Editor's LETTER

Partly Cloudy with a Chance of Showers

The National Science Foundation (NSF) and the U.S. Department of Energy (DOE) asked the National Research Council (NRC) to convene a panel that would benchmark the research competitiveness of the U.S. in chemistry. The panel was charged with addressing three specific questions: (i) What is the current position of U.S. chemistry research relative to that of other regions or countries? (ii) What key factors influence U.S. performance in chemistry? (iii) On the basis of current trends in the U.S. and abroad, what will be the relative U.S. position in the near term and in the longer term?

The panel's report, *The Future of U.S. Chemistry Research: Benchmarks and Challenges*, was released in March 2007. A Report in Brief and an Executive Summary can be downloaded free from the National Academies Press web site (www.nap.edu/catalog.php?record_id=11866). The full report can also be read on this web site (individual pages may be printed free), and copies can be purchased.

The report concluded that today, chemistry research in the U.S. is stronger than in any other single country, but competition from Europe and Asia is rapidly increasing. In 2003, the U.S. published ~19% of the world's chemistry papers, down from 23% in 1988. Although U.S. chemists have been publishing at a steady rate of ~15,000 chemistry papers per year, chemists from other nations are increasing their rates of publication. U.S. chemistry citations account for 28% of total citations compared with the next two ranked countries, Japan and Germany, both with 9%. More important, U.S. chemists lead in the quality of their publications: they contributed to 50% of the 100 most frequently cited chemistry papers, while Western European countries together contributed 41%. In a further effort to characterize chemistry leadership, experts from the U.S. and abroad were asked to identify the "best of the best" in chemistry, that is, who they would invite to an international conference. The national makeup of these "virtual congresses" provides another indicator of U.S. leadership in chemistry by the strong predominance of U.S. speakers (from ~40% to 70% for the different areas of chemistry) selected for virtual world congresses. U.S. chemistry is particularly strong in emerging cross-disciplinary areas such as nanochemistry, biological chemistry, and materials chemistry.

The panel provided more detailed assessments for 11 areas: analytical chemistry, atmospheric chemistry, biological chemistry, chemical education, inorganic chemistry, macromolecular chemistry, materials chemistry and nanoscience, nuclear and radiochemistry, organic chemistry, physical chemistry, and theory/computation. The assessment of biological chemistry, entitled "The United States Is the Leader in Biological Chemistry", appears on pages 46–48 and is shown in Box 1. The prognosis, entitled "The United States Will Maintain Leadership in Biological Chemistry", appears on page 120.

The panel suggested that key determinants of U.S. research leadership in chemistry include the wide range of funding sources supporting academic chemistry research, early independence of investigators, mobility across academic institutions, and a steady supply of Ph.D. chemistry graduates, many of them foreign-born.

The panel projected that chemistry research in the U.S. will remain stronger in the next decade than in any other single country, but competition is increasing. Because of the ad-

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Box 1. The United States Is the Leader in Biological Chemistry

Biological chemistry involves the use of chemistry to develop a better understanding of biological processes. To assess the current status of the U.S. contribution to biological chemistry, five subareas were examined:

Chemical and structural biology is concerned with the development of chemical and biological approaches to solving problems in living systems, which usually involve determination of the three-dimensional structures of biomolecules, mainly proteins and nucleic acids, and their complexes with ligands, receptors, drugs, or other interacting components. The structural information provides a basis for understanding the mechanism and function of the biomolecules and for molecular design.

Biocatalysis is the study of biological catalysts with regard to their kinetics, mechanisms, specificity, and application in synthesis and analysis. In addition to the traditional study of mechanistic enzymology, biocatalysis is concerned with the use of recombinant DNA technology, site-specific mutagenesis, directed evolution, pathway engineering, substrate design, and structure-based approaches as tools for the development of novel catalysts and reactions.

Nucleic acids and functional genomics cover the chemistry and biology of gene-related substances. Current subjects of study include genomic sequencing, genotyping, and genomic profiling with arrays; DNA damage; and the functional study of genes, including, for example, the study of transcriptional and translational processes that translate into cellular function at the protein level.

Signaling pathways is a subarea of biological chemistry that is concerned with the study of molecular interactions and/or reactions in sequence in the living system that triggers a functional event.

***In vivo* molecular imaging** refers to the spatial and/or temporal visualization of different cellular elements and biochemical reactions in a living organism using different imaging methodologies and labeled tracers with high molecular specificity. Tracers are labeled with radioisotopes for nuclear imaging (with positron emission tomography (PET), microPET, and single photon emission computed tomography), fluorescent probes for optical imaging or paramagnetic ions for nuclear magnetic resonance (NMR) imaging.

