The Chemistry Enterprise in 2015

Message from ACS President William F. Carroll, Jr.

Throughout 2005, members of the American Chemical Society have engaged in a project whose goal is to understand the vectors driving the chemistry enterprise today and how the enterprise will change during the next 10 years. This paper, The Chemistry Enterprise in 2015, is the outcome of that study and dialog.

We all agree that the chemistry enterprise is now, like many other disciplines, truly global. Global development affects the future composition, size, and shape of the chemistry enterprise in the United States, as well as the role of the working chemists in it. By analyzing our current situation and speculating about the Society's future, we can help our current and future members adapt to changes and take advantage of the opportunities they offer.

Last spring, we published a Situation Analysis based on interviews conducted with 30 senior researchers, teachers, business executives, government scientists, and policy makers. This final paper integrates much of that analysis with further information gleaned from national meeting presentations and discussions within committees, divisions, and local sections. It is divided into five sections: The Enterprise: Background; Economic Issues; Science and Technology; Education, Workforce, and Career; and Government Policy. Some common themes echoed through the comments of many of our interviewees, such as cost, multidisciplinarity, geography, demographics, and long- vs. short-term planning.

Whether you find yourself agreeing or disagreeing, please feel free to log comments on the paper at http://chemistry2015.blogspot.com/. I hope we can have a robust discussion of what I think is a unique look at our situation. I will monitor this blog and comment as needed.

In the meantime, I welcome your thoughts on this paper and the future of the enterprise. Please email chementerprise2015@acs.org with your comments.

Bill Carroll

The Chemistry Enterprise in 2015

William F. Carroll, Jr., Occidental Chemical Corp., ACS President 2005
Douglas J. Raber, GreenPoint Science

Acknowledgment

First, we would like to thank the members of the Senior Advisory Group who were interviewed extensively to comprise the first part of the project, the Situation Analysis. In addition, we thank the Governance Advisory Team who helped us with the strategy and peer review of the Situation Analysis. Thanks to those chemists who contributed specific predictions contained in the paper itself. Finally, thanks to all the ACS members and staff who participated in or facilitated dialog and debate; you provided the engine to bring the Enterprise Project to completion.

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Altogether, this document represents a synthesis of views from across the chemical enterprise, but *does not necessarily represent the views of ACS*. Occasional redundancies and potentially controversial statements have been retained in an effort to convey the breadth of the input from our colleagues.

The Chemistry Enterprise in 2015

Background—The Chemistry Enterprise[1]

The chemistry enterprise—including industry, universities, and government laboratories—plays a central role in our nation's well-being. It helps to maintain our intellectual vitality, and it lies at the core of the country's economy. Broadly, the industry extends beyond traditional chemicals and petrochemicals to include energy, biotechnology, and pharmaceuticals as well. The enterprise is dynamic, and change is both normal and essential. In the last century, chemical science moved from working with a small number of known chemicals, in quantities ranging from only a few grams to a few tons, to the current state where we have the capability to manipulate quantities as small as a single atom and as large as the entire biosphere.

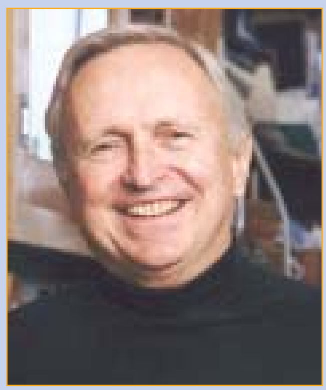
Chemistry—Disciplinary Structure

The nature of our discipline is changing. Many of the longstanding fundamental questions in chemistry have been addressed and are well understood. Chemists now can work on applications that previously were beyond our capabilities and might not have even been considered chemistry as little as a decade ago. Today's studies are leading to new fundamental discoveries and an expansion of the boundaries of molecular science. This in turn leads to a bewildering increase in scope and the resulting need to comprehend ever more information from increasingly diverse disciplines.

The notion of chemistry as a central science is widespread, and scientists and engineers in many disciplines now work at the molecular level. This centrality leads biology, geology, astronomy, and other disciplines to add chemistry instruction to their basic courses, and in some cases to devise chemistry courses that will be taught "their way," thereby clouding the mission of chemistry departments. While chemistry education in the United States is strong, it is increasingly taught as a service for premed students by "Chemistry and Biochemistry" departments. Some have suggested that chemistry is just a tool for use in their canonical disciplines or that chemistry as a distinct discipline will disappear in the coming years. All this leads to an important question: In the 21st century, what is chemistry? Or, for that matter, what is not?

The overlap between chemistry and biology has increased dramatically, and the boundaries between chemistry and materials science have dissolved. The inherent multidisciplinary aspects of these areas, together with new technologies such as high-throughput screening, are generating advances at an accelerating pace, and the needed expertise often requires multifield collaborative work. These trends may produce an "identity crisis" for the chemists working across boundaries. Who will be their peer group, and who will evaluate their work?

- From announced capacity expansions to development of new markets, the chemistry enterprise will show strong growth as we move toward 2015. Inevitably, this growth will be accompanied by change. The field—both intellectually and economically—will be different from the way we know it today, just as it is dif-



Ronald Breslow,
University Professor, Columbia University

> "The biggest difference in 2015 will be that chemistry will no longer be limited to only the properties of pure substances. Instead it will be refocused largely onto the properties of self-organized multimolecular systems that have interesting and useful properties."

[1]The main text in this document describes the chemistry enterprise in 2005 and also indicates some of drivers for change and the initial direction of the changes.
● Primary bullets are characterized by "will be" and describe the situation to be expected in 2015.
■ Second-level bullets are characterized by "must be"—actions to be undertaken by the chemistry community if the situation in 2015 is to be different from

ferent today from what we knew in previous decades. We must be willing to identify opportunities as we adapt to new challenges.

- The most dramatic advances will occur at the boundaries—where the frontiers of knowledge always are found—but there will be many opportunities to solidify and strengthen the core. Exciting questions remain in analytical methods, catalysis, small-molecule synthesis, and computational chemistry, to name only a few. The physical sciences stand on their own as they simultaneously provide the foundation for advances in the biological sciences. The chemistry enterprise will remain an intellectually vibrant area that generates new ideas, fundamental science, and products.
- Multidisciplinary research—collaboration by scientists in different disciplines who bring a depth of expertise and an interest in the periphery—will be increasingly common. Ultimately it may be difficult to identify a project's disciplinary origin, and the question will seem irrelevant. Strength in core chemistry will remain the essential platform for advances in all of molecular science.
  - The success of the chemistry enterprise in the framework of multidisciplinarity will require that our scientists be deeply trained in the core of chemistry but also be able to communicate and collaborate with those in related disciplines.

Ironically, by expanding at the borders, chemistry is returning to its roots. As in the original meaning of organic chemistry, the field has long been driven by a desire to understand the underlying science of life. Advances in molecular manipulation, in combination with the power of modern computing, are allowing us to understand the individual chemical reactions and interactions of life processes.

Ge Li, *Chairman and CEO, WuXi PharmaTechs.*

> The biggest difference in 2015 will be the rising of China and India. As a result, the global economy and the geopolitical landscape will bear little resemblance to what we know today. Free flow of capital, information, and people will create opportunities for the most efficiently run and cost-effective businesses.

ECONOMIC ISSUES

Globalization

The history of the U.S. chemical industry has been shaped by global events. For example, the organic chemical industry effectively began as a result of the German embargo in World War I. In a similar way, much of the evolution of the U.S. enterprise in this century will be driven by global rather than domestic influences.

Rapid economic development, along with an increase in research, is taking place overseas, particularly in Asia. This economic growth is accompanied by foreign industrial investment and is facilitated by the tools of modern technology and electronic communication. Many companies traditionally thought of as American or European have built capacity in developing countries to serve both developing and traditional markets—a phenomenon called globalization.

