Sustainable U.S. Manufacturing: Chemical and Allied Industries

Technology Area 4:
Next Generation Chemical Manufacturing

Current industrial production methods have approached the practical performance limits of established, contemporary technologies. So far, efforts to improve these methods have yielded diminishing returns, yet markets continue to demand higher quality, enhanced performance, greater durability, more precision, and lower prices. In addition, the likelihood of a carbon-constrained future will require the Chemical and Allied industries to go far beyond incremental improvements. These factors make it necessary to undertake new research, development, and demonstration (RD&D) work to create the next generation in chemical manufacturing technologies. Successful deployment will have a fundamental impact on productivity, resource utilization, emissions, and profitability. It will enable the manufacturing of completely new products with new processes. In essence, this RD&D will make the Chemical and Allied industries more sustainable, dramatically reduce greenhouse gas emissions, and provide a competitive advantage in the global marketplace.

A. NATIONWIDE ADVANTAGES

- Innovative, sustainable products with corresponding advantages in costs, materials sourcing and waste reduction
- Fundamentally different processes and manufacturing capabilities that provide competitive advantages
- Development of technologies that spill over to other U.S. manufacturing industries
- Sustainable and challenging scientific and engineering research to attract and engage our best minds

Immense benefits will accrue from employing new chemical manufacturing technologies. The Chemical and Allied industries will achieve dramatic reductions in energy and raw material consumption, and in waste byproducts and emissions. The development of many new manufacturing jobs and entirely new products will result from the new technology and process advancements.

B. NATIONWIDE SAVINGS, REVENUE, JOBS, & REDUCTION IN EMISSIONS

- Saving **870** trillion Btu/yr in natural gas - equivalent to the consumption of 20 million households
- Saving **250** million barrels of oil per year - equivalent to 25 days of all U.S. oil imports
- Lowering greenhouse gas emissions by **160** million tons - equivalent to removing 31 million cars from U.S. roadways
- Providing revenue to potentially support **220,000** direct jobs
- Providing almost $**6.6** billion in corporate tax revenue

The enormity of the technical and scientific challenges facing the creation of such new technologies, while also achieving sustainable manufacturing goals, requires fostering and supporting extensive RD&D partnerships among industry, academia and government. Innovative partnerships that augment and hasten the Chemical and Allied industries' efforts will further accelerate the development and implementation of these next generation technologies.

C. NATIONWIDE FISCAL REQUIREMENTS

- Federal investment of $480 million to initiate, augment, and promote targeted RD&D partnerships
- Federal incentives and investments to expand RD&D-related postgraduate education and develop a highly skilled workforce

Technologies developed in the last 50 years, including microelectronics, computers, automatic controls, genetic and biological engineering, computational science, analytical methods and nano-science provide the underlying research that forms the basis for developing these new technologies. Progress in the following six RD&D areas is essential:

1.) Process Intensification — The development of smaller (i.e., intensified) process equipment with production rates equivalent to those of current equipment, can result in significantly improved material utilization, reduced energy and capital requirements, and safer equipment designs. Intensification reduces size by taking advantage of small dimension effects of heat and mass transfer phenomena (e.g., microchannel reactors) and by combining multiple unit operations into a single unit (e.g., reactive distillation). Process intensification RD&D requires not only in-depth understanding of complex thermochemical and mass transfer phenomena, but also highly effective process and equipment design skills. Micro-reactors represent one of the key technologies that will enable the use of process intensification on a wide scale, but further research could lead to improved performance in particulate clogging, rapid gas evolution, and continuous flow reactions.

2.) Active Analytical Devices — Making sure inputs, conditions, and outputs precisely match the engineering

and operating specifications is difficult in the Chemical and Allied industries because of the interdependence and control requirements of their many processes. Out-of-spec operations can ruin entire runs of products or, at the very least, require higher amounts of resources, time and/or effort to correct.

