BOOK REVIEWS

Scaling Up: The Institution of Chemical Engineers and the Rise of a New Profession. Colin Divall and Sean F. Johnston, Kluwer Academic Publishers, Dordrecht, The Netherlands, 2000, 347 pp., £83 (£50 to IChemE members).

Chemical engineering, as a profession, has traditionally found itself at the intersection of chemistry and engineering (especially mechanical engineering in its early history). Balancing itself between these two has not always been an easy task. As a result, the role of the chemical engineer has not always been clearly understood. Indeed. George E. Davis, considered by many as one of the "founding fathers" of chemical engineering, stated in the very beginning of his seminal work, *A Handbook of Chemical Engineering* (1901), "The functions of the Chemical Engineer are very generally misunderstood." Excerpts from this work are included in the authors' book.

This misunderstanding, along with a strong resistance of industrial chemists to relinquish any of their "turf" to this new profession, created significant challenges to the development of chemical engineering. The authors have effectively covered the problems of this burgeoning profession as it struggled for acceptance in Britain. They have done an excellent job of meshing the history of the profession with the history of its professional society in Britain, the Institution of Chemical Engineers (IChemE). Both aspects are covered in sufficient detail to provide a complete story but not in such excess detail as to make it burdensome for the reader.

James F. Donnelly has contributed an excellent chapter on the early history of chemical engineering before the First World War. The authors show how the development of university courses in chemical engineering (often taught by chemists) influenced the growth of the profession. They also show the effect of the two world wars on the development of the profession and its acceptance by both government and industry. They discuss the influence of these two entities on the formation and expansion of IChemE. The authors cover the rapid growth of the chemical and petrochemical industries following the Second World War and how this helped to promote both the profession and IChemE. They show the relationship between the institution and other chemical and engineering organizations and how these relationships impacted, both positively and negatively, its development.

Scaling Up is an excellent history of the chemical engineering profession in Britain and the development and growth of the Institution of Chemical Engineers. It is well laid out and the text is generally easy to read. The authors use a number of acronyms, many of which are not readily recognizable to someone from the U.S., but they define each at first use and include a list for ready reference. Unfortunately, there are very few illustrations and no photographs.

Overall, it is a highly recommended book for anyone interested in the history of chemical engineering. The price is a little high, but worth it for those who really want to learn how it all began. *Stanley I. Proctor, Proctor Consulting Services, Chesterfield, MO 63017.*

Mauve: How One Man Invented a Color that Changed the World. Simon Garfield, W. W. Norton & Company, New York, 2001. 222 pp, Cloth (Typeset), $ 23.95.

The days when accounts of the romance and history of chemical industry attracted a large readership among the public are long gone. It has become increasingly difficult to find any powerful nostalgic pull. Enthusiasm has been replaced by cynicism, chemistry is no longer the leading science, and industrial organic chemistry has often reinvented itself as the life-sciences industry. Those publications on the development of chemical industry that do appear nowadays tend to be self-serving corporate promotional exercises, or short-run, low-readership, over-priced academic tomes (generally prepared from camera-ready copy). In the meantime, many of the great chemical firms that dominated the 20th-century scene and developed the products on which modern society relies have lost their identities, generally through takeovers, mergers, bankruptcy, and dismemberment, particularly the process known as "spin off."

While we cannot expect much in the way of lamentation for lost corporate names, it is a sad state of affairs when, at a time of great technological and business change, the achievements and contributions of chemical industry as part of the "old economy" are hardly known outside of industry and a handful of historians. But, perhaps, all is not lost. A new genre of industrial histories may well be on the way—well-researched, balanced, readable, and exciting. The authors are award-winning journalists and science writers. And, in their fascination with history and quest for accuracy, they rely on original sources, interviews, and—most heartening—the academic scholarships of both historians and practitioners of chemistry.

Mauve is one of the first of the new breed. Its author, Simon Garfield, is recipient of the prestigious Somerset Maugham Prize. His beautifully produced small-format volume charmingly informs the layperson that there is a direct lineage from William Perkin's much-heralded discovery of the first aniline dye to such corporations as BASF, Bayer, Hoechst, ICI, Du Pont, Ciba, and Geigy. While this is the theme, and there is plenty of detail of the early years, there are frequent and disarming changes of focus, though always linked, one way or another, by the color mauve or the range of human activities that it helped to spawn.