Most chemical professionals are employed in the sector of the industry called specialty chemicals. Specialties are materials that carry unique properties (typically lower volume and higher price), are differentiated by quality, and are brandable. Fewer professionals are employed in the commodity sector, which involves large-volume, lower-cost materials that are neither differentiated nor brandable. Knowledge also can be either a commodity or a specialty product. Most chemists are used to thinking that their creative work is a specialty; however, formula-type research, which involves more limited creativity and produces little intellectual property, can be viewed as a commodity that typically commands a lower price.

In recent years, an increase in new, lower-cost production capacity outside the United States has driven down the price of some specialty products and caused them to conform to commodity economics. Such *commoditization* has occurred to a significant extent in the specialty chemical market, although domestic producers have worked hard to differentiate products in terms of properties and service.

The development of manufacturing in Asian economies coincides with a long-term de-emphasis of manufacturing in the United States. Developing countries are producing specialty products, including chemicals, at competitive volume and lower cost, and they are exporting these products to developed countries at lower prices. Consequently, many specialty products are driven to commodity economics, causing reduced profitability for manufacturers in developed countries.

Chemical production capacity will expand in the coming years, but most will be in large-population, developing markets. Approximately 95% of the world's population, and thus 95% of the potential market for products of the chemical industry, lies outside the United States. Locating manufacturing facilities close to markets reduces shipping costs. Development, including that of the chemical industry, fuels increases in standard of living. Asia's

Samuel W. Bodman,
Secretary of Energy

"In 2015, the biggest difference will be an economy that has been transformed by innovation and built upon new and advanced technology. Many of those innovations—in energy, sustainability, and the physical sciences—will have been made possible by the Department of Energy, the single largest federal government supporter of the basic research that is so vital to the nation's future."

total gross domestic product (GDP) will equal that of the United States within 10 years, although per capita GDP will still lag significantly.

Globalization has led some companies to utilize contract organizations in developing countries for research or other technical functions—a process commonly called *offshoring*. Large companies are also building research laboratories overseas, integrated within their global enterprise. Despite concern, the true current impact of offshoring on the number and quality of U.S. jobs is unknown.

Regulation and government investment. Industry is concerned about the uncertainties and costs of environmental and financial regulation (e.g., the Sarbanes-Oxley Act) as well as benefits (e.g., health insurance). Government incentives that reduce effective cost make overseas investment more attractive. This attraction is offset by the uncertainty in stability, security, and infrastructure in those countries, and intellectual property protection continues to be a concern.

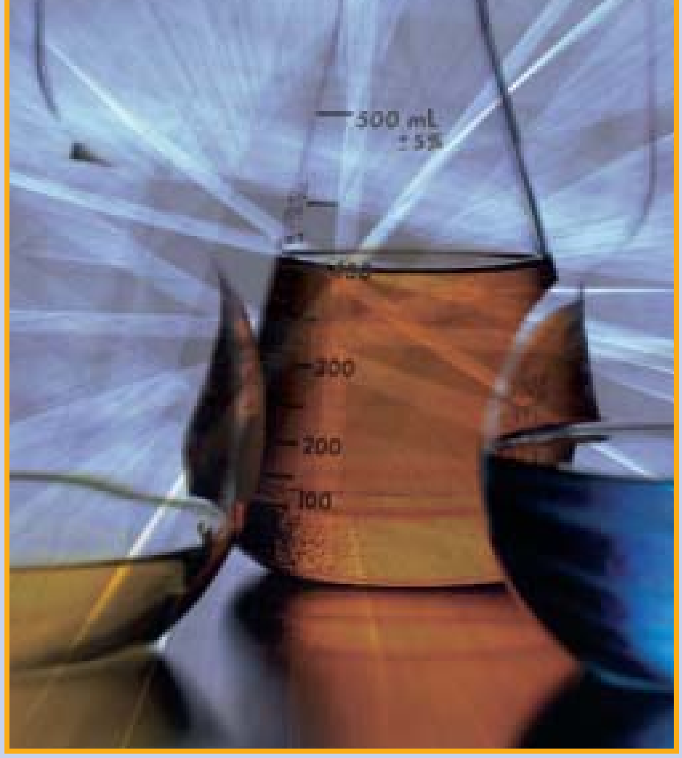
Engineering, labor, and energy costs. Production has begun to shift to countries such as China, where newer, more efficient plants reflect lower engineering and labor costs. Energy costs may also be lower in some developing countries, providing an incentive for U.S. industry to build new facilities there.

Intellectual depth and economic growth. In recent decades, the world has sent its students to study in the United States. Many of those foreign-born scientists made their careers here and facilitated technological and economic growth. The technological edge accrues to their home countries when those students return or are educated there in the first place.

- By 2015, barring gross societal upheaval or environmental disaster in China and India, global chemistry enterprises will have balanced their portfolios in manufacturing, sales, marketing, and technology to serve those emerging markets. China will be a balanced producer or net exporter of commodities and will also be a strong international competitor in specialty manufacture and technology, including biotechnology.
- A greater fraction of chemical manufacturing will take place in Asia, but investment returns from global enterprise will also flow back to the United States. As the standard of living increases in Asia, labor costs will rise accordingly, and salaries will rise most rapidly for the best and the brightest scientists. This will decrease, but not eliminate, the pressure for U.S. companies to offshore their activities.
- The 2004 U.S. trade deficit of more than $600 billion cannot continue indefinitely without drastic currency impacts, and exporting to the United States will not remain a primary economic strategy for other countries. China and the emerging economies will find it necessary to stimulate growth within their own borders or find other export markets. At the same time, China will have many global companies by 2015, and significant chemical capacity in the United States will be Chinese-owned.
- The traditional flow of foreign students to U.S. universities and the U.S. workforce will be greatly attenuated by 2015. For example, Chinese companies (which now contract out much of their research or employ joint ventures with Western companies) will develop greater in-house capability, and their universities will compete for world-class students. Chinese students will continue to travel abroad for graduate school or postdoctoral work, but the numbers will decrease as opportunities at home expand.
- The globalization trend will also extend to universities, which will leverage their brands worldwide either in bricks-and-mortar facilities or distance learning.
- By 2015, a majority of Chinese doctoral graduates of U.S. universities will be returning to China within five years of graduation.

Energy and Raw Materials

Energy cost translates directly to economic competitiveness, jobs, and prosperity. Escalating energy prices have been a major driver for change in the United States over the period 2000–2005. Increased demand for traditional resources—especially petroleum and natural gas—will accompany economic growth in developing countries, and that growth will not be as energy efficient as growth in developed countries. The resulting higher costs for fossil fuels will cascade through the product



chain and inhibit economic development.

Energy costs have begun to cause a shift in the location of investment, especially for manufacture of commodities. However, increased raw material costs appear unlikely to limit worldwide growth in the chemical industry. Chemical products, including commodity chemicals, have greater value as materials than the value of the fuel from which they are derived. Moreover, the costs of alternative products (to chemicals and plastics) are also increased by higher energy prices.

Natural gas. The U.S. chemical industry is heavily dependent on natural gas as a raw material and an energy source, and the industry's global competitiveness has been damaged by recent increases in domestic gas prices. Natural gas supplies in North America are limited in the absence of new drilling, and shortfalls of supply—which must then be eased by imports—are projected by the U.S. Department of Energy. Currently, increased costs of natural gas and petroleum are being passed on to customers, but the sustainability of North American-based commodity-chemical production has been questioned.

