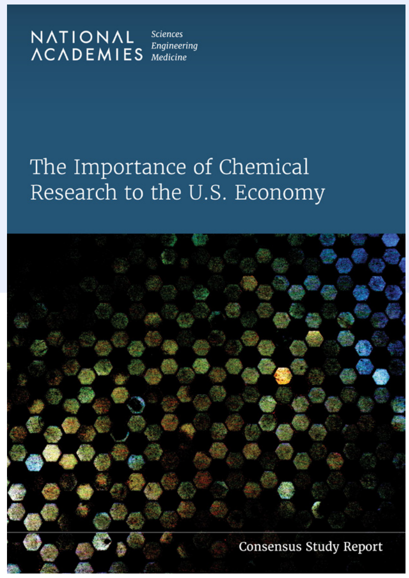
The Importance of Chemical Research to the U.S. Economy



Chemistry plays a pivotal role in the strength of the U.S. economy and in the well-being of humankind. Among their achievements, chemists have created life-saving pharmaceuticals, developed energy solutions, improved agricultural productivity, and produced novel materials used in a wide array of products, from cookware to clothing to electronic devices. The many sectors reliant on the U.S. chemical economy are responsible for $5.2 trillion, or 25%, of the U.S. GDP, and the entire chemical enterprise supports 4.1 million jobs in the United States.

While the United States remains a key player in the global chemical enterprise, the nation faces several challenges related to the changing landscape of the chemical economy. One challenge is the urgent need to integrate sustainability into manufacturing, product usage, recycling, and product disposal, and also to address the many negative impacts that chemical processes and products have already had on the environment. Keeping pace with technological change is another challenge, as the ability to apply emerging processes, tools, and technologies will require significant investment in research infrastructure and in the training, educating, and preparation of the future workforce.

Conducted at the request of the American Chemical Society, the National Institute of Standards and Technology (NIST), the National Science Foundation, and the U.S. Department of Energy, this report identifies strategies and options for research investments that will support U.S. leadership while considering environmental sustainability and developing a diverse chemical economy workforce.

FUNDAMENTAL CHEMICAL RESEARCH AND THE U.S. ECONOMY

Chemistry is a foundational and central scientific discipline, and sustained investment in fundamental chemical research has generated discoveries that are the basis for critical innovations across the economy. Examples of such innovations include the development of ubiquitous Li-ion batteries, the adoption of biocatalysis in synthetic methodologies, advances related to silicon chips, and widely impactful pharmaceuticals such as oral contraceptives and pharmaceuticals developed to fight SARS-CoV-2. Additionally, the report's analysis showed a spillover of chemical knowledge and products into other areas of the economy.

While the United States has often led in the international chemical enterprise, continued leadership in the chemical industry cannot be taken for granted. In considering actions that will help to grow and strengthen the U.S. chemical economy and U.S. competitiveness, the report recommends that:

- The U.S. chemical enterprise should support funding, workforce, and policy structures that attract international researchers and support all research talents.

- Funding agencies should support as large a breadth of fundamental chemical research projects as possible.

- The chemical industry, pharmaceutical companies, and instrumentation developers should continue to invest in research and development at universities and scientific research institutions in the United States.

- The U.S. government should continue to produce policies that support international and open exchange of ideas in the chemical sciences.

- In order to better understand the impact of fundamental chemical research on the U.S. economy, federal agencies should collaborate to collect and make available any related tools and data.

FOCUSING CHEMICAL RESEARCH ON SUSTAINABILITY

Even as the chemical economy has contributed to innovation and economic growth, it is also responsible for considerable negative impacts on the environment such as the production of greenhouse gases, plastic waste, and cases where toxic chemicals have been released into the air or into soil or water. Ironically, chemical research will be critical to solving many of these issues. For example, there are many areas ripe for chemical discovery in a new energy landscape that prioritizes clean alternatives and decarbonization. To achieve the scientific advances necessary for a sustainable future, external factors also need consideration, such as the changing demand for metals and minerals that arise with the shift to electric vehicles and complications with acquiring those materials based on shifting international politics.

Pressures in the form of policy are also necessary to encourage this paradigm shift where chemical research and the entire chemical economy are premised on sustainability and environmental stewardship. Market- and procurement-based policies are particularly important tools for supporting a green and circular economy and encouraging innovation in sustainable chemistry.

As the chemical enterprise continues to look for avenues where chemical research could make the largest impact in sustainability, there are a number of specific areas where initial steps have already been made, and further progress is possible. Those areas include better measurements for life cycle assessments; the enhancements of recycling technologies and co-design of plastic products for recyclability; sustainable syntheses; sustainable feedstocks and energy sources; carbon capture, utilization, and storage; and monitoring and improving air quality, water safety, and food safety.

