made important early contributions to the development of the petrochemical industry, have collaborated in polypropylene technology. The picture shows a plant at Seadrift, Texas.

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This history of the petrochemical industry is dedicated to the memory of Professor Glenn Bennett, who taught chemistry and physics at Germantown Friends School in Philadelphia for many years. Mr. Bennett was one of those inspiring teachers who can shape people's lives. He endowed me with a lifelong interest in chemistry and in the application of chemistry to industrial processes.

Foreword*

It's almost fifty years since I entered the freshman class in chemical engineering at Oregon State University in the fall of 1938. That was just about the time that the word "petrochemicals" entered the vocabulary of chemical engineers. The industry has grown since that time from a few pockets of competence scattered around the world into a massive force responsible for about ten percent of the gross national product of the industrial countries. Its processes and products impact the lives of billions of people in both developed and undeveloped nations, almost always in useful ways, frequently in unseen ways, sometimes in dramatic and lifesaving ways, very rarely in damaging ways.

Petrochemicals: The Rise of an Industry paints an interesting and thought-provoking mosaic of interconnected scientific, engineering and economic achievements over the course of the past century. Those of us in the chemical engineering profession, beginners and veterans alike, will profit from some reflection on these achievements and on the character and abilities of the individuals who made them possible. In the early days of the chemical industry, persistent and creative scientists and engineers with an appreciation of economic realities built the industry.

*By Robert W. Lundeen, formerly chairman, Dow Chemical Company.

Today, successors of those pioneers with many of the same talents are required to lead the industry into its future.

As a young researcher in the early 1950s, it was my privilege to have had as a counselor and role model a European scientist of the old school, Dr. Wilhem Hirschkind. He had been a graduate student of Fritz Haber's at the Technische Hochschule of Karlsruhe during the early years of this century, when Haber was doing his research work in ammonia synthesis. Hirschkind carried with him to this country strong views about professional integrity and about the broader responsibilities of those of us in the chemical business to our profession and to society. Of equal importance, he believed and demonstrated in his own work that any significant advance in chemical production practice must be based on solid scientific understanding and carefully done research. And to this day, I vividly remember a comment he made to me in his office at Pittsburg, California, one afternoon almost forty years ago: "Any otherwise well-qualified individual who aspires to a position of business leadership and high professional achievement must also be a gentleman!" Great advice then; great advice now.

I give this personal anecdote space in this foreword because it says something significant about the character of the people who were the builders of our industry. Character and breadth are even more essential qualities for today's petrochemical leaders. The industry lives in an unforgiving environment with the long-established requirement for making sound technical and economic judgments, but with even greater pressure for making sensible and sensitive judgments in a whole variety of sociopolitical issues, e.g., balance of constituency interests, political risk assessments, ethical standards, public policy development, constituency communications. Professional competence, self-confidence, personal integrity, and intellectual breadth—those are the qualities that today's leaders must bring to the job.

The petrochemical industry began an aggressive migration from the United States to a variety of seemingly attractive foreign production and market opportunities in the late 1950s. Its accomplishments in Europe are well documented, and American companies stand there today as formidable competitors in a sophisticated market. Perhaps less well appreciated is the transfer of petrochemical technology and management skills from the large industrial nations to the less developed and/or smaller countries in Latin America and Asia. In those countries, the impact of the transfer

was relatively larger, because what was brought was generally of a much higher standard than what had been developed locally up to that time. Transfer of technology and management skills was of obvious value, but the companies brought something else of equal or greater value . . . opportunity. Until foreign investors, frequently but not exclusively from the United States, introduced their advanced technology and built their factories, job opportunities for technically trained and ambitious young people were distinctly limited. Local petrochemical investments enabled talented young men and women to work at home rather than being forced to emigrate to capitalize on their skills.

Even less appreciated is the fact that in many instances American petrochemical investors in less-developed countries set the standards for environmental protection and worker safety. (It is of course popular in some sectors of our society today and was even more popular a few years ago to "bash" the chemical industry for its sins of omission in environmental matters. The industry was not perfect, to be sure, but in the great majority of cases it acted responsibly on the basis of information available at the time.) In most less-developed countries, environmental standards were completely absent or elementary at best when American petrochemical investment began in the late 1950s and early 1960s. Having no national guidelines, companies normally applied their U. S. standards. Those company standards frequently provided a foundation for the local authorities to get started on their own environmental programs. The same can be said of worker safety: the gap between local and U.S. safety standards was probably even greater than in environmental matters. I was always very proud of Dow Chemical's policy (and I paraphrase): With respect to worker safety and environmental protection we will apply the stricter of either our own or the national standard.