- A U.S. energy policy that facilitates the development of new supplies of natural gas will place the U.S. chemical industry in a better competitive position.
- Chemical commodities most directly dependent upon natural gas as both an energy source and a raw material will grow predominantly in areas that are either close to new markets (Asia) or close to inexpensive raw material supply (the Middle East).
- The Middle East will become a large supplier of liquefied natural gas and gas-derived liquid fuels, which can be shipped more easily.

Petroleum. While the U.S. chemical industry is largely powered by natural gas, European industry relies more on naphtha, a product of petroleum refining. The price of these two commodities on a BTU basis is not always equal, and competitive feedstock advantage fluctuates. Supply dynamics are not equivalent either: petroleum is more easily transportable than gas.

- Oil prices in 2015 are unlikely to return to the comfortably low prices of the 20th century. If world oil production peaks prior to 2010 and is accompanied by large growth in global demand, substantial further price increases will result. High oil prices will encourage more exploration, discovery, enhanced recovery, and creative use of coal and natural gas.
- China's economy and energy use will nearly double by 2015, and its resulting need for gasoline alone will maintain pressure on the global petroleum supply—regardless of measures taken elsewhere.
- Most new ethylene crackers will be built in the Middle East. Ethylene derivatives (such as ethylene oxide, ethylene glycol, and polyethylene) will also be produced there and will be imported by the United States.

Coal. The majority of U.S. electric power is derived from coal (which is more plentiful in the United States than natural gas and petroleum). Coal is also an abundant resource in China—and is therefore an important factor in China's economic development.

- Many governments, particularly those that are less dependent on coal, will have CO_2 emission policies in place in 2015. In the United States, Europe, and China, clean coal technologies (to

Chad Holliday,
Chairman and CEO, DuPont

"The biggest difference in 2015 will be our emphasis on using nature's sustainable processes to create products that address global needs in a safe manner. Chief among those needs are food, materials, health care, and energy. Biotechnology is a powerful tool at our disposal in this effort, and it will enable us to keep pace with exponentially growing human and societal needs."

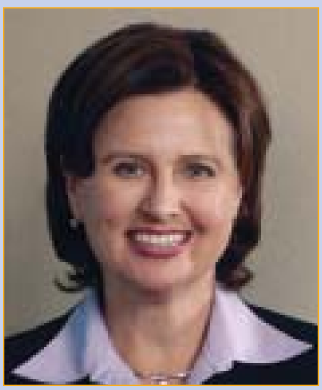
some extent in combination with CO_2 sequestration) will find increased use—for both energy and raw material production.

Nuclear energy. In 2005, nuclear power plants accounted for 20% of U.S. electricity generation, but no new plants have come on line in the past 15 years. Technology expertise in the United States is decreasing as the nuclear scientists and engineers trained during the Cold War reach retirement age.

- Driven by a number of factors, including newer technology and the price of fossil fuels, at least one new nuclear power facility will be built in the United States. By 2015, China will have built 30 new reactors, making nuclear a significant contributor to its electrical energy generation capacity.
  - Enormous challenges exist in both the public policy and technology arenas. Chemists and chemical engineers will need to participate in resolving a variety of issues for the nuclear fuel cycle, including spent fuel reprocessing and disposal of nuclear waste. A new generation of nuclear chemists and engineers will need to be trained in these areas.

Renewable resources. New processes based on biological or renewable resources are currently being commercialized, and relatively abundant clean water may provide the United States with a competitive advantage over developing areas.

- Niche advances will be made in agriculture-based specialty materials, but a fundamental shift to bio-based products in the chemistry economy will be precluded by the high energy life cycle costs of cultivation to use as fuel or commodity chemicals.
- Many chemical processes can take advantage of enzyme-catalyzed reactions, some of which will be adapted to different temperatures, solvents, and pHs. Whole organisms will be adapted to carrying out much more complex reactions than have been possible with single enzymes.



Stephanie Burns,
President, CEO, Dow Corning Corp.

"In 2015, we will innovate more specifically and rapidly to benefit less-developed countries and regions. Our customers will demand new technologies that address the diversity and immediacy of ecologically and socially-driven global needs. As a result, we will find new strengths, scientific and social, for chemistry as we collaborate with other disciplines. Communicating about benefits to society will be an ever-present challenge."

Solar energy. High manufacturing costs make solar cells noncompetitive for current large-scale energy production.

- Fundamental research will produce significant advances in the efficiency of photoelectric generation of power by 2015, but the commercial impacts in that time frame will be incremental rather than transformational.

Hydrogen. The so-called hydrogen economy—in which hydrogen serves as a storage medium for energy produced by other technologies—is attractive, but it faces huge efficiency and infrastructure cost challenges.

- The hydrogen economy is ultimately predicated on advances in catalysis that would enable efficient direct cracking of water. If the basic science is accomplished, the years after 2015 will be spent engineering systems to produce large volumes of hydrogen cost-effectively. At the same time, challenges of infrastructure will keep hydrogen itself from becoming the fuel of choice for automobiles or other large volume applications.
- Hydrogen-derived liquid fuels and raw materials such as methanol have a greater chance of ultimate commercialization—particularly if the synthesis includes the use of CO_2 as a reagent. But these fuels will not be developed by 2015, and the problem will remain an outstanding opportunity for the development of high-throughput catalysts that mimic photosynthesis. In the interim, nuclear energy may provide the best means of producing hydrogen from water.

A strong national consensus on the need for an energy-independent future does not yet exist, but it is close. Development of diverse technologies for energy production in the United States will work in conjunction with our abundant natural resources to provide a solid basis for a strong and healthy chemical industry in future years. Chemistry is pivotal to the commercialization of all those technologies, including the aforementioned catalysts, photovoltaics, lightweight and high-capacity batteries, LEDs to replace incandescent lighting, and new high-strength materials for construction of windmills.

PRODUCT PORTFOLIO

The product mix of materials produced in the United States is changing. Few commodity chemicals plants have been built in this country during the past 15 years (although there have been incremental expansions). Economic forces favor more geographically diverse investment and are creating drivers for change in the U.S. industry's product portfolio.

Company portfolio balance. Most petroleum companies are restructuring to focus on their core energy-related businesses, and some are spinning out their petrochemical subsidiaries. Global companies that are primarily chemical companies (rather than petrochemical companies) are balancing commodity and specialty chemicals as they diversify geographically. However, these specialty products, unless backed by proprietary product or service technology, are vulnerable to commoditization.

Pharmaceuticals. Developments in biomedical science and health care—together with their associated costs—are major drivers of change. Forces that are not strictly scientific—research productivity, profitability, and liability litigation—have affected the work of chemists in many parts of the enterprise. The impact is particularly strong in the pharmaceutical industry, generating pressures to reduce prices and decrease consumer risk from side effects of pharmaceuticals. Accommodating variation in individual responses to drug benefits and risks will become increasingly important.

- New R&D tools that have proved extremely useful in the pharmaceutical industry (e.g., high-throughput screening, combinatorial methods, and genetic manipulations) have not yet been successfully applied to new product development in the more traditional areas of chemistry, but they are likely to be used more widely by 2015.

Some traditional activity in the pharmaceutical industry—for example, making molecules—can now be carried out less expensively offshore (although that work is limited currently almost entirely to formula-based synthesis, which is far from the strategic research core).

- Pharmaceutical companies will continue to grow, acquire, consolidate, restructure, and become more global, but profitability will depend heavily on local government policies on risks, benefits, and liability.
- If factors such as low-price drug re-importation or reduction in government-provided benefits cause the U.S. drug market to become more price competitive, cost-cutting will expand markedly. This could accelerate the pace at which core "knowledge-based" research is transferred to lower-cost operations.
- If pharmaceutical companies are able to help stabilize or reduce the rapidly rising cost of health care (now 15% of the U.S. GDP), a new wave of growth will occur in this sector.

