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Thought Starter: How do we Mainstream Green Chemistry?

The Green Chemistry and Commerce Council (GC3) was established in part to promote the development and adoption of Green Chemistry across sectors. Now eight years after the founding of the GC3, it is a good time to reflect on the progress or the lack of progress in the adoption of Green Chemistry and consider what the GC3 might do now to advance its original mission.

It has been twenty years since the EPA initiated its Green Chemistry program and fifteen years since the publication of Paul Anastas' and John Warner's seminal book *Green Chemistry: Theory and Practice* that defined and presented twelve principles of green chemistry, catalyzing a field of chemistry that combines molecular development with sustainability. In the ensuing decade and a half we have made significant strides in advancing Green Chemistry research and have begun practical implementation in industry and government. Some successes include:

- The Presidential Green Chemistry Challenge, a federal government awards program introduced in 1995, has recognized dozens of innovative green chemistry research initiatives in business and academia.
- The American Chemical Society's Green Chemistry Institute has supported successful Green Chemistry Roundtables, such as the Pharmaceutical Green Chemistry Roundtable, and 17 annual Green Chemistry and Education conferences that have brought together hundreds of researchers from around the world to share research and experiences. Many other conferences on Green Chemistry occur regularly around the world, spurred by interdisciplinary networks and private and public organizations.
- A number of university and K-12 Green Chemistry education and training programs have been established in academia, such as at the University of Oregon and the Berkeley Center for Green Chemistry, and non-profits, such as Beyond Benign.
- Numerous Green Chemistry research programs have been established in academic institutions, such as at Carnegie Mellon University, Green Centre Canada, and the University of York in the UK, and for-profit institutions, such as the Warner Babcock Institute for Green Chemistry.
- A variety of state-level Green Chemistry programs, such as those in Michigan, Oregon, and Minnesota, and the New England states have been established that engage industry, academia, non-profits and government in building a foundation for green chemistry research and education.
- New networks such as the Green Chemistry and Commerce Council and the Biz-NGO Working Group have been organized to bring together companies and other stakeholders to address cross-cutting challenges and identify opportunities to advance Green Chemistry.
- Individual companies across sectors have initiated programs to integrate Green Chemistry into research and development and design decisions.

- Sector-based collaborations have been established that include small start-up chemical manufacturers, large chemical manufacturers, downstream users of chemicals, retailers and industry organizations to advance development and application of Green Chemistry.
- The President's Cancer Panel and the CDC's National Conversation on Chemical Exposures both acknowledged the need to apply Green Chemistry to prevent chemical risks.
- In recent years there has been rapid development of new toxicological screening approaches and tools to support designers in developing and selecting safer chemistries.
- A growing movement of environmental and health advocates that support policies and programs to implement economic development around Green Chemistry exists.

The growth of Green Chemistry activities in the past twenty years and the increasing momentum over the past five years is impressive. It provides us with clear examples of the opportunities and prospects for a more sustainable chemical enterprise. In the past five to seven years, public, government and marketplace concern about chemical hazards has greatly increased and as a result there is significant collaborative activity focused on identifying, evaluating, and implementing safer chemistries. However, often those safer alternatives do not exist, creating great opportunities for Green Chemistry Innovation. These concerns are likely to increase in coming years as will marketplace activities in sustainable chemicals management through supply chains.

Nonetheless, despite the number of programs, initiatives, awards, educational programs and meetings we have a long way to go to achieve the goal of "mainstreaming" Green Chemistry. We must ask three fundamental questions: What does it mean to mainstream Green Chemistry? Has the Green Chemistry movement succeeded? And, if not, what will it take for it to succeed?

Similar to Green Chemistry, the pollution prevention movement – representing a paradigm shift in how to approach environmental protection and led by visionary thinkers who believed in the power of innovation – faced a similar set of questions. As a result of several thought-provoking essays questioning the impact of pollution prevention as a movement, the National Pollution Prevention Roundtable, state agencies and the U.S. EPA initiated a series of discussions about the past and future of pollution prevention. These discussions led to a short term energizing of pollution prevention activities in the states and at EPA, with an advocacy movement funded to support these efforts. However, without a long term strategy, effective coordination, or stable funding, this energy slowly dissipated. Nonetheless, pollution prevention is has been successfully integrated as a manufacturing strategy in a large percentage of firms. Given this experience, it is a propitious moment for the Green Chemistry movement to begin to ask a similar set of questions.

First, what does it mean to "mainstream" green chemistry? If mainstreamed, Green Chemistry would be the dominant culture of chemistry and engineering research, education, and policy. Anastas and Warner have stated that Green Chemistry would just be "chemistry" with toxicity or safety being considered as a design attribute alongside cost and performance. Is mainstreaming measured by government activities or integration into the everyday operations of chemical design and manufacturing?