I dwell on the foregoing, because I believe a strong case can be made that the petrochemical business is a very useful business, useful not only in economic terms but in social terms. Its products, its opportunities, and its standards are now part of many societies that didn't even know the term "petrochemicals" twenty-five years ago. The industry's impact on the standard of living, personal health, and economic opportunities for people around the world is pervasive and positive.

Looking back on a forty-year career in the business, it seems to me that the driving forces in world petrochemical developments are

three: (1) advances in the physical sciences, (2) opportunities for economic gain, and (3) changes in the global social and political movement. In the "olden days", i.e., when I began my professional career, advances in physical sciences and opportunities for economic gain were the recognized driving forces. Little if any recognition was given to changes in the global sociopolitical environment. Today, industrial leaders who fail to develop awareness of and competence in dealing with the impact of these latter forces on their enterprises will not be leaders for long. In saying this, I am reinforcing what Peter Spitz says in his excellent concluding paragraphs on the future. He cogently sums up the whole issue in one sentence "One way or the other, the future is up to the industry's current and future management." Quality management does make a difference, a huge difference. The premier managements in the industry have prepared themselves by building reserves, both financial and human, to withstand hard times brought on by forces outside their control and, more importantly, to capture opportunities when they present themselves. Failure to build such reserves is as lethal in the long term as failure to do research or to provide quality products on a continuing basis.

Management of petrochemical enterprises must now be viewed in global rather than national or regional terms. Individual national markets and national policies are receding in significance. It is the complex simultaneous global equations of supply and demand, relative economic strength, political equilibria, military power, ideological fervor, and the relentless advance of scientific knowledge that are the major determinants of the future of the petrochemical business. Those who involve themselves in the mastery of these equations have in prospect as challenging, exciting, and personally rewarding careers as any of us who had our career in the first half-century of the petrochemical age.

ROBERT W. LUNDEEN

Pebble Beach, California, March 1987

Preface

The petrochemical industry is unique in that it experienced an unusually rapid transition from its birth in the early 1920s to what many people called "maturity" by the mid-1970s. Between 1940 and 1960, it became one of the largest industry sectors, providing an astounding variety of chemical intermediates used for the manufacture of plastics, fibers, synthetic rubber, and many other end products. The petrochemical industry was to a large extent "made in America," because it was in the United States that an unusual combination of circumstances existed at a certain point in time: an abundance of inexpensive gaseous and liquid petroleum feedstocks, suitable technology, a large market, and an incentive for rapid development, occasioned by military needs in World War II. This was followed by a consumer-oriented boom that developed when the war was over.

Much of the technology, of course, came from Europe and particularly from Germany, which had built up a formidable chemical industry over a 100-year period. But the German chemical industry was based on coal. And it was largely built by chemists, before chemical engineering became a separate discipline. Chemical engineers in the United States, and later in many other countries, were primarily responsible for the success of the new petrochemical industry.

This book is written for people interested in the origins of the petrochemical industry, in its technology, in some of the personalities who founded this industry and made it grow, and in the development of the business aspects of a new industry. It was a magnificent achievement and deserves being remembered at a time when the chemical industry is under a cloud, due to a history of benign neglect of the environment and, at times, a lack of sensitivity to health hazards caused by some of its products. It is no longer a glamor industry, since the production of commodity chemicals, as bulk petrochemicals are now often called, became a relatively unprofitable business. Many producers of these materials have now diversified into other fields. But to those of us who remain involved in the petrochemicals business, many challenges still remain: new polymers, "breakthrough" processes with novel catalysts, lower production costs through energy savings, etc. A mature industry doesn't have to be dull! And is it really *mature*?

Parts of this book will seem like a course in industrial chemistry. I must admit that was, in fact, part of my intention. The curricula of many chemical engineering departments in universities no longer feature industrial chemistry courses, concentrating instead on the more theoretical aspects of chemical engineering (transport phenomena, computer applications to complex physical chemistry problems, etc.). This has apparently been justified on the basis that students will develop a practical knowledge of manufacturing operations when they enter industry. But, as a result, many of these graduates will not go into the chemical industry, because they have not been exposed to the challenges and excitement this industry can evoke. Perhaps, by reading this book, some students will have a better opportunity to appreciate this, while learning about the origins of the modern organic chemical industry. Some of them may, in the future, experience the excitement of participating in the process whereby a new synthesis that at first produced just a few grams of material is transformed into a plant producing 100 million pounds per year.

Although I did not have a well-developed thesis when I started to write, it became evident that a number of conclusions could be drawn from the historical growth of the industry I was examining. Several themes suggested themselves and they became more firmly established, as the work progressed.