Business development and new technology. For reasons of restricted capital availability, startup companies in nonbiological chemistry-related areas have been less likely to become major factors for economic growth in the near term. Nevertheless, new opportunities are being created at the interfaces of chemistry with biology, physics, materials science and computer science. While biology has not yet delivered fully on its promise to open new areas for development, huge opportunities exist for continued growth.

- U.S. industry will become increasingly specialty-oriented. By 2015, the landscape for chemical technology in the United States will be more entrepreneurial and developmental, as small companies innovate in new technological areas or market lower-volume existing specialty chemicals. The United States will be one of the most expensive places in the world to manufacture, and products made here will need to provide sufficient added value to support these costs.
- Biotechnology must gain worldwide public acceptance as a safe undertaking (rather than one to be feared) in order to be a major platform for growth.

Facilities. Changes in the domestic product mix of commodities and specialties are creating the need for reevaluation of chemical

Harry B. Gray,
California Institute of Technology

> "By 2015, chemistry will be the hottest topic on the world stage! Why? Because chemists will be producing environmentally friendly materials and superior life-saving medicines. What is more, chemistry and energy will be front and center, as clean fuels from solar-driven water-splitting reactions begin to replace fossil fuels."

manufacturing facilities. However, new technology for old products rarely achieves the "shutdown" economics that would allow an old plant and process to be abandoned in favor of a new plant and process.

- Many existing facilities will be operated as marginal capacity or retooled for process enhancement and improvement in safety, security, and environmental performance. Few will be closed outright.
- Expansion of commodity chemical facilities in the United States will be rare, as will construction of refineries, but the industry will still be of global scale—neither disappearing nor growing markedly.

MANUFACTURING, PROCESSING, AND BIOPROCESSING

Movement away from petroleum, gas, and coal as raw materials is possible, but progress will be slow and economically challenging. As the need for cost reduction becomes more acute in the chemical industry, so does the need for improved manufacturing efficiency and waste reduction. The greatest opportunities for cost reduction lie in early stages of development.

Information technology. Computing advances have enabled major changes in the gathering, control, and use of data.

- Automated process control—using instrumentation previously found only in research laboratories—will substantially improve both quality and efficiency in chemical and pharmaceutical manufacturing.

Process intensification and scaleup. Safety and security concerns create pressure to build smaller plants that retain the high efficiencies of larger facilities. Significant research efforts will be directed toward overcoming the advantages traditionally associated with economies of scale.

- Research in microfluidics will provide new approaches to efficient chemical manufacturing. By 2015, a modest but significant fraction of specialized chemicals and materials will be produced using systems of microreactors operating in parallel.
- As industry seeks to exploit new sources of raw materials and manufacture products in facilities with smaller, more environmentally-friendly footprints, biotechnology processes can be optimized at very low scale and will comprise a greater portion of the enterprise that manufactures highly-specialized chemicals.

SUSTAINABILITY

The chemistry enterprise generates an array of products that are essential to our way of life, thereby making the industry itself an essential part of our world. Industry is under increasing pressure to provide important benefits without diminishing an increasingly limited supply of resources, harming the human population, or damaging the broader environment.

- By 2015, the chemistry enterprise will be judged under a new paradigm of sustainability. Sustainable operations will become both economically and ethically essential.
- Global treaties are in place for phasing out the production and use of persistent organic pollutants, but they will become effective only through aggressive government policies, especially in developing countries.

Green chemistry. The tools and principles of Green Chemistry and Engineering address efficiency, safety, and environmental protection. These principles will be critical, especially in developing-

Nancy B. Jackson, *Deputy Director, Int'l Security Center, Sandia National Laboratories*

"The biggest difference in 2015 will be in the security threats to our nation. No longer will nuclear weapons be a significant part of the National Laboratory portfolio. Instead, threats will arise from global poverty, energy shortages, environmental degradation, and failed states. To remain relevant, the Laboratories must address these complex challenges."

Morton Z. Hoffman,
Professor Emeritus,
Boston University

> In 2015, the biggest difference will be the ubiquity of exceedingly rapid personal computers that have virtually unlimited storage capacity; this development will completely change the nature of communications and social interactions. In the realm of education, the very different learning experiences students will bring to their college experience will make the challenges of teaching even greater than they are now

country operations.

- In conjunction with regulatory compliance, the tools of Green Chemistry will be used with increasing regularity in the chemistry enterprise, either explicitly or tacitly.
- The greatest leverage for Green Chemistry will be early in process design and especially in high waste-to-product industries such as pharmaceuticals.

Energy. Most issues associated with sustainability ultimately devolve to questions of energy. Projected increases in atmospheric carbon dioxide—combined with projections of global energy needs and available energy supply—are causing increasing concern. The science and technology needed to address these issues in the near term—ranging from carbon sequestration to solar and nuclear energy—currently exist or are being developed. Nevertheless, huge research challenges remain.

- Intensive R&D efforts will develop approaches that will allow the world's energy consumption (and energy supply) to grow without environmental harm as the worldwide standard of living improves. It is unlikely, however, that the new approaches will be implemented by 2015.
- Fossil fuel use by the chemical industry is dwarfed by its use for energy and transportation in the United States. Inexpensive sources of energy derived from proprietary, licensable, and exportable technology will provide the single best contribution chemistry can make, especially in the years following 2015.
- Industry will not be able to eliminate waste output and nonrenewable energy impact by 2015. However, economic factors (resources, waste, and regulation) will force continuous improvements in process efficiency that will reduce environmental impact.
- Experience gained in anticipating and addressing public concern about the "unknowns" of chemistry and technology will foster greater diligence in generating hazard and risk information and in establishing safety procedures in new disciplines.
  - The chemistry enterprise must avoid some of the mistakes of the past: For example, industry will need to stay ahead of the curve on risk analysis and mitigation, especially for exposure of the population and the environment to products of nanotechnology, biotechnology, and new materials. Public policy challenges, including sustainability and green chemistry, provide an opportunity for the American Chemical Society to educate the public and the authorities.

SCIENCE AND TECHNOLOGY

Research and Innovation

Analogous to the old economic basics of land, labor, and capital are the three basic needs for research: equipment, scientists, and funding. In the days after Sputnik, all three of these became plentiful. Some might say "too plentiful" as the days of plenty became a painful oversupply of scientists in the early 1970s.

Today those three basic needs are at risk for the physical sciences. The public often seems uninterested in science that is not directly tied to medical research. Science for its own sake does not win the annual federal funding battle. University scientists are finding fewer sponsors for traditional research, and pressure on existing granting institutions is increasing.

The traditional paradigm of single-investigator, intellectually-driven research is under pressure as well. The grand challenges of today—energy, climate, health care, materials, and the environment, among others—will only be solved by strong collaborations among scientists and engineers in universities, industry, and government laboratories.

At the same time, breakthroughs in the grand challenges are at risk in an environment without single-investigator, long-term research in new chemistry. New single-discipline chemical research in single-atom/molecule visualization, computational methods, and telecommunications also will be critical.

- Moore's Law will still be alive by 2015. Enhanced computing power and speed, together with more complete databases and more powerful searching techniques will speed development—from basic research and literature analysis through design, construction, and operation of manufacturing facilities.
- The issue of whether scientific information should be available to users free of charge— and if so, who should pay for infrastructure support—will be resolved by 2015. New technical searching and data-analysis approaches will help researchers efficiently isolate their targets from the vast sea of information on the Internet.

Industry. Is the traditional chemical industry mature? Certainly, many of the old problems—such as development of polymers and process engineering for commodities—have been solved. Yet Dow Chemical generates half of its revenue from Performance Products; DuPont expects to double revenues in five years, largely driven by new product growth.