Precise knowledge of manufacturing parameters in real-time allows for improved process control, which increases productivity, profitability, safety and product quality. On-line, real-time, precise analytical devices can improve current process performance at minimal cost to the manufacturer. RD&D investment in microelectronics, low-cost, durable (chemical, thermal, impact, etc.) sensor materials, improved wireless communications and on-line and computational resources will provide a greater understanding and more efficient use of resources.

3.) Advanced Separation Processes — Separations, the most energy-intensive and inefficient operation in the Chemical and Allied industries, has the ability to achieve advancements in both materials (e.g., membranes) and processes (e.g., membrane-reactors). Advancing chromatography (a mainstay in analytical work) to commercial-scale and continuous operations could decrease costs and improve product purity. Ionic liquid processing, a more recent development with an unknown scope of applicability, offers the potential for cleaner, more energy-efficient and precise separations. These low-temperature liquids offer new solvent chemistry for reactions and low-energy separations. Carbon dioxide capture and sequestration technologies demonstrate yet another valuable application for advanced separations. Currently available methods struggle to achieve success due to the scale, or multiple source and stream compositions, of our operations. Potentially, CO_2 sequestration can succeed beyond just physical techniques (burial or storage), and the Chemical and Allied industries may benefit from biological offsets (growing and using biomass) or chemical bonding methods (transformation to other chemicals).

4.) New Energy Forms for Thermal Processes — Photochemical, microwave, ultrasonic and electron beam energy sources remain greatly unexplored in terms of their direct application or their ability to augment large-scale manufacturing applications. Microwave heat treatment in the metal casting industry has improved energy efficiency and ease of use, and yielded better product uniformity and precision and increased process flexibility. Basic research on photochemical reactions has shown many-fold decreases in dissociation time compared to similar thermal reactions. Because of their high precision and fine control, ultrasonics provides a non-destructive study of material properties and accurate measurement of energy transfer and usage. Ultrasonic chemical dissolution and decontamination studies have reported advantages in comparison to typical thermal processing. Semiconductor development has utilized electron beam processing, which can also serve as an alternative to conventional manufacturing techniques, and thus can have many applications for the Chemical and Allied industries. Overall, these energy forms could offer significantly lower energy use, improved process control and lower emissions.

5.) Computational Modeling — Progress in the computational sciences will accelerate next generation manufacturing developments. Increasing computing power to analyze massive data sets, provide visualization and integrate finite-element analysis with biological, chemical, thermal and mechanical modeling allows scientists and engineers to study and improve the performance of technologies before expending major resources on development. This advance work allows early redesign, avoiding costly downtime, retrofits or failures.

6.) Automation, Robotics, Computing, and Intelligent Systems — Integrating more computational and mechanical systems will produce the automation and intelligent systems necessary to provide active and continuous monitoring and feedback of the manufacturing processes. This will enable greater efficiency, higher-value products, production of fewer wastes, and enhanced safety and other sustainable benefits. Intelligent and robotic systems improve worker safety by analyzing performance and by carrying out the most dirty, hazardous, and/or physically demanding jobs in the industry. They also ensure greater precision and uniformity of product. Developments in these systems can benefit our industry directly, as well as many other U.S. manufacturing sectors.

This technology brief describes one of six areas in need of technological advances to support sustainable growth in the Chemical and Allied industries. These six areas require significant federal investment ($1.5 billion) in RD&D, and an increase in the number (>1,000) of chemistry and chemical engineering post-graduate degree workers. The potential commercial benefits include a 65% reduction in fossil fuel use, a 34% renewable resources mix in energy and feedstock supplies, and an industry-wide reduction in GHG emissions of 63%.

The ACS Presidential Roundtable on Sustainable Manufacturing brings together industrial, government, academic, and scientific and engineering organizations to enable sustainable manufacturing in the chemical and allied products industries. The Roundtable will provide a consistent source of credible, sound information on the application of principles of sustainability to chemical manufacturing industry stakeholders to influence public policy, standard setting organizations, and third parties directly relevant to the chemical enterprise. These briefs originated from the 2009 Vision 2020 Workshop. For more information on these six areas, and how focused investment can maintain the United States' position as the leader in global RD&D, visit: www.acs.org/smrt