The first is that technology keeps advancing in an inexorable manner, certainly to the benefit of mankind, sometimes to the considerable benefit of the inventor, but not always to the expected

financial gain to the firm or firms employing the new technology. Companies in the petrochemical industry derived meaningful profits from inventing a new technology only if it was really unique and they could maintain control over it through the use of the patent system. That this is more difficult than expected, in many cases, must come as a surprise to many people. Many times it is easier than one might think to get around patents. At other times, the patent is not really broad enough to dominate. Many of the technological developments made in the petrochemical industry were not enough of a "breakthrough" to provide major entry barriers for competitors. And where inventions were made by engineering firms eager to sign up licensees, there was no reason to expect anything but a free-for-all, as new entrants to the industry lined up to purchase the new technology.

The second theme is that an industry can undergo a total transformation when its raw materials base changes. It didn't matter that coal, alcohol, crude oil, or natural gas could all be transformed into many of the same organic chemicals. The important thing was that this could be done most inexpensively from feedstocks derived from petroleum or from the natural gas discovered by companies drilling for oil. When these materials became abundantly available, coal and alcohol chemistry was no longer economically viable for the production of commodity organic chemicals. Regardless of the fact that Europe's chemical industry was for a long time more advanced than that in the United States, the future of organic chemicals was going to be related to petroleum, not coal, as soon as companies such as Union Carbide, Standard Oil (New Jersey), Shell, and Dow turned their attention to the production of petrochemicals.

European chemists in the 1800s and 1900s had concentrated on synthesizing molecules from available coal-derived feedstocks, which largely involved aromatic chemicals. They therefore largely neglected industrial aliphatic chemistry. Alcohol-based chemicals did become of some importance in the years between World War I and the 1930s. Then U.S. oil and chemical companies recognized the value of reactive petroleum-derived hydrocarbons and not only came up with a number of industrially significant processes for aliphatic chemicals, but also found out how to make the originally coal tar-derived chemicals more inexpensively and in much larger quantities. The fact that European know-how greatly helped in this effort is an important sidelight.

The third theme relates to the conditions under which business

has been conducted in the chemical industry over time. Before the war, the number of producers of each chemical was small, there was relatively little real competition as we know it today and, in fact, there existed a system of cartels and "clubs" that made the production of chemicals (and a number of other products) sort of a gentleman's game. This was often illegal, but governments tended to look the other way for a number of reasons, some vaguely associated with "national security." After the war, this system became obsolete, replaced with an industry so competitive as to deny reasonable profits to many of its participants much of the time. It seems, however, that the pendulum may have swung too far the other way. It is partly swinging back now, as the number of industry participants is being reduced through a restructuring program and profitability is again on the rise.

This brings me to the fourth theme, the one I had the most trouble with. It is closely related to the other three, namely: How could it be that an industry that fostered so much innovation, produced so many desirable consumer products, and was characterized by such remarkable growth over such a short period of time turned out to be so unprofitable for so many of its participants? Could the companies engaging in this industry have played the game differently, to reap greater advantage from the technological magic they created? Was the petrochemical industry unique in fumbling away a large part of its potential profits and, if so, what were the circumstances that caused this to happen? Some of the answers to these questions suggested themselves during my work, but other parts of the question remain unclear. While some of the methodological business analyses derived with current strategic planning theory (matrices, growth/maturity charts, etc.) have validity, a comprehensive answer is certainly more complicated. The history of the petrochemical industry needs to be studied in greater detail so that future managers engaged in rapidly growing industries can learn the appropriate lessons.

One point kept coming back to me, as I focused on what had transpired over the 40 years or so during which these events took place (a period that started when I was in grammar school in Austria, where I was born): It had all happened so rapidly! I now know that when I first heard my father play Caruso and Gigli opera records on a gramophone that said "His Master's Voice" (then the RCA symbol), these records had been made of phenol-formaldehyde plastic or hard rubber—not from vinyl resins. PVC (polyvinyl

chloride) had not yet been invented. The records were blank on one side and, of course, they turned at 78 revolutions per minute. At the time, it seemed miraculous to me that you could hear the voice of an opera star in your own home.

Nylon came to my attention when I was going to high school in Philadelphia and a friend of my parents showed us a pair of "nylons" he was bringing home to his wife. He was in the stockings business, a customer of DuPont. When war broke out, there was gasoline rationing (we had "A" coupons—the lowest priority) and everybody looked for old tires to be recycled for shredding and rubber recovery. Then, when we received gas masks in Army basic training, we were told that this was one of the uses for this recycled rubber. Rubber was in very short supply and the synthetic rubber development program took a long time to start making a contribution.