The chemical industry doesn't fit Wall Street's ideal of fast growth and large returns. Major innovation takes time—years or decades—but our economic system keeps score by months, quarters, or at most, a few years. Shorter horizons and the need for cost reduction have affected job security and facilitated global outsourcing. Lengthy government approval processes and limited-term patent protection squeeze pharmaceuticals' profitable proprietary lifespan.

The aforementioned grand challenges are generally not being undertaken by industry, where short-term commercialization opportunities are not obvious. Large, recognizable companies have decreased their strategic, long-term research because the payback in productivity and profitability is not obvious.

For large companies, developing global presence and capability takes precedence. On the other hand, statistics indicate that approximately half the chemistry graduates in 2005 who enter industry go to small (<500 employees) companies.

- Innovation in industrial chemistry will increasingly take place in smaller, more focused, riskier ventures. Small companies, universities, National Laboratories, and consortia will develop and commercialize products on their own, or license or transfer intellectual property to larger companies.

The National Laboratories. The Department of Energy supports a large portion of the federal government research in the physical sciences through its missions in national security, energy, and the environment; however, the multi-program National Laboratories face an assortment of challenges. All are wrestling with mission, fluctuating budgets, aging infrastructure, and changing compliance requirements. Securing adequate resources is a significant and continuing problem.

The gradual shift away from long-term projects is analogous to that seen in industry. While the National Nuclear Security Administration laboratories have the largest operating budgets, there is no clear understanding or general agreement of what the appropriate level of responsibilities of these institutions should be for either the nation's energy and environmental needs or the broader spectrum of national security issues. The same applies to the Office of Science laboratories.

Today, there is spirited competition for resources in all business sectors. Questions continue about the wisdom of privatization or whether a university should independently manage a National Laboratory. This may signal a shift to laboratories that are more "corporate" and less "academic."

There are cultural and operational barriers to effective, long-term collaborations between laboratories and universities and/or industry. Industry and the National Laboratories tend to operate in teams; universities are rooted in the single-investigator model, although this is changing.

Simon Campbell,
President, Royal Society of Chemistry

> "The biggest difference in 2015 will be that governments, funding bodies, and the public all will have realized that the chemical sciences are absolutely essential for meeting the economic, environmental, scientific, and human challenges of the 21st century."

- Integrated collaborations are needed to solve grand-challenge scientific problems, and the National Laboratories are well suited to the task. As energy policy gels, and conflicting missions are resolved, the National Laboratory system—at some scale—will provide the most powerful asset for large research programs with a long time line and broad scope (in such areas as energy, climate, and water) that are unlikely to develop in universities or industry.

Universities. In the past, funding organizations have worked to maintain a portfolio of investments in diverse institutions. Research requires a critical mass of equipment and people, and most research must be augmented by interactions with other groups, programs, and teams.

- Peer review (both internal and external) and foundation funding of interdisciplinary and collaborative projects will operate more smoothly as this mode of working becomes increasingly common.

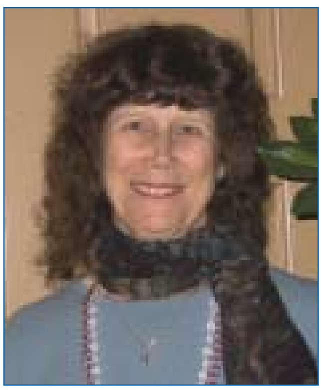
A gap is developing between the best private and public universities. State funding for public universities is decreasing, and federal and private funds are becoming increasingly important (e.g., in the fellowship opportunities available and startup packages offered to new faculty).

- Limited funding and increasing costs of research infrastructure will generate changes in the university research system. Future funding may move toward a small number of universities that already have the greatest financial and research resources. This could result in the consolidation of effort in the elite universities, a decrease in the number of research universities, or consortia sharing expensive infrastructure.

- With the increasing importance of undergraduate research, four-year colleges, especially those that are not highly ranked or endowed, will feel funding pressure most acutely during this decade. Consolidation, restructuring, or closure will follow for a significant number of these schools.
- Competition for a smaller number of graduate students (along with financial pressures) will force institutions to find the best matches with their customer base, by either model. Some universities will be able to expand graduate education in response to these pressures, while others will contract or rethink institutional goals entirely.

The Bayh-Dole Act—which enabled commercialization of federally-funded research—has had a huge influence on university research, and the term "applied" no longer has a distasteful meaning, especially in biomedical areas. Innovation leading to startup businesses in university research programs has generated new ethical concerns by blurring the boundaries of what students and postdocs should do, thereby generating potential for conflict of interest.

- By 2015, the ethical boundaries will be clear and comfortable for researchers. Safeguards will exist to minimize conflict between educational and entrepreneurial goals, protect universities, and ensure continued public confidence and support. Business and education will both prosper as a result.



Barbara Pressey Sitzman, *Chatsworth High School, Los Angeles*

"The biggest difference in 2015 will be an increased demand for high school science teachers with a deep understanding of chemical concepts. As our knowledge base increases, effective teachers will recognize that decision-making will become increasingly complex for our citizens. Teachers will need to be better prepared to help their students evaluate scientific information."

The increasing emphasis on shorter-term research is not restricted to industry. Research in academic laboratories often is accompanied by the short-term financial imperatives of possible startup companies or the need to show a constant stream of results to feed the funding process. Even some federal funding—particularly in the post-9/11 world—demands output that can be rapidly moved into the production phase. The terrorist attacks of 2001 created intense pressure on federal agencies to develop responses in the short term.

- By 2015, barring new emergencies, the research portfolio will be rebalanced to encompass long-term research as well. This includes research for which marketable technology will not be developed for some years as well as individual research projects that may require more than just a three-year period to achieve significant results.

Startup companies. Small startups provide a commercial outlet for the innovation process in universities, and some have had remarkable successes, especially in the biomedical area. The innovation process needs products and production, not just ideas, and universities are a more likely venue for the latter than for the former.

All are familiar with the "valley of death"—the development gap between proof of concept and capital-worthy venture. The startup academic spinout model, which is still in its early development in 2005, will continue to evolve.

- When the product is largely knowledge rather than a manufactured article, the entire startup process may remain very close to the university. But more complex products will require an intermediate stage (e.g., through an R&D incubator or pilot production) to facilitate the transition to commercialization.
- Universities (and their intellectual property licensing groups) will become more astute about licensing decisions and will learn to work more in collaboration with potential industry licensees in order to optimize returns from their discoveries.

Research centers and industry-university collaboration. With a shorter-range internal focus, industrial R&D has less emphasis on the centralized model for long-term fundamental research. Instead, industry has been seeking university alliances (both here and abroad) and technology from early-stage new companies in efforts to reduce long-term employment commitments while still potentially developing new intellectual property.

For universities, industry funding fills gaps and supports graduate students. The costs and complexities of modern research have increasingly led to collaborative work, the formation of research teams, and ultimately, multidisciplinary or multisector research centers. Commercialization of academic innovation by industry completes the cycle of economic flow and helps justify (to decision-makers and the public) federal funding for the science. To some extent, domestic universities provide low-cost alternatives to offshore research relocation.

- Funding will remain the major challenge for research and development. The need for research centers—with their capability of providing shared equipment and instrumentation—will continue to grow. Chemistry is unlikely to abandon the single-investigator model, but multidisciplinarity and the expense of research will drive many individual investigators toward collaborative work at centers where they can obtain access to expensive-yet-essential infrastructure.
- It will be critical in the next 10 years to demonstrate the linkage between research funding, commercial products, and overall economic activity. The linkage to an essential industry that has strong geographic and infrastructure advantages will help maintain strong investment in U.S.-based research. As with manufacturing, world-class research programs will be found with increasing frequency in developing countries, and those institutions will compete for industrial research investment.