To accomplish this paradigm shift in the chemical sciences, a concerted effort will be needed from government, industry, and academia. The report recommends that the chemical industry and their partners at universities, scientific research institutions, and national laboratories align the objectives of fundamental research to directly assist companies with implementing new practices toward environmental stewardship, sustainability, and clear energy. In addition, all chemistry-related research grants and proposals should have an opportunity to explain the "environmental impacts" of the proposed research, as an option under a "broader impacts" statement.

EMERGING AREAS AND NEEDS IN THE CHEMICAL SCIENCES

In order for chemistry to continue making advances in different areas of sustainability, emerging areas of chemical research, along with new tools and technologies, will be critical. Among the various tools and technologies that are available to scientists at present, a few key pillars are particularly valuable in understanding the molecular world and promoting high impact discovery. These include:

- **Measurement:** Our ability to quantify and visualize molecules and their interactions is becoming faster and more accurate, and can be accomplished on smaller instruments. These instruments are driving new research and measurement capabilities.

- **Automation:** High-throughput techniques for measurement, synthesis, and other areas of chemistry, particularly in combination with flow chemistry, offer new avenues to researchers by enabling large numbers of chemicals or reactions to be tested, measured, and analyzed, and thus to more quickly determine new research questions to pursue.

- **Computation:** Computational chemistry is integral to fundamental research in every discipline of chemistry, and fundamental, multidisciplinary research in chemistry, physics, and engineering has in turn played a critical role in the ongoing development of modern computing architecture.

- **Catalysis:** In order to establish new methods of synthesis and manufacturing that do not rely on energy intensive processes, new advances in catalysis will be important. Particularly promising areas include photocatalysis, electrocatalysis, and biocatalysis, coupled with efforts to synergize theory with experimentation.

Chemical Data and Analysis

In assessing emerging tools and technologies, a common thread appeared: well-curated and accessible data benefit all aspects of chemistry. A comprehensive supply of experimental chemical data would be particularly helpful for developing models and for understanding different molecular properties and interactions, as well as learning how to more accurately measure chemical systems. It would benefit the chemical enterprise if databases could request and archive data associated with all chemical projects, including outcomes from experiments that do not achieve their intended result. Researchers should make a concerted effort to establish standards for how chemical data are collected, stored, and distributed. Specifically, NIST, in consultation with the International Union of Pure and Applied Chemistry, the American Chemical Society, and other global chemistry professional societies should lead an effort to explore pathways that provide an open-source, accessible, and standardized way for chemical researchers to store, share, and use data from chemical experiments.

DEVELOPING A SKILLED CHEMICAL WORKFORCE

Several critical components to training, preparing, and empowering the next generation chemical workforce include the need to support a diverse workforce and provide equitable training practices, the need for well-developed mentorship and professional development programs, and an emphasis on education that is adaptable to the future needs of the chemical enterprise.

Preparing a future workforce will require chemistry curricula to be adaptable to the future needs of a chemical enterprise that is constantly adopting new tools, methods, and technologies in order to better understand, measure, and build molecules and materials. Accomplishing those goals will require a serious and sustained investment from funding agencies, universities, industry partnerships, and accreditation programs. This investment is crucial because the tools and practices that enable chemical research are constantly evolving, and training programs must be able to adapt to best facilitate the learning of basic-to-advanced chemical principles that will help students succeed.

To realize these ideas, the committee recommends that steps be taken to fund research in chemical education, continually reassess chemistry curricula, and continue to provide opportunities for professional development. Funding agencies should make substantial investment toward education research to enable innovative ways of teaching about emerging concepts, tools and technologies. Universities, colleges, and accreditation programs should regularly update curriculum requirements and pedagogical practices to ensure students are receiving state-of-the-art inclusive training.

FUNDING MECHANISMS TO DRIVE INNOVATION

The funding landscape for chemical research in the United States is quite broad and includes a diverse set of private and public sources that provide support for many different types and scales of chemical research. However, a shift in the support of fundamental chemical research has occurred as chemical manufacturers have chosen to decrease the size and scale of in-house basic research programs over the past couple decades. Some specific funding mechanisms that have a high likelihood of being impactful for the chemical economy. For example, the Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR) programs in chemistry is one of the few government funded opportunities available to convert fundamental chemical research into a product, process, or technology. The report recommends that funding agencies continue to support innovations in the chemical sciences through SBIR/STTR programs.

In the landscape of public and private funding for scientific research, one area that has risen in prominence over the past several years is philanthropic support. While philanthropies have contributed to fundamental chemical research, relative to current federal funding for basic research, philanthropy supports far fewer schools and research projects. To ensure that science works to address big societal issues such as climate change and human health, funders will need to consider investments in the fundamental chemistry that will help yield solutions to these challenges and inform so many other areas of science.

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FOR MORE INFORMATION

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