Garfield's main story is perhaps too well-known to readers of this journal to justify more than a reminder. In the Easter vacation of 1856 the teenaged William Perkin, inspired by a suggestion put out by his boss, August Wilhelm Hofmann, head of the Royal College of Chemistry in London, attempted to synthesize the important natural drug quinine from allytoluidine. Perkin's experiment failed, but his efforts were not in vain. On repeating the reaction with aniline, he obtained a solution that dyed silk a beautiful purple. Believing that he had stumbled across a useful commercial colorant (and why not, since some of the most successful were made from all manner of waste, including bird excrement), Perkin decided to file a patent for the process. Though he had little idea of what the market was worth, he gained the confidence of his father and brother George, who together erected a small factory in a remote part of northwest London called Greenford Green. By the end of 1858 they were in the business of manufacturing from coal-tar benzene what was originally called Tyrian purple, but that in 1859 acquired the name mauve from the fashionable ladies of London. It was the beginning of synthetic dyestuffs and, by extension, the modern organic chemical industry.

This odyssey is divided into two main sections, Invention and Exploitation. The first deals with the discovery and manufacture of mauve and the second with where it led. The account of Perkin's early work is accessible in both style and content, providing a fresh interpretation for the historian, and an ideal conceptual framework for the lay reader through joining the moment of discovery with celebratory events in 1906 and 1956. Mauve fired the hearts and imaginations of generations of chemists. Perkin, however, retired from the business in 1873 after making a second fortune with synthetic alizarin. He realized then that the Germans had cornered the science, the technology, and the markets.

Garfield's biographical details are based on his own thorough research, as well as the many accounts that have appeared in the United Kingdom and the United States. The gallery of greats that get into the story include individuals such as Caro, Duisberg, von Baeyer, Graebe, and Liebermann, and all major firms that have dabbled in synthetic dyestuffs. Garfield leads us through the myriad connections between the 19th-century coal-tar colors and the 20th century successors, particularly, salvarsan, prontosil, the sulfonamides, and Bakelite. He goes on to the present, when phthalocyanine colorants, a British invention of the 1930s, are employed in cancer therapy, natural dyes are being reinvestigated as inks for computer printers, and, of course, the fashion world continues to expect its colors on demand. He does not forget environmental problems and difficulties with toxic byproducts encountered and produced by the industry, starting with the 1860 fuchsin process that employed arsenic acid as an oxidant.

The great achievement of this book is that Garfield has taken a story that has been endlessly rewritten for different audiences and at different times, and refashioned it into a form that will appeal strongly to modern-day readers—not just students and teachers of science, but anyone interested in the origins of our modern world.

The nature of journalism is often to make things more important than they are, or might really be. While there may be good reason to criticize or condemn this approach, it is certainly an effective tool, as used here, in drawing the public's attention to what we are trying to tell each other in our muted tones. That is one of several reasons why this book should also be read by serious historians. *Anthony S. Travis, Sidney M. Edelstein Center for the History of Science, Technology, and Medicine, The Hebrew University of Jerusalem, Jerusalem ISRAEL 91904.*

Linus Pauling: Scientist and Peacemaker. Clifford Mead and Thomas Hager, Ed., Oregon State University Press, Corvallis, OR, 2001. [x] + 272 pp, Cloth, ISBN 0-87071-489-9. $35.00.

The preface to this centenary volume for Linus Pauling indicates that it is modeled on those for Albert Einstein and Niels Bohr published by Harvard University Press about twenty years ago. Thus, even though the editors do not specifically say so, the intended audience should, by analogy, be "the general public, as well as professional [chemists] and teachers of science." Like those two earlier volumes, this one also presents a variety of pieces by and about its subject, and the collection includes some material in print for the first time from the Ava Helen and Linus Pauling Papers at Oregon State University. The variety of pieces is both the strength and weakness of this collection.

According to the editors, the pieces were chosen for this volume on the basis of their "quality and comprehensiveness" though there is no claim for a complete picture of this "multi-faceted crystal with many dimensions," as Pauling once described himself. The book consists of three major sections, The Man, The Science, and The Peace Work; a shorter fourth section entitled Facets; and a Selected Bibliography, which lists about one hundred of Pauling's 1100 published articles, most of his sixteen books, and twenty books and articles about Pauling. Facets is in some ways the most interesting part of this collection. Certainly the best for browsing, it contains snippets of writing both by and about Pauling. These snippets provide insights—often humorous ones—into Pauling's character in terms of what he tended to notice and what others tended to notice about him.

