An Agenda to Mainstream Green Chemistry

Green Chemistry & Commerce Council

November 2015

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The GC3 is a program of the The Lowell Center for Sustainable Production.

The Lowell Center for Sustainable Production uses rigorous science, collaborative research, and innovative strategies to promote communities, workplaces, and products that are healthy, humane, and respectful of natural systems. The Center is composed of faculty, staff, and graduate students at the University of Massachusetts Lowell who work with citizen groups, workers, businesses, institutions, and government agencies to build healthy work environments, thriving communities, and viable businesses that support a more sustainable world.

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Letter from the Director

GREEN CHEMISTRY IS AN IMPORTANT FIELD OF PRACTICE THAT BUILDS ON CONVENTIONAL chemistry by ensuring that environment, health, and sustainability are critical criteria for molecular design, similar to performance and cost. Green chemistry applies 12 principles that lead to the use of more sustainable feedstocks, conservation of energy and water, and reduction of waste and toxicity.

The Green Chemistry & Commerce Council (GC3) was formed in 2005 to advance this growing field by bringing together key business leaders, government experts, academic researchers, and environmental and health advocates. One of the GC3's driving philosophies is that challenges in green chemistry research, adoption, and scale can most effectively be solved with cross-sectoral, supply-chain dialogue, collaboration, and partnership.

One of the GC3's driving philosophies is that challenges in green chemistry research, adoption, and scale can most effectively be solved with cross-sectoral, supply-chain dialogue, collaboration, and partnership.

In the ten years since the GC3 was founded, public, government, and marketplace concerns about chemical hazards, resource scarcity, and climate impact have been on the rise. This has led to significant collaborative activity focused on identifying, evaluating, and implementing green chemistry solutions: supply-chain activity on safer, more sustainable chemicals, materials, and products is growing; new research is occurring; new businesses are emerging; partnerships are being formed; and educational programs are expanding—all focused on green chemistry. The growth of green chemistry-related activities in recent years is impressive, clearly demonstrating how the building blocks of the products we use every day can be made in ways that reduce impacts on people and the planet, at competitive prices and with improved performance.

Nonetheless, green chemistry is still viewed primarily as an environmental activity rather than one that, as experience shows, yields economic benefit, and it has yet to be integrated into the fabric of the chemical enterprise, educational systems, or government programs. For example, it has received little attention or support from the White House or agencies outside of the Environmental Protection Agency and the National Science Foundation, which have only small and under-resourced green chemistry programs. The National Institute of Standards and Technology has eliminated its Technology Innovation Program under which safer chemistry was a focal area. Green chemistry has mistakenly not been widely viewed as a key part of "clean tech" and as such has not attracted the type of public or private investment that other clean technologies have. We have a long way to go to get to the point where green chemistry is standard practice

The GC3 sees the vast benefits and opportunities for growth in green chemistry, yet also recognizes that many barriers have kept it a niche consideration. In 2013, the GC3 embarked on an ambitious effort to understand how to "mainstream" green chemistry. The GC3 defines the mainstreaming of green chemistry as being when all chemistry—including chemistry and engineering research, education, and policy—becomes green chemistry.

This GC3 report, *An Agenda to Mainstream Green Chemistry*, integrates existing and original research on green chemistry barriers and accelerators, along with input from our members who are leaders in the field. It describes the importance of green chemistry to our economy and environment, and identifies strategies and actions needed from all corners to significantly accelerate its impact. The GC3 views this *Agenda* as an opportunity to engage with policy makers, investors, firms, researchers, and advocates to move actions forward that will help grow this impor-

In 2013, the GC3 embarked on an ambitious effort to understand how to “mainstream” green chemistry. The GC3 defines the mainstreaming of chemistry as being when all chemistry—including chemistry and engineering research, education, and policy—becomes green chemistry.

tant field of sustainability. This is a living document, and we welcome your thoughts, suggestions, and reactions. Please send them to *mainstream@greenchemistryandcommerce.org*.

Given the current economic climate and the challenges of complex global production systems, embedding a paradigm shift toward green chemistry will require strategic thinking, coordinated and collaborative activities, careful planning, resources, and time. The GC3 will continue to be a strong advocate for and convener of this work, as well as a resource to those who can help support the strategies and actions described in this document. We encourage dialogue and input into this Agenda to Mainstream Green Chemistry so that together we can build innovative solutions that transform and strengthen the chemical enterprise.

We look forward to partnering with you on this journey.

Sincerely,

Joel Tickner, Director
on Behalf of the GC3

Why *An Agenda to Mainstream Green Chemistry*?

OVERVIEW

Ninety percent of manufactured goods are in some way linked to the chemical industry. Yet, despite its many environmental, public health, business, and economic benefits, green chemistry is still only a small part of the chemical enterprise.

Green chemistry is the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances throughout their lifecycles: design, manufacture, use, and end of life. It is a growing field of practice, emerging in the 1990s, that builds on conventional chemistry and engineering by applying 12 fundamental principles that guide the molecular design of sustainable chemical products and processes. Adhering to these principles prevents pollution and waste, leads to synthesis of chemicals in less hazardous and more efficient ways, promotes the use of renewable feedstocks, and leads to the design of safer chemicals. Green chemistry is a solution to the increasing demand for safer products from businesses and individuals.

The Green Chemistry & Commerce Council (GC3) is a business-to-business forum that works collaboratively to accelerate the application of green chemistry across industry sectors and supply chains. Through its Mainstreaming Green Chemistry Project, the GC3 seeks to gain a more in-depth understanding of the drivers and barriers to green chemistry, and to recommend steps to accelerate its growth so that *all chemistry becomes green chemistry*.

This *Agenda to Mainstream Green Chemistry* is one step in this process. Its purpose is to identify actions that, in the short term, will:

- scale innovation in green chemistry,
- elevate the importance of green chemistry in education and research, and
- yield smart policies that support green chemistry markets, research, and innovation.

This document describes the important benefits of green chemistry, identifies barriers to its adoption, makes the case for more public and private sector support to overcome barriers, and identifies five overarching strategies to accelerate the adoption of green chemistry. These strategies are to:

1. ***Enhance Market Dynamics*** by continuing to build a comprehensive, ongoing understanding of green chemistry enablers, market drivers, and obstacles.
2. ***Support Smart Policies*** by designing and advocating for innovative state and federal policies that increase the supply of and demand for green chemistry solutions.
3. ***Foster Collaboration*** by facilitating the flow of information about green chemistry solutions among suppliers and product makers, and assembling partnerships to tackle priority challenges.
4. ***Inform the Marketplace*** by