Assessment. The United States is the leader in biological chemistry, especially with regard to innovative research in the areas of chemical and structural biology, signaling pathways, nucleic acids, and functional genomics, and is among the leaders in biocatalysis and *in vivo* molecular imaging.

(continued)

Box 1. Continued

In more specialized journals, U.S. authors contributed 60 percent to *Biochemistry*, 56 percent to *Protein Science*, 47 percent to *Bioconjugate Chemistry*, 45 percent to *Proteins*, 42 percent to *Nature Biotechnology*, 59 percent to the *Journal of Biological Chemistry*, 22 percent to *ChemBioChem*, 65 percent to *Nature Structure & Molecular Biology*, 45 percent to the *Journal of Molecular Biology*, and 62 percent to *Chemistry and Biology*. Taken alone, these data place the U.S. as the leader or among the leaders in biological chemistry.

Of the highly cited journal articles in biological chemistry, 56 percent were authored by U.S. scientists during 1990–1994, 57 percent during 1995–1999, and 54 percent during 2000–2006. The journal *Biochemistry* had 78 percent of its most accessed articles authored in the United States (2004–2005).

The virtual congresses in chemical and structural biology and nucleic acids and functional genomics had very high representation from U.S. participants, with 75 and 83 percent, respectively, of selected speakers from the United States. The virtual congresses in signaling pathways and *in vivo* imaging also had high representation from the United States, with 69 and 63 percent respectively. The subarea of biocatalysis had 49 percent of selected speakers from the United States. The virtual congresses also showed strength in chemical and structural biology for the United Kingdom and Germany; strength in nucleic acids and functional genomics for The Netherlands; and great strength in biocatalysis for Japan, the United Kingdom, and The Netherlands.

When all the data for the area of biological chemistry are evaluated in concert, the results point to the U.S. as the leader in biological chemistry.

vance of chemistry in other nations, competition is increasing, and the lead of U.S. chemistry will shrink. The report suggests that U.S. chemistry will be particularly strong in emerging areas, such as nanoscience, biological chemistry, and materials chemistry, which continue to attract new funding initiatives. In contrast, U.S. chemistry leadership in some fundamental core research areas is projected to continue to erode in part because of decreased funding for basic research in areas such as physical, inorganic, and organic chemistry.

The panel had two major concerns that will affect the ability of the U.S. to maintain its leadership in innovation. First, the sustainability of the supply of U.S. chemists was seen to be in jeopardy. For the past 15 years, the number of Ph.D.s in chemistry granted at U.S. universities has been relatively steady at ~2000 per year. However, this level has been maintained by increasing reliance on international students (from ~25% in 1985 to ~40% in 2005). Unless we are able to persuade more U.S. students to pursue careers in science, it is likely that the number of U.S. citizens receiving chemistry Ph.D.s will continue to decrease. At the same time, U.S. chemistry may find it increasingly difficult to attract and retain outstanding international graduate students and postdoctoral research associates as chemistry and other opportunities in other nations improve. **Second, U.S. funding of chemistry research and infrastructure was projected to remain under stress.** Support was forecast to continue to barely keep up with inflation and to be concentrated in emerging and interdisciplinary areas. Core research areas of chemistry, which underlie advances in the emerging areas of science, were viewed as being stretched thin.

The recent passage of the America Competes Act (HR 2272) is a very hopeful sign. This act authorizes $43 billion over 3 years for science, technology, engineering, and mathematics (STEM) research and education programs and places NSF, the National Institute of Standards and Technology, and the DOE Office of Science on a near-term doubling path. The American Chemical Society (ACS) took a leadership role among scientific and educational organizations in advocating for this legislation. Although the America Competes Act is an authorization bill, it cements a solid, bipartisan consensus in Congress for doubling funding for the key science agencies. Turning authorizations into appropriations is a difficult business that will require continued advocacy. We urge U.S. chemists to join the ACS Legislative Action Network (LAN) to help advocate for increased appropriations for science, which will lead to innovation and new jobs, and for increased funding of STEM education, which will provide the scientific workforce needed to maintain U.S. leadership in science and innovation. The LAN is a free national advocacy program that notifies its members of major issues and facilitates communication with members of Congress before key votes. Several times a year, members receive emails asking them to contact their members of Congress. The ACS's positions, background on science and education issues, and a draft of a suggested email (that is easily modified and personalized) are provided. Because few constituents contact Congress on science issues, these LAN emails have a notable impact. To join LAN, go to www.chemistry.org/government/action.

Charles P. Casey

Department of Chemistry, University of Wisconsin–Madison, Madison, Wisconsin Chair, NRC Panel to Benchmark the Research Competitiveness of the U.S. in Chemistry

Chi-Huey Wong

Scripps Research Institute, La Jolla, California, Academica Sinica, Taiwan, Panel Member

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