Green Economic Innovation for the 21st Century: The Molecular Revolution

Cutting edge developments in two scientific disciplines—environmental health science and green chemistry—are revealing opportunities to stimulate US economic innovation with significant implications for disease prevention and lowering the cost of health care. Discoveries in environmental health science are confirming that some chemicals in widespread use have unanticipated consequences for human health. Advances in green chemistry offer a path toward new materials that are inherently benign. Together these fields hold the promise to affect a sustainable shift in America's chemical infrastructure.

The opportunity is tremendous; the perils of not acting are daunting. The current ways in which we address chemicals in society have ill-served every community impacted by them:

- Public health has been demonstrably imperiled by a range of chemical related tragedies in children's toys, human and pet food, medicines, and many materials that make up the basis of our economy.
- Vulnerable chemical plants put US national security at risk.
- Current regulations and the way they are applied impede business innovation and make it very difficult to bring greener materials into the market while also making it extremely challenging to take bad materials off.
- The scientific community that has provided insights and understanding of chemicals and their impact on humans and the environment has had its science ignored due to a regulatory process which is no longer "science based".
- US workers who would most benefit from an innovative, "green" chemicals sector have seen jobs shipped elsewhere in the world even while their productivity has increased.

The U.S. can launch an integrated green chemistry and environmental health initiative that would yield:

- An American chemical infrastructure that allows scientists and engineers to design truly sustainable and resilient products that do not pose a health or terrorism hazard.
- A boost in competitiveness across US industrial sectors - from automotive, construction, energy, pharmaceuticals, agriculture, electronics, waste treatment to consumer products.
- A cost-effective modernization of the regulatory process that will protect human health and the environment while also reducing burden to industry.

How can the US grow "green jobs", rebuild its economy, protect health and the environment, and enhance security?

- Invest in environmental health sciences research to help develop accurate chemical design criteria
- Invest in environmental health science research to monitor human and environmental health to increase understanding of synthetic chemicals impacts generationally.
- Invest in green chemistry and engineering research and development of safer chemical alternatives and the processes used to make them.
- Invest in environmental health sciences and green chemistry education so the up-coming generation is equipped understand the design criteria and act on them to knowingly design safer and more effective chemical alternatives.
- Provide financial incentives to recapitalize existing chemical manufacturing infrastructure to enable transformational changes.
- Provide research and development incentives to move from traditional fossil-based feedstocks to sustainable feedstocks.

Background: Environmental Health

Chemicals in society and advances in environmental health science

During the Twentieth Century, commerce experienced dramatic and unprecedented growth in the quantity and complexity of the materials—chemicals—used in the economy. Modern chemicals have enabled profound improvements in the quality of human life. Yet there have also been unintended consequences for human, wildlife and ecosystem health because potential toxicities and degradation pathways were not explored, and indeed, often unknown, before the materials became widespread.

Some of the unintended consequences of these chemicals are now well understood and characterized. These include occupational exposure to toxic substances, accidents at industrial facilities and special vulnerabilities to terrorism of chemical plants and chemicals during transportation.

As environmental health science has progressed, however, and especially as it has incorporated scientific discoveries and tools from molecular genetics and from increasingly sensitive assays capable of measuring contamination in people at unprecedentedly low levels, new issues and challenges have become visible. Foremost among these are four issues:

- Some chemicals, including some previously considered benign, are capable, at extremely low levels, of interacting with biological systems and altering how the genes of living organisms, including human, behave. These changes are implicated in the causation of many human diseases, including cancers, infertility, learning and behavioral disorders, heart disease and type 2 diabetes.
- Chemicals that behave like hormones, called endocrine disruptors, can violate basic assumptions that underpin regulatory toxicology, with low doses causing effects that are different and unpredictable from classic high dose experiments that are the basis for setting current "safe" exposure levels.
- Direct measurements of contamination in people, made possible by significant advances in analytical chemistry, have established the fact that people have within them hundreds, if not thousands, of contaminants simultaneously. While scientific understanding of the consequence of exposure to mixtures is in its infancy, studies consistently show that exposure to multiple chemicals at the same time can cause effects even though each of the chemicals is at a level so low that, by itself, it would not be expected to cause harm.
- Early life exposures, especially in the womb, may contribute to diseases much later in life, including diseases of middle age and aging. These effects will not have been apparent to the methods used for decades to establish chemical safety.

These emerging discoveries have come as surprises to traditional toxicology, because they raise questions about many chemicals in common use that conventional approaches had deemed safe. The clear message is that current health standards developed by agencies like the US FDA and the US EPA have missed problematic compounds, and that it will be essential to revise the processes used to establish these standards so that they incorporate current science. Given the range of diseases for which current science has reported plausible links to environmental exposures, diseases that include some of the most costly and burdensome in America today, including prostate and breast cancers, contributors to infertility like endometriosis, uterine fibroids and polycystic ovaries, type 2 diabetes and heart disease, modernizing safety standards holds the promise of a healthier America and the potential for reduced health care costs.

Background: Green Chemistry

21st Century Materials Science

With current science creating incentives for a new generation of health standards will come enormous scientific and economic incentives for new chemicals and new chemical processes. Green chemistry offers a practical way forward. By providing the scientific basis for a new wave of inherently safe materials, green chemistry can stimulate scientific and economic innovation, avoid the unintended health consequences of inadvertently hazardous materials, and contribute to sustainable economic growth and job creation. This is green chemistry's promise; to achieve it fully will require sustained effort and commitment of resources.

While the principles guiding green chemistry appear to be common sense, they bear little resemblance to the way we do chemistry today. Currently feedstocks are generally non-renewable; products we make and their building blocks often have significant toxicity; many of our substances persist, biaccumulate and biomagnify. We have historically tried to control exposure to hazardous substances in ways that are costly and often fail.

Global demand is rising for sustainable materials - materials that support health instead of undermining it. Other countries, e.g., the EU, China and India, have already begun investing significantly in green chemistry innovation to supply this growing market. Notably, the REACH program in the EU is the first major effort to require chemical transparency in products; it is setting standards for the global economy. The US could simply abide by these rules, but America would be better served to be the innovative leader in this field. We cannot afford to lag and lose leadership in this market—one based on American innovation—to others.

Green chemistry began as an initiative out of the U.S. Environmental Protection Agency in the early 1990's and has emerged to involve networks of industry, academia, and environmentalists in thirty nations around the world. This rapidly evolving field of science is governed by twelve specific chemical design principles, which move products and processes toward an economy based on renewable feedstocks, where toxicity is deliberately prevented at the molecular level. Chemicals and chemical processes are designed to:

- Be less hazardous,
- Eliminate waste,
- Minimize energy use, and
- Degrade safely upon disposal.

Green chemists and engineers employ life cycle and biological systems thinking in the act of creating the chemicals that would form the foundation of our economy. The science is rigorous and many specific applications are now emerging in industry and in academia, including: renewable energy technologies, plastics, pharmaceuticals, pesticides, paints and coatings, textile manufacturing, pulp and paper, water purification and basic chemical feedstocks.

Over time green chemistry will change chemistry as a whole, re-orienting societies toward an economy based on sustainable feedstocks, renewable energy, bio-based production and green jobs. The key is guiding the creative power of chemists with design criteria that specify safety and sustainability at the outset. Focused investment in these fields will drive the transition.

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