Plastics were around in the 1930s, but they really burst on the scene in the late 1940s. Polyethylene and polystyrene were unknown to consumers before that time, but then all sorts of molded and extruded articles started to appear. We learned that the clear and rigid objects were made of methyl methacrylate (Lucite or Plexiglas), acetate or polystyrene, and the flexible articles, of vinyl resins or polyethylene. A little later, the Bakelite telephone earpieces (heavy, black, and conical) started being replaced with headsets made of lighter plastics that had more pleasing colors. At some point, it became obvious that the industry that was making these materials had come a long way over a very short time.

After my discharge from the Signal Corps, I returned to college. MIT used to send about ten percent of its chemical engineering graduates to Standard Oil Development Company (a Standard Oil of New Jersey affiliate), and this is where Professors Lewis and Gilliland suggested I should apply. When I joined Esso Engineering in 1949, all of the so-called "Four Horsemen" (Standard Oil technical executives) who had invented fluid cat cracking were still with the company. I now feel that there couldn't have been a better place to start my career.

In 1956, I accepted an offer from Scientific Design Company and was fortunate to have been in responsible positions there when many of that company's petrochemical process "breakthroughs" were made. In the mid-1960s, I left to start Chem Systems.

One problem that presented itself in writing this book related to the varied audience I felt I was addressing. A considerable part of

the subject matter is necessarily highly technical and beyond the reasonable knowledge of a reader without any chemical background, who might nevertheless be interested in this book from a historical or business standpoint. On the other hand, highly trained industry people will feel that I am elaborating the obvious. I thought about putting some of the information in "boxes" that could either be read or skipped, but then realized that I would have to decide whether these boxes should contain the simpler or the more complicated material. Unwilling to judge who would be the main readers, I decided not to use this technique. I have, however, included an appendix with a list of some of the more important technical terms used in the text, so that the lay reader can perhaps follow the subject matter in some of the chapters in a more informed manner. Some readers may also want to skip ahead here and there, if progress becomes too slow or, in other cases, if the text becomes too technical for a few paragraphs.

Another problem I encountered was in the organization of the material and in its presentation to the reader. It was immediately obvious that a totally chronological development would be wildly confusing, since so many different strands of product families, technologies, and historical company development would then somehow have to be brought along in parallel. This would require a great deal of jumping back and forth, which would cause major problems in following the development of any one subject. On the other hand, there had to be a certain sense of historical development in the organization of the material; otherwise I would have to keep returning to a much earlier period each time a new subject was commenced. Actually, either of these techniques make for a rather dry narrative style and I had already decided that I would try and make the book interesting and readable rather than a scholarly historical work. I had neither the time nor the ambition to write a book with the dimensions of Haynes' *American Chemical Industry* (published in 1946 in five volumes). I leave this task to others, hoping that this will also soon be done.

It seemed obvious to me that I would start with the German chemical industry and trace its development through World War II. My early research confirmed that many of the products that later became the most important "petrochemicals" were first made in Germany between 1900 and 1930, but from feedstocks other than petroleum (see Table A.1). During the later years of this period, the companies comprising I.G. Farbenindustrie, the vast German

TABLE A.1 Historical Dates for the First Commercial Production of Some Important Organic Chemicals

Chemical	Producer	Year (Approx.)
Phenol	F. Raschig (Germany); Hoffmann-LaRoche (Switzerland)	1901
Carbon tetrachloride	Griesheim-Elektron (Germany)	1903
Trichloroethylene	Wacker (Germany)	1908
Ethylene	Griesheim-Elektron (Germany)	1913
Ammonia*	BASF (Germany)	1913
Acetic acid	Wacker (Germany)	1916
Ethylene Oxide	BASF (Germany)	1916
Acetaldehyde	Hoechst (Germany)	1916
Acetone	Hoechst (Germany); Weitzman (U.K.); Standard Oil of N.J. (U.S.)	1917
Vinyl acetate	Shawinigan Chemicals (Canada)	1920
Methanol	BASF (Germany)	1923
Butanol	BASF (Germany)	1923
Vinyl chloride	Wacker (Germany)	1930

*Not an organic chemical.

chemical combine, came close to dominating much of the chemical industry as the world then knew it. They also provided the Nazi government with some of its most critical war materials. Perhaps for these reasons I found it interesting to start Chapter 1 with the victorious Allies' inspection tours of some of the I.G. Farben plants and then to use flashbacks to develop a number of chemical themes. Chapter 1 sets the technical tone of the book, including an appreciation of coal chemistry, which is later contrasted against the production of many of the same chemicals from petroleum feedstocks.