For example, one snippet suggests that Pauling did not suffer the same fate that Niels Bohr did, as noted by the editors of the latter's 1985 centenary volume: "Bohr . . . is different [from Einstein] in that his name, although known to every student of natural science, is not widely recognized by the public." Early one morning in the 1960s Richard Feynman "found himself sharing a ride through the desert with a trio of [Las Vegas] prostitutes . . . and when Feynman told the group that he was a researcher at Caltech, he was surprised to hear one of the women reply, 'Oh, isn't that the place where the scientist Pauling comes from?' . . . The women . . . had read about him in a recent issue of *Time* magazine, in a cover story about U.S. science that they had combed through for pictures of the youngest and handsomest researchers." Of course, Pauling's name became even more widely recognized by the public with his winning of the Nobel Peace Prize for 1962 and his notoriety in the 1970s and 1980s in connection with combating maladies from colds to cancer with megadoses of vitamin C.

In another anecdote William Lipscomb tells how Pauling had his beard shaved off during a transcontinental train ride in the 1930s. "Ever conscious of his image as seen by others, he returned to his seat by Ava

Helen and pretended to make advances which sprained the eyebrows of several other passengers who were saying 'Just wait 'til the guy with the beard comes back.'" And another story about Pauling as he was leaving the office of one of his graduate students: he paused and picked up "a small device consisting of an eyepiece with a lens containing a photograph which could only be viewed by looking directly into it against a strong light. The photograph was that of a beautiful girl, completely naked, standing on a large black rock in the middle of a rushing mountain stream. Pauling . . . clapped it to his eye. 'Hmmm,' he said. 'Basalt.' And he walked out without another word."

The three major sections are less humorous and somewhat more uneven. Each contains pieces by Pauling, an interview with Pauling, and, except for the third section (The Peace Work), pieces by others about Pauling. The first section begins with "The Roots of Genius" by Tom Hager, one of the editors. He notes that while it is easy to understand the events of Pauling's life—he has, in fact, written two of the some half dozen biographies—"understanding Pauling at deeper levels" is more difficult. Adept at posing penetrating questions, Hager admits that many of them remain unanswered, but this piece does offer valuable insights into "Pauling's sometimes contradictory genius" and provides clues about his character to keep in mind while reading subsequent pieces.

Hager also has an interesting piece in the second section, The Science. "The Triple Helix" examines Pauling's loss to Watson and Crick in determining the structure of DNA and provides a counterpoint from Pauling's perspective to Watson's version in *The Double Helix*. Watson, as well as some historians of science, has attributed Pauling's failure with DNA to the Federal government's refusal to issue him a passport to travel to England in May 1952 since that prevented him from seeing Rosalind Franklin's X-ray photographs. As a result of the ensuing uproar, however, Pauling did receive a passport in time to attend two international meetings in France in July 1952. Afterwards, he spent a month in England without ever bothering to visit Franklin or trying to see her data. Hager argues that Pauling's failure was actually due to three unrelated factors: his focus on proteins, his lack of adequate data, and his pride. Pauling's youngest son Crellin adds another twist to this story in a snippet in Facets. In August 1948 Pauling crossed the Atlantic on the same ship as Erwin Chargaff, whose findings that adenine and thymine, as well as guanine and cytosine, are present in equal amounts in DNA were crucial in Watson and Crick's eventual unraveling of the DNA structure. Pauling later mused that if he hadn't heard about those results "straight from the horse's mouth"—a horse that had a reputation for being headstrong—and had read about them instead, he might have paid more attention to them and recognized their true significance. But, of course, he didn't, and that's part of the story of DNA.

Although Pauling is invariably the most interesting writer on Pauling, The Man and The Peace Work might have benefited from insights by others. Other views—particularly about his antinuclear activities, the Nobel Peace Prize, his opinions about vitamin C, and his difficulties at Caltech—could have added more corners to the "cubistic view" of Pauling in each of the three major sections. The transcript of Pauling's 1958 interview on *Meet the Press* is one of the few pieces that deals with the negative popular attitudes toward Pauling and his antiwar activities at the time. It is particularly surprising that there are no pieces by Ava Helen Pauling—if such pieces exist—since Pauling characterizes his meeting her as "the event that had the greatest effect on my life." He also describes her specific influence on him in the late 1940s in his becoming a social activist in "An Episode That Changed My Life."