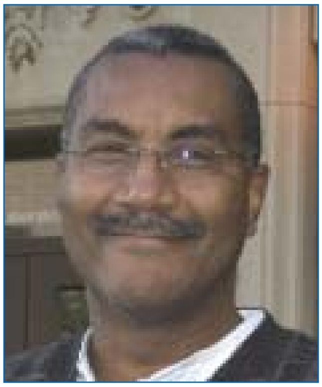
EDUCATION, WORKFORCE, AND CAREER

Education and Institutional Structure

The United States has a strong university system, and U.S. graduate education in science is widely recognized as the best in the world—for now. Other nations are catching up at the graduate level, and our K–12 education has major weaknesses. Many science teachers are inadequately prepared in science, while those who are well-prepared often face bureaucratic and financial impediments to entering the teaching profession. At the same time, students who study chemistry at the college level are seeking employment in a changing environment. Chemistry students are moving on to academic and industrial positions in nonchemistry fields, a phenomenon driven by the centrality of chemistry to

Marye Anne Fox, *Chancellor, University of California, San Diego.*

"The biggest difference in 2015 will be that top students will aim to become global citizens. They will do so by seeking to understand world cultures, promulgate American values, and exhibit market-driven behavior. They will succeed by acquiring technical expertise, improved communication styles, familiarity with working in cross-disciplinary teams, and entrepreneurial approaches to problem solving and risk taking."



Joe Francisco,
Proessor,
Purdue University

"In 2015, the biggest difference will be that the chemistry enterprise will engage the full intellectual talent and assets of our culturally diverse American population. The increasing needs of research universities to fill graduate positions as foreign enrollments decline—together with industry's demand for more homegrown talent—will lead to a strong pool of American students."

many areas of research.

Departments. Chemistry and chemical engineering departments are heavily influenced by the field of biology and research funding in the biomedical area. Joint appointments across departments are more common, and revisions of traditional curricula are sometimes accompanied by the renaming of departments.

Relatively expensive departments such as chemistry compete with other departments for scarce resources. Cost pressure causes a shift of lower-level teaching loads to adjunct professors and instructors. Similar pressures have led to the elimination of some university chemistry departments in the United Kingdom, although those departments do not have the responsibility for teaching chemistry to non-majors as do departments in the United States.

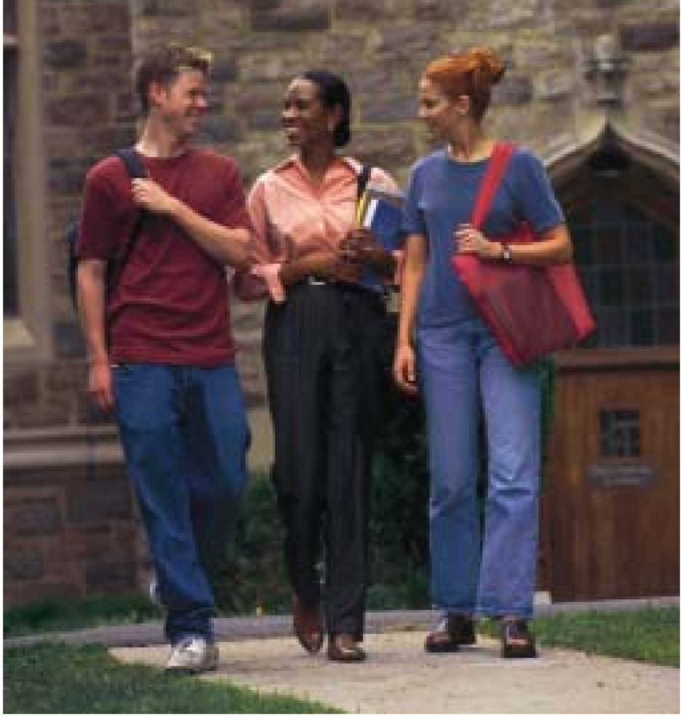
- While service teaching will still be important, scarcity of personnel and equipment will result in fewer laboratory classes and fewer available graduate teaching assistants. Some state systems will consider centralizing chemistry activities at specific sites, with the elimination of chemistry programs at other institutions.
- The distribution and focus of expertise among chemistry faculty will vary with individual institutions, particularly as it becomes increasingly expensive to provide the scientific infrastructure needed for each individual subdiscipline.

Students. In recent years, fewer foreign students have come to graduate school in the United States due to immigration and visa policies here and developing educational systems elsewhere. Thus, continued dependence on foreign students (with their strong backgrounds in math and science) to fill graduate positions is becoming a matter of concern. There is a strong sense that we will need to increase the numbers of American chemistry students, especially those from underrepresented groups. Our system also will need to respond to changing educational outcomes, as students more frequently enter nontraditional chemistry careers outside academics and large companies.

- By 2015, we will have established a balance between security and openness, but the traditional flow of foreign students to U.S. universities and the U.S. workforce will be greatly attenuated. While educational experience in the United States or Europe will still be desirable, Asian university systems will mature and compete for the best students, thereby reducing the need for foreign study. Student enrollment from areas such as Eastern Europe will increase, but more U.S. graduate students will be needed to maintain enrollments at 2005 levels.
- Chinese companies (which now contract out much of their research or employ joint ventures with Western companies) will develop greater in-house capability, and domestic career opportunities for university graduates will expand.
- On a practical basis, universities still will be remediating poor primary and secondary training in 2015. For many, new styles of teaching and mentoring will be needed to make up for poor economic situations and inadequate preparation during the pre-college years.
- The high school graduates of 2015 are currently in third grade. The 2015 Ph.D. graduates are the high school class of 2005. Currently, more women than men enter college, and chemistry degrees are granted in equal numbers to each gender. The "baby boomlet" Ph.D. graduates of 2015 will enter graduate school in a more equal gender ratio and will more closely resemble the U.S. population than do current Ph.D. graduates.
  - Minorities will become the majority over the next several decades. If educational institutions and the chemistry enterprise are to thrive, we must engage the intellectual talent of these groups, although this ideal state will not be fully reached by 2015.
  - Continuing support of ACS programs such as Project SEED and the ACS Scholars Program will provide a key mechanism for reaching out to the full cross section of our country's students.
  - Engaging groups now classified as underrepresented will require individual care and systematic transformation from elementary education forward.

Faculty and teaching. Teachers comprise 4% of the U.S. workforce. Major challenges can be expected as aging faculty leave the workforce over the next decade. Approximately half the faculty at the top universities are age 55 or over, and 50% of high school teachers are within 10 years of retirement.

In 2005, most university faculties are not very diverse. At the



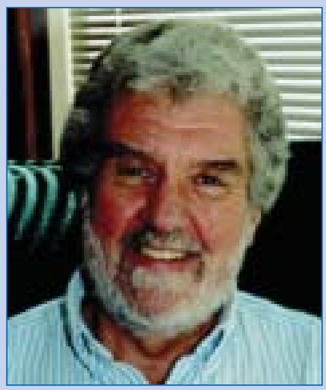
same time, many universities report difficulties in hiring outstanding candidates (including women and minorities), many of whom have multiple offers.