Chapter 2 describes the beginning of the petrochemical industry and here I found it useful to describe the accomplishments of four companies I considered major contributors in this effort: Union Carbide, Dow Chemical, Standard Oil (N.J.), and Shell. Chapters 3 and 4 then show how the outstanding contributions of the United States refining industry during World War II really put the petrochemical industry on the map. In the course of describing how this was done, it was possible to show how commercialization of the more sophisticated petroleum refining technology also happened to

create petrochemical feedstocks. It seemed particularly important to focus on the development of catalytic cracking, catalytic reforming, and aromatics extraction technology—in other words, on the refinery processes that make ethylene, propylene, butadiene, benzene, toluene, and the xylenes.

World War II represents an important dividing line, not only between coal and oil chemistry, but also in the way that companies conducted business. Before the war, there was a cartel mentality. After the war, the chemical industry became highly competitive. Since I had, from the start, intended to deal in later chapters with some of the business problems of the industry, I wanted to cover the conduct of chemical industry business before and after World War II in sufficient detail to allow some conclusions to be formulated at the end. I also found my research on cartels interesting and wanted to share some of it with readers of the book. Thus, Chapter 5 on prewar cartels and clubs.

Now, I could shift the narrative to the phenomenal growth of the industry in the postwar period, from the late 1940s to the late 1960s, mainly involving the development of plastics and synthetic fibers (Chapters 6 and 7), from their inception to the point where the industry started its explosive growth. Then I explain, in Chapter 8, how the sort of technical monopoly that a small number of firms had established over the production of certain key chemicals was broken through the dissemination of production technology by engineering firms and by some of the companies themselves. This allowed the addition of new capacity as fast or faster than the increase in demand for its products increased, a process that can now be seen to have started industry down the slippery slope.

Chapter 9 on international developments has two main themes: first, the efforts by U.S. firms to benefit internationally from their advantageous position in the new, originally largely U.S., industry and second the European and Japanese response to this effort.

By the late 1960s, a number of patterns had been established. It had become obvious that in spite of the industry's hugely successful development of technologies and products to serve continually expanding markets, the manufacture of commodity chemicals was becoming a considerably less profitable business than before. I decided to select one product, vinyl chloride monomer, used for the production of PVC resins, to illustrate how and why this happened (Chapter 9). And then I showed in Chapter 11 on "Large Plants" how a number of operating companies and engineering contractors

crowned the technological achievements of the industry through the development of truly outstanding low-cost processes for ethylene, ammonia, and several other chemicals, only to recognize that even these developments would only add to the industry's profitability problems.

Conceivably, I could have concluded the book at this point. However, I wanted to address the question of how the events of the 1970s, involving energy and feedstock economics, the construction of chemical plants by the oil-rich nations, and the slowdown in product demand growth changed a number of things and might, in the future, influence the further development of the industry. For this reason, I decided to add Chapter 12, "Discontinuities and Uncertainties," and then attempted to arrive at some conclusions (Chapter 13).

It is impossible in a book of this kind to provide adequate background information on many of the technical, economic, and market issues concerning the industry. A number of books would serve as good references on this subject including *Petrochemical Manufacturing & Marketing Guide, Volumes I & II,* by Robert B. Stobaugh, Jr., Gulf Publishing Company, Houston, Texas, 1966; *Industrial Organic Chemicals In Perspective, Parts I and II,* by Harold A. Wittcoff and Bryan G. Reuben, John Wiley & Sons, New York, New York, 1980; *Trends in Petrochemical Technology, The Impact of the Energy Crisis,* by Arthur M. Brownstein, Petroleum Publishing Company, Tulsa, Oklahoma, 1976; *Kirk-Othmer Encyclopedia,* John Wiley-Interscience, New York, New York; and *The Chemical Plant: From Process Selection to Commercial Operation,* edited by Ralph Laudau, Reinhold Publishing Company, New York, New York, 1966.

Writing this book has been both an exciting and humbling experience. Certainly, I did not realize at the start how many hours of research would be required for every hour spent at the word processor and how difficult it would be to write a book in short bursts in the evening, on weekends, or on business trips. When traveling, I would try to visit libraries in such cities as Washington, Houston, London, Duesseldorf and Zurich. There, I would look for additional reference books or for useful articles in chemical industry trade publications, going back as far as the 1930s. I also wrote to companies for corporate biographies and to people in the industry for verification of specific issues, and I interviewed a number of industry participants in the United States, Europe and Japan, who I felt