The Science section does contain interesting pieces by other writers, especially "The Scientific Contributions of Linus Pauling" by Jack Dunitz, which was taken from an appreciation that appeared in *Biographical Memoirs of Fellows of the Royal Society*. The majority of pieces in this section, both by Pauling and by others, focus on biological topics, and this section expanded my view of him as a scientist. Many of the pieces in this section, as well the other sections, are not dated—nearly half in all. This is understandable for reminiscences by Pauling that he may have left undated, but the editors should have noted the dates of other pieces when they were known.

This is a minor drawback to a collection that is far stronger on the positive side than the negative. Although I might quibble with a few of the editors' choices, they are generally interesting and informative and contribute to the overall "view of a fascinating man." The book is strewn with wonderful photographs of Pauling from every stage of his life, from a five-year-old in furry chaps to an old man with his trademark beret. There is even one of Pauling "as a good-looking little gal" at a fraternity smoker in 1920! The photograph of Linus and Ava Helen Pauling at the Nobel ceremonies in 1963 shows how much they came to resemble each other after forty years of marriage since several pictures of them as a young couple show no such resemblance. There are also short quotes from interviews conducted by Tom Hager dispersed throughout the book as Marginalia. Although these occasionally duplicate material in the text, they add to the "cubistic view."

This collection expanded my view of Pauling considerably, from that of primarily a physical chemist, the author of *The Nature of the Chemical Bond,* and an originator of the valence-bond model, to a scientist broadly interested in applying his knowledge of chemistry to biological and medical problems, as well as one committed to using his own prestige for social activism in warning the world of the dangers of nuclear war. In comparing how he valued the two Nobel prizes, Pauling wrote, "the Nobel Prize in Chemistry pleased me immensely, but . . . it was given to me for enjoying myself—for carrying out researches in chemistry that I enjoyed carrying out. On the other hand, I felt that the Nobel Peace Prize was an indication to me that I had done my duty as a human being—my duty to my fellow human beings." This collection succeeds in presenting the picture of a remarkable human being, who divided his energies between what he enjoyed doing and what he felt obligated to do.

The editors specifically refer to two kinds of readers of this book. The "more knowledgeable scholars" whom they mention in the preface may find "new and perhaps valuable source materials" here, but I doubt that "first-time readers about Pauling" will find this a particularly satisfying book. It succeeds quite well on its own terms, a "mosaic . . . almost cubistic view . . . of one of the central scientists in twentieth-century history," but it is too fractured a view for someone wanting to learn about Pauling for the first time. Instead, a reader who has some knowledge of Pauling's life and work, but who wants to learn more, should find this a fascinating collection. I found it more and more intriguing as I went back and dipped into it here and there after initially reading it straight through. It has motivated me to read more about Pauling, especially one (or perhaps even both) of the books by Tom Hager. *Richard E. Rice, General Education Program, James Madison University, Harrisonburg, VA 22807.*

Chemical Sciences in the 20th Century. Carsten Reinhardt, Ed., Wiley-VCH, Weinheim, 2000. 281 pp, ISBN 3-527-30271-9, DM 158.

Chemistry in the twentieth century has seen unprecedented growth in both the depth and the breadth of its understanding of scientific phenomena. The complexity and the varied interrelationships among the sciences and their changing perspectives on what constitutes a particular area of study have caused many science historians to examine this area of twentieth century chemistry in a new light. Indeed they have expressed a strong interest in cross-disciplinary studies involving this era. It was the European Science Foundation, desirous of bringing together an international network of historians of chemistry and of addressing the new realities of twentieth century chemistry, that began a five-year program focusing on the evolution of chemistry. They formed the Commission on the History of Modern Chemistry in 1997. The first conference of the commission, focused on "Between Physics and Biology: Chemical Sciences in the Twentieth Century," was held in Munich in 1999. Most of the papers and clearly the main ideas in this collection came out of the conference. The aim of this book is to bridge the boundaries between chemistry and the other sciences as well as to illustrate how chemistry interfaces with technology and mathematics.

The contributors propose to explore these interdisciplinary developments in three sections covering the areas of theoretical chemistry, nuclear chemistry and cosmochemistry, and the newest area of solid-state chemistry and biotechnology. An important addition was the chapter on disciplinary changes in organic chemistry, which is actually divided into four areas of study. The contributing authors are internationally recognized in their areas and able to address the issues raised in their respective disciplines. The number of references and notes per chapter varied from four in a short chapter to 118. The editor reminds the reader early that disciplines create unity, that the existence of hybrid fields helps to forward the unity of science, that disciplinary identity in chemistry does exist and yet most chemists are involved in activities from the territory of several disciplines.

The first chapter covers the various factors that have impacted on the development of organic chemistry since 1900 and how organic chemistry played a major role in the creation and expansion of the new discipline of bioinorganic chemistry. Three central areas are explored. It is pointed out how this dominant area of organic chemistry is impacted by physical chemistry to give rise to physical organic chemistry. Then it is noted that classical structural chemistry is replaced by physical instrumentation with a major impetus coming from industrial companies that promoted techniques such as ultraviolet spectroscopy, infrared spectroscopy, nuclear magnetic resonance, and X-ray crystallography. Lastly, the origin and growth of bioinorganic chemistry are traced as chemists seek to understand biological reactions at the level of organic reaction mechanisms; and the areas of chemistry and biology secure a small degree of unity.

In the next section one explores the origin and development of quantum and theoretical chemistry. Several questions are examined, such as the reduction of chemistry to physics: the degree to which mathematics should enter chemistry; and to what extent theoretical methods can explain chemical behavior. The emergence of quantum chemistry is explored by considering the impact of textbooks and computers and how specific chemical ideas such as the chemical bond and resonance are affected. Two chapters in this section describe the efforts of Giovanni Bonino to establish quantum chemistry in Italy and of Jean Barriol in setting up the theoretical chemistry laboratory in Nancy, France. The influence that social and political factors can have in the establishment of a discipline is also examined in these two chapters.

The following section covers changes from radiochemistry to nuclear chemistry and cosmochemistry, which are viewed as completely interdisciplinary fields. Chapter 6 outlines the section and identifies four critical issues to consider: the approaches to weigh physical evidence in these areas; the relationship between identification and production of a new element; the way in which artificial elements are viewed relative to natural elements; and relationships illustrated by these new fields. The interplay between chemistry and physics is presented in the next two chapters. The work of the Noddacks in their successful discovery of element 75-Rhenium but their failure with element 43 is traced to their utilization of traditional chemical means but not of newer nuclear techniques. Then follows a description of the delay of discovery of nuclear fission, caused by limited interdisciplinary collaboration, and how this discovery resulted in improved knowledge of nuclear behavior and clarification and extension of the periodic table. The last chapter of this section shows how cosmochemistry grew from achievements in geochemistry, meteorite science, astrophysics, and nuclear physics to become an established field of science that is completely interdisciplinary in nature.

The last section comprises an introductory chapter and four other chapters focusing on solid-state chemistry and biotechnology. In chapter eleven it is argued that biotechnology is not a new area but existed in an earlier decade and was reflected in academic/industrial cooperation in such areas as hormone production, fermentation advances, and plant hormone studies that resulted in various agricultural herbicides. The next chapter covers the building of polymer science from organic chemistry and the physical chemistry of polymers. Chapter 13 is a case study of the work of Michael Polanyi, who used both chemistry and physics in his scientific work but also became a philosopher who reflected on the boundaries of science and the humanities. The last chapter is a reflection on various aspects of the history of the still emerging area of material science research covering such developments as the contributions of metallurgy and polymer science to the beginning of materials science and the triumph of function over structure that resulted in composite materials.

Overall this book will be a useful addition to the library of anyone interested in recent chemical trends. Many challenging ideas are presented, which are to be evaluated by the individual reader; and this is part of the strength of this book. It is hoped there will be additional studies in this emerging area of the history of chemistry. *Robert H. Goldsmith, Department of Chemistry, St. Mary's College of Maryland, St. Mary's City, MD 20686.*

Transforming Matter. A History of Chemistry from Alchemy to the Buckyball. Trevor H. Levere, Johns Hopkins University Press, Baltimore, MD, 2001, 215 pp, paper, $17.95.

This new history of chemistry is impressive in its coverage with only 199 pages of text (16 pages for notes and index)—much shorter than Brock's history published about ten years ago. It could be very useful for chemistry courses and for courses in history of all the sciences. Levere's book is short enough to be used and would enable better coverage of chemistry than usually happens in such survey courses. The writing is excellent with occasional insightful epistemological comments. For example, p. 51, "Words change their meaning as time passes."

Levere's history of chemistry is particularly strong from alchemy through Lavoisier. Alchemy and other developments preceding Lavoisier are presented in depth. Black, Hales, Cavendish, and Priestley are covered very well with an economy of words. Lavoisier's work is beautifully explained with detailed drawings of the gasometer and the ice calorimeter. With each drawing is an explanation of how experiments were carried out with the instrument. Such inserts with drawings and explanations are a feature of this book. The last chapter, "Where Now and What Next? New Frontiers", is only 18 pages but includes five of these presentations which give those topics (e.g., Buckyball and DNA) some depth. On p. 23 is a marvelous short summary of Renaissance metalworking with a drawing taken from Agricola.

After Lavoisier, the chapters are: 8. The Rise of Organic Chemistry; 9. Atomic Weights Revisited; 10 The Birth of the Teaching-Research Laboratory; 11. Atoms in Space; 12. Physical Chemistry; 13. The Nature of the Chemical Bond; and 14. New Frontiers.

Brock's "The Norton History of Chemistry" covers more areas of modern chemistry, but in only 199 pages of text Levere gives impressive insight into the development of chemistry. *Paul Haake, Wesleyan University, Middletown, CT 06459*

Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food Production. V. Smil, The MIT Press, Cambridge, MA, 2001, xvii + 338 pp. Hardcover, $34.95.

This comprehensive account of the discovery and commercialization of ammonia synthesis by Fritz Haber and Carl Bosch extends from historical uses of nitrogen in agriculture to the use of synthetic fertilizers and their impact on the environment. The author, Vaclav Smil, Distinguished Professor of Geography at the University of Manitoba, provides extensive notes and references for each chapter, along with graphs, charts, and appendixes to accompany the text.

The book begins by highlighting the important discoveries that elucidated the role of nitrogen in agriculture. Although the significance of nitrogen in agriculture was recognized by the late 1830s, the mechanism by which it was assimilated was unknown. Justus von Liebig pondered, "How and in what form does nature furnish nitrogen to vegetable albumen, and gluten, to fruits and seeds?" Jean-Baptiste Boussingault became the first researcher, in 1838, to recognize the ability of legumes to restore nitrogen to the soil. Subsequent work by Théophile Schloesing in 1877 demonstrated the ability of bacteria to fix nitrogen. The biospheric nitrogen cycle was complete when researchers led by Ulysse Gayon isolated pure cultures of bacteria capable of reducing nitrates.

Chapters Two and Three examine agricultural sources of nitrogen, both pre- and post-Industrial Revolution. Restoration of nitrogen to the soil initially involved crop rotation, planting of leguminous species, and application of manure. As the need for nitrogen fertilization increased, nitrogen sources expanded to include guano and sodium nitrate. Additional sources for sequestering nitrogen for agricultural use included the recovery of byproduct ammonia from coking, synthesis of cyanamide from calcium carbide and nitrogen, and generation of nitric oxide by passing an electric arc through air. All of these processes were highly energy intensive, however; and a more efficient, economical method for fixing nitrogen was required to meet the nutritional needs of the world's growing population.

The stage was set for Haber's synthesis of ammonia, a discovery that built upon work by numerous chemists such as Claude-Louis Berthollet, Wilhelm Ostwald, and Henry Louis Le Châtelier. Haber began his work on ammonia synthesis in response to a request from the Österreichische Chemische Werke in Vienna, initially focusing on the position of equilibrium of NH_3 around 1,000∞ C. Despite the low yield of ammonia obtained by passing N_2 and H_2 gases over iron and nickel catalysts, Haber's calculations predicted higher yields with decreasing temperature. Haber suspended his work on the synthesis of ammonia for three years, when a dispute with Hermann Walther Nernst prompted further experiments that yielded more ammonia at lower temperatures and higher pressures. Haber collaborated with Robert Le Rossignol in designing a high-temperature, high-pressure apparatus for ammonia synthesis that was patented in 1908 and is the basis for every ammonia plant in operation today. The high-pressure synthesis was completed when osmium was identified as the best catalyst for the process.