- By 2015, our faculty will look much more like our U.S. population than in 2005, but the two- and four-year institutions will make progress more rapidly than the comprehensive universities. Currently underrepresented groups will be more recognizable as part of the faculty in the teaching universities, which will facilitate recruitment of a more diverse next generation of students. The "leaky pipeline" will be plugged.
- New approaches will be developed in faculty hiring and retention, and many more women will assume faculty positions in research universities.
- Continued evolution of the educational models for colleges and universities will produce a new distribution of responsibilities—varying with the size and scope of the institution—among tenure-track faculty, part-time faculty, and graduate teaching assistants.
- Fewer schools will offer tenure in the traditional way and in the traditional numbers, opting for renewable contracts of varying length by expertise (research or teaching).
- Flat graduate student enrollment will lead to greater use of undergraduate teaching assistants and peer-led teaching. In some cases, the number and duration of lower-level laboratory classes may be reduced. Multidisciplinary courses will require greater team-teaching.
- Motivational teachers will be essential to improving the recruitment and teaching of science students, and an investment of greater effort and resources in teacher training and recruitment will be essential to accommodate this need.
- Teacher shortages loom for the next 10 years, as those trained in the early 1970s reach retirement. In order to alleviate the shortage, merit pay and promotion may reach high school science teachers.

Curriculum. Industry is seeking graduates equipped with higher-order skills beyond the basics of science. Success in industry frequently demands understanding of aspects of business, law, management, and international issues, to say nothing of learning to work with short-term focus in geographically-dispersed teams. At the same time, universities must address the increasing time-to-degree, which is inhibiting the flow of U.S. students into the research workforce.

Financial and safety concerns loom large for high schools and universities. This has led to increased reliance on computers and instruments and has resulted in revision and, in some cases, elimination of wet laboratory courses.

- Curricula will evolve to provide courses of instruction that are more easily adaptable to the needs of individual students. This approach will help to further emphasize the value of chemistry as a key component of postsecondary education in a number of majors.
  - Enabling these changes will pose significant challenges, both to faculty at various institutions and to ACS in defining new accreditation specifications.
- Professors are a long way from obsolescence, especially for traditional students. However, more universities are making notes and materials available on the Web, and distance learning is becoming more common in the traditional universities. As a



John Clevenger,
Professor, Truckee Meadows Community College, Nevada.

"In 2015, community colleges will be more diverse—in their students, instructional technologies, curricula, times, locations, and nontraditional revenue sources. This will necessitate more alliances among institutions to serve students with diverse educational backgrounds, ethnicity, economic backgrounds, disabilities, and ages. And there STILL won't be enough parking."

result, professors may find themselves teaching and mentoring more students, with students more effectively teaching themselves from available Web resources.

- Universities will increasingly employ the analogy of a business model. Donors (whether alumni or government) are investors; students are customers for the education product and products themselves for other customers—potential employers. Either model brings more focus on educational process efficiency. These business models already are central organizing principles for institutions, such as two-year community colleges and online universities.
- Major changes will occur in the teaching of introductory chemistry by 2015. A multidisciplinary focus with more descriptive chemistry will be the norm. As of 2005, 300,000 students enroll in introductory chemistry each year, but only about 4% of them major in chemistry. New approaches in the chemistry curriculum that reflect research on how students learn, particularly in freshman chemistry, will help to increase both the number of majors and the satisfaction of nonmajors.
  - The challenge in this area is daunting. The great desire for autonomy at individual institutions may preclude a coordinated set of changes (e.g., under the leadership of ACS). In that case, the challenge will be upon a smaller set of institutions, which must undertake change on an individual basis—with success to be demonstrated by growth in size, productivity, and funding.

Education and institutional structure. Ultimately, the complex drivers for change demand a reengineering of the system throughout primary, secondary, and university education.

- ACS and its members must rise to meet the challenges of an evolving institutional structure. Chemistry is a pivotal part of the educational system, and reform will require action by stakeholders across the entire chemistry enterprise in collaboration with other professional, scientific, and educational societies and in both the public and political arenas.

WORKFORCE

The U.S. chemical industry is currently in, at best, a slow-growth phase. Guaranteed lifetime employment, which many chemists came to expect, evaporated in the 1990s and gave way to the reality of multiple "careers" and larger numbers of consultants. Hiring slowed in the chemical industry, and pharmaceutical hiring took up the slack in the years leading to 2005. Many chemists became discouraged with the employment potential of chemistry. However, the retirement of the baby boomers, who reach age 60 starting in 2006, will modulate this picture.

- Projections from the Bureau of Labor Statistics indicate that chemistry-related jobs will increase by 3% for the decade 2002–2012. The number of jobs in chemical production will decrease with increased productivity and minimal new plant construction. However, retirement and modest growth will create a large number of openings, essentially allowing the chemistry enterprise to hire new employees at the same rate as the overall U.S. economy. Approximately one-third of the 2002 workforce will need to be replaced with new hires during the course of the decade—a total of 129,000 total enterprise job openings.
- Graduates must be more agile and willing to take on unusual assignments over the course of a career; in exchange, they will meet new and challenging opportunities, especially from small companies and those in multidisciplinary, innovative fields.
  - To achieve lifetime success, chemists will need to develop, maintain, and grow skills through continuing education, both formal and informal. In a world of commoditization, personal differentiation and marketing will be critical.
  - Enhanced career counseling will be needed, and ACS volunteer efforts could provide an effective means of accomplishing this task.
- We will see increased parity at all levels for women and minorities—on both technical and managerial tracks.
  - Chemists—and particularly ACS members—must serve as mentors and role models to facilitate and encourage the education and careers of women and other underserved minorities.
  - ACS has always been the place where chemists network. In a quickly changing and migrating market, networking and contacts are critical to career management. Finding novel ways for members to interact and build a network without the need for face-to-face meetings could be the new "killer app" for ACS.

Where will our new scientists come from?

Over the past 20 years, the number of native U.S. advanced-degree graduates has been declining by 1% annually, and foreign-born scientists have made up the difference.

- As noted above, large increases in the foreign student population and immigrant workforce appear unlikely, and the United States will be challenged to utilize its existing talent pool—in part by recruiting more women and underrepresented minorities into the field of chemistry. Faculty will continue to come preferentially from highly-rated universities, where the strongest and best-funded research programs are found.

Where will our newly-trained scientists go?

- Chemists will still work primarily in industry, although perhaps in new types of careers, and preferentially in smaller companies. Industry will utilize more technicians. The nature of industrial research will undergo significant evolution. Creative efforts will be needed to attract the best talent to the chemical profession.
  - Two-year colleges will need to play a leadership role in meeting the challenge to train more technicians. Universities will need to develop new training and education pathways that facilitate the success of their graduates in the global workforce and in those small companies that will provide career opportunities.
- Nontraditional careers will become more and more common

because a chemistry degree provides preparation for a wide variety of professions and careers.

Is chemical employment still attractive?

- Globalization will offer professionals the opportunity to work in different places, but they will need a broad educational experience that is augmented in nontechnical areas, such as working in teams, developing communications skills, and interacting with foreign colleagues.
- Offshoring of research will, to some extent, modify demand for chemists in this country, but the many job openings in domestic and global companies generated by retirements and global growth will create the challenge of maintaining an adequate scientific workforce—in quality as well as in numbers.
  - A challenge for ACS. ACS has an opportunity to reach out to the increasing number of people who are trained in chemistry but don't call themselves chemists. Most of these individuals work in industry—but not in the traditional chemical industry. We must modernize to remain the "big tent"—the home for all who do chemistry, regardless of where it is or what it is called.

GOVERNMENT POLICY

Government Funding of Research

Academic-style research, done at both universities and government laboratories and supported by public funding, is an important part of the nation's machinery for economic well-being. Research generates two major benefits: intellectual progress from new discoveries and the training of new members of the technical workforce. A strong research base requires cooperation among government, academia, and industry.

- Policy-makers understand the need for investment in advanced education and the discovery processes; but recognition is not the same as funding. Investment in science, technology, and education must compete with spending on national security and social programs.
  - In order to maintain robust support for science, we must demonstrate to the public the value that science and educated practitioners can provide to them, and we must show that federal research dollars are a strong economic investment. Without a compelling value argument, science will suffer.
  - Educational efforts by ACS members and other scientists will be needed.