Has the green chemistry movement succeeded? Or more importantly, has the green chemistry movement even started? Despite the current plethora of activities, we have a long way to go to achieve the goal of mainstreaming Green Chemistry or having an organized or coordinated movement. Green Chemistry is still a marginal consideration in chemistry and chemicals research, education and policy. For example:

- Only a very small number of academic institutions teach Green Chemistry or even include a course on toxicology in their chemistry curricula. An even smaller number have degree programs in Green Chemistry. Green Chemistry is not yet a focal element of sustainability education in engineering, social sciences, or business.
- Despite efforts of the GC3, ACS, and others, we have been unable to secure passage of a Green Chemistry Research and Education Act for $25 million, despite similar funds being allocated to study the risks of single chemicals. While the passage of the America Competes Act created a Green Chemistry program at the National Science Foundation, the Act provided no funding. Other major funding agencies, such as National Institutes of Health, the Department of Commerce, or Department of Defense have provided very little funding for Green Chemistry. There are some significant pockets of funding for bio-based materials development, but much of this has focused on fuels development.
- Newer policy proposals, such as the Safe Chemicals Act and most state chemicals policy proposals, give a nod to Green Chemistry but focus primarily on hazard or risk evaluation, labeling, on restricting known chemicals of concern, or in some cases evaluating safer alternatives rather than supporting research and development on Green Chemistry. In fact, Green Chemistry is often mistakenly identified as synonymous with chemicals policy. This has led to Green Chemistry proposals and initiatives that focus more on chemical restrictions or alternatively any sustainability activity in industry, potentially undermining the definition and principles that Warner and Anastas created.
- In contrast with policies on renewable energy, Green Chemistry is still viewed primarily as an environmental rather than an economic development activity. It has received little attention or support from the White House or agencies outside of EPA, which still has only a small and under resourced green chemistry program. NIST has eliminated its Technology Innovation Program under which safer chemistry was a focal area. Green Chemistry has not been viewed as part of "clean tech" and as such has received very little venture capital and other investment funding and even fewer tax and other fiscal incentives.
- Most advocacy, government and business efforts on safer chemicals have focused primarily on the "demand" side of green chemistry such as market and government policies to identify and remove chemicals of concern from products, but have had little focus on the "supply" side, which includes the design of safer alternatives. While there is a significant increase in activity around "alternatives assessment", this has focused primarily on comparing existing chemical alternatives rather than on the design of new molecules.
- While some efforts have been made to advance renewable sources of chemical feedstocks, the primary source of industrial chemicals remains non-renewable petroleum.

- Few company leaders or major industry associations have publicly supported Green Chemistry education, research, development, and application or made it a priority of their firms or organizations.
- We have only a handful of case studies, analyses, or empirical arguments making a strong business case for Green Chemistry.
- Global and disperse supply chains, driven by cost considerations, have made it extremely difficult for firms to obtain the basic information necessary to understand what chemicals are in the products they sell and their potential impacts or to demand or verify the development and application of safer chemistry in their supply chains.
- While there are over 25 states with existing pollution prevention programs, there are only six states have established Green Chemistry initiatives aimed to support supply chain integration, education and economic incentives. Of these, the first state program in Green Chemistry in Michigan faces an uncertain future as its initial funding has expired.
- No effective metrics or means of measuring the growth of Green Chemistry adoption has emerged that could be used to effectively assess the success (or lack thereof) of Green Chemistry

What will it take for green chemistry to succeed? These examples provide some evidence that Green Chemistry has yet to be integrated into the fabric of the chemical enterprise, education or government. If this is the case, what will it take for green chemistry to succeed? There is no doubt that given the current economic climate and the challenges of global production systems, imbedding a paradigm shift toward Green Chemistry will require strategic thinking, coordinated activities, careful planning, resources, and time. It will need a short and long-term strategy to both build and sustain a movement. We believe that the Green Chemistry and Commerce Council can play an important role in this strategic thinking process. At the 8th GC3 Innovators Roundtable, we will engage GC3 members and participants in a discussion of the following questions.

- What are the primary barriers and challenges that are inhibiting the growth and adoption of Green Chemistry?
- What are the most important fundamental and incremental changes (in education, policy, research, incentives) that must occur in the next 10-15 years to mainstream green chemistry?
- For which of these changes is the GC3 most suited to have a meaningful impact?
- What goals, strategies, and programs should the GC3 pursue in the next 3-5 years to help make these changes happen?

This discussion will continue over the coming year with the goal of mobilizing a plan and set of actions toward mainstreaming green chemistry. The GC3 was established eight years ago because participating firms understood the benefits of green chemistry and believed that collaboration was necessary to advance its application in practice. The increasing attention to safer chemistry through supply chains is providing an important impetus for Green Chemistry education, research, and application. By taking the time to review our progress, we can begin to map out a course that will help move us towards achieving a goal that few would disagree with but has remained elusive.