Bosch was instrumental in transforming Haber's bench-top process into a commercial success. Not only did Bosch recommend that BASF proceed with the commercialization of Haber's process, but he also set up a technical workshop to resolve the three key obstacles to full-scale implementation: a low-cost supply of hydrogen and nitrogen; the identification and production of effective and stable catalysts; and the construction of durable, high-pressure converters. Bosch designed a converter made up of two tubes that employed interior heating generated by the ignition of air forced into the hydrogen-rich mixture inside the converter. Along with his colleagues, he devised instruments for continuous monitoring of temperature, pressure, flow rates, and other parameters. Alwin Mittasch and coworkers used a systematic approach in identifying a catalyst to replace the rare and easily oxidized osmium employed by Haber. Extensive trials showed that a mixed catalyst, composed of magnetite (Fe_3O_4) and a catalyst promoter such as alumina or magnesium oxide, was effective and economical. Finally, an inexpensive source of hydrogen gas became available when a catalytic process for producing water gas was developed. Incredibly, only ten months passed between Haber's bench-top demonstration and the production of ammonia at BASF's experimental site. The first full-scale, commercial plant for ammonia synthesis began operation on September 9, 1913 at Oppau, Germany. The BASF ammonia synthesis was redirected to nitric acid production for munitions applications during World War I.

Following the end of the First World War, the Haber-Bosch process was adopted in other countries, including France, Great Britain, and the United States. Although the basic process remains essentially unchanged, a number of innovations have increased both size and efficiency of ammonia synthesis plants. In particular, reforming of natural gas provides a source of hydrogen while methane serves as the principal source of process energy. Plants based on natural gas account for approximately 80% of the world's ammonia production capacity. Ammonia synthesis capacity was further expanded by the introduction of single-train ammonia plants.

The final four chapters of the book are devoted to the use of synthetic fertilizers, their impact on the environment, and the nitrogen cycle. Increasing use of nitrogen fertilizers has driven the synthesis of ammonia since the end of World War II. Smil summarizes our dependence on the Haber-Bosch synthesis of ammonia as follows:

> For about 40% of humanity it now provides the very means of survival; only half as many people as are alive today could be supplied by prefertilizer agriculture with very basic, overwhelmingly vegetarian, diets; and prefertilizer farming could provide today's average diets to only about 40% of the existing population.

The author identifies the Haber-Bosch process as the single largest cause of human-driven intensification of the biospheric nitrogen cycle. The consequences of this global experiment are not yet fully appreciated, although environmental problems such as eutrophication of lakes and coastal waters caused by fertilizer runoff have already been recognized.

A Postscript chapter summarizes the lives of Bosch and Haber after the development of the ammonia process. Following World War I, Bosch became chair of the BASF board and then the first chairman of the I.G. Farben board of directors in 1926. He was instrumental in promoting the development and commercialization of coal hydrogenation to produce liquid fuels from lignites. Bosch received the Nobel Prize in 1932 for the synthesis of ammonia, the highlight of his professional career. He died on April 26, 1940, depressed and fearful following the Nazi takeover of Germany. Haber's life took a tragic turn during World War I when he began working on gas warfare despite the Hague Conventions ban on the use of gases during war. His wife, Clara, committed suicide in 1915; he married Charlotte Nathan in 1917; but, despite the arrival of two children in 1918 and 1920, suffered from a deepening postwar depression. He was recognized for the synthesis of ammonia from its elements with the 1918 Nobel Prize. In his Nobel address, Haber noted:

It may be that this solution is not the final one. Nitrogen bacteria teach us that Nature, with her sophisticated forms of the chemistry of living matter, still understands and utilizes methods which we do not as yet know how to imitate.

Haber died in 1934 during a brief visit to Switzerland.

This book provides an excellent framework for the significance of Haber and Bosch's development of the ammonia process. By including extensive information on agricultural practices, nitrogen assimilation, and nutritional needs of the global population, Smil goes well beyond a standard biography by placing this scientific discovery in context. The industrial synthesis of nitrogen from its elements has directly impacted the lives of the six billion people who inhabit the earth today. *Mary M. Kirchhoff, Green Chemistry Institute, American Chemical Society, 1155 Sixteenth Street N.W., Washington, DC 20036.*