By 2015, as one of the world's high-cost producers, the United States will need to operate in highly value-added areas that can support high cost. The necessary long-term research to enable this economy is unlikely to be taken on by industry, so it will probably be funded by the government in the hope of creating economic development through spinoffs.

Organizational changes. The criteria governing support for research are evolving. An applicant for research funding must be ready to demonstrate how the proposed research will have value to society beyond the field of chemistry, and issues of diversity and inclusiveness have become an important focus. More generally, the relative focus on basic vs. applied research will depend on which agencies are funded.

- Scientific and technological advances will change many—but not all—of the ways that research is carried out. There will be shifts in the time frame for which research programs are designed and changes in the time frame for which research is funded. Collaborations, consortia, and cooperative agreements will become more common, and the industry–university interface will change accordingly, particularly for the relationships of faculty and students with startup companies.

Biology and new paradigms. The chemistry enterprise is driven by where we allocate federal funding. Many of the old disciplinary borderlines are blurring, and increased support within the funding agencies for work in the nano-, bio-, and materials areas has led this trend. Modest increases in training grants—with the necessity for working as teams—have shifted some responsibilities and benefits from senior investigators to graduate students.

From the time that Fredric Wöhler was first able to synthesize urea from inorganic starting materials in 1828, chemists have worked to understand, modify, and even improve the chemical

Arthur B. Ellis,
Director, Chemistry Div., National Science Foundation.

> "The biggest difference in 2015 will be the routine use of "Cyber-enabled chemistry," which will eliminate traditional boundaries of time, place, and discipline; meld experiment, theory, simulation, and modeling; and remove geographic, institutional, and demographic limits on participation, collaboration, and professional development. See: www.nsf.gov/chem/cyber [Views expressed are those of the author and do not necessarily reflect the views of NSF.]"

processes of living organisms. Today, spending in the health-related area, applying the tools of chemistry to biology, swamps everything else. Funding is becoming less disciplinary and more focused on specific biomedical problems. This trend is pushing chemistry research toward that same focus—with corresponding shifts in faculty hiring and graduate student training. The lack of balance between funding for the physical sciences and the life sciences may be preventing us from maintaining expertise in certain strategic areas (with nuclear being just one).

- The grand challenges extend beyond biology, and government policy-makers will recognize this by 2015. There will be an increase in support of the physical sciences in response to the need for materials and energy solutions.
  - As the linchpin for all molecular science, chemistry must provide new tools for advances at the interfaces and generate new knowledge to ensure continued advancement of the frontiers of science.

HOMELAND SECURITY AND IMMIGRATION POLICIES

Within the U.S. chemistry enterprise, the two most clear-cut impacts of the terrorist attacks of 2001 have been visa and immigration restrictions and concerns over chemical plant security. After several years of delays and restrictions on student and worker visas, bureaucratic improvements have been made. Industry has made strong efforts to address the issue of plant security, but public concern and political pressures continue.

- As long as the threat of terrorism remains, there will be hurdles associated with immigration. However, the choices are clear: Expand the domestic talent pool and/or continue to welcome immigrants, or see fewer scientists.
- The challenges in homeland security have created new research opportunities and a potentially significant redirection of federal funding that will continue through the decade.

Regulation. Government regulation in this country is mature in the safety and environmental areas. The chemical industry also has adopted and implemented strong voluntary codes of behavior. Still, there is a global desire for continuous improvement in the management of chemicals and greater availability of information on hazards and possibilities of exposure to chemicals.

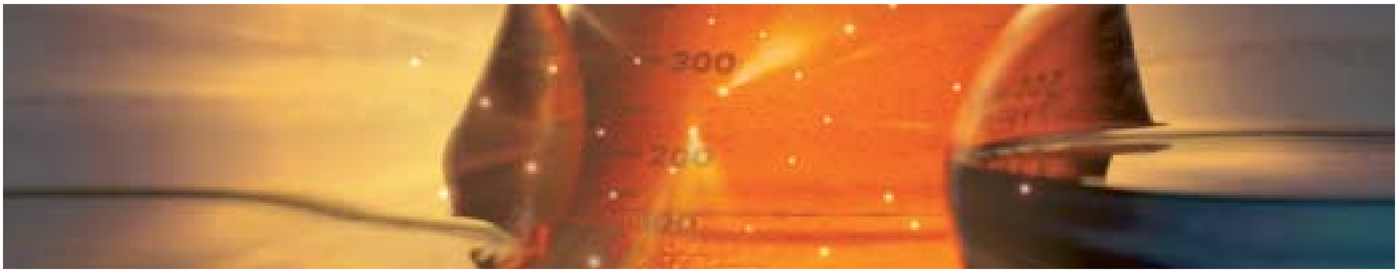
- Safety and environmental regulations will be applied fully in universities by 2015. The cost of meeting regulations will be a serious financial challenge.
- A global chemical management system will be in place that provides greater information to governments and the public about chemical manufacture, use, and environmental impact.

There is universal concern for the well-being of humanity and for our global environment. Debate on the origins of climate change and global warming is leading to increased agreement regarding anthropogenic impact, but any mitigating actions have economic consequences. Chemistry will be crucial for sound policy and decision-making that produces long-term net economic and environmental benefit. Aspects of chemistry now help in early identification of potential environmental problems, without the need for waiting to observe impact on biological populations.

- We will have a greatly improved understanding of global climate change and its root causes as well as more complete models that include the detailed chemical and molecular processes responsible. These advances will enable action on a global scale.
- The national debate on the costs of health care and concerns over both the cost and safety of drugs will lead to new regulations affecting the profitability of the pharmaceutical industry.
- Experience gained in environmental management of chemicals over the past three decades will help to guide new approaches to address issues of public exposure to nanotechnology products and other chemicals.
  - The chemistry enterprise must work with the regulatory community and stakeholder groups to develop a chemicals-management policy that accommodates industrial growth while avoiding environmental damage. Public education efforts by the scientific community—including ACS—will be essential in implementing optimum risk management strategies.

Change is on the horizon in regulation and in approaches to protecting intellectual property (IP).

- As IP protection becomes more important to developing countries, greater safeguards against piracy will be put into place. Global patent law harmonization will be a mixed blessing for the United States.



A CONCLUDING REMARK

The chemistry enterprise has a promising future, replete with challenges. Following the advances of the 20th century, we are poised to begin dramatic new explorations in molecular science—explorations as bold as those of the seafarers who sailed the world's oceans in the 15th and 16th centuries.

Breakthroughs—both intellectual and practical—will allow us to understand the chemical nature of consciousness and the molecular origins of life. We will discover new medicines and materials that improve our health and enhance our quality of life. If the enterprise rises to the challenge, our journey through the next century will be powered by safe, sustainable, and inexpensive energy. We will have improved transportation, housing, and manufactured goods that are produced in new ways, without harm to the environment. Individual chemists will be the professionals meeting these challenges.

Our journey will not always be easy sailing. Chemists must work with policy-makers and the general public to chart a course that will provide a safe passage for all.

Opportunity will remain alive and well for chemists, especially those graduating in the next 10 years. The changeover from one generation to the next will have major consequences, as much of the current workforce retires, scales back, or moves into different fields.

We will manage careers differently—more actively. Individuals will view themselves as specialty products whose value must be defined, differentiated, and marketed. Careers will no longer be equipped with an "autopilot."

We would do well to adapt and live by a paraphrase of Dow Corning's vision: "We will be innovative leaders unleashing the power of chemistry to benefit everyone, everywhere."

In 2015, it still will be good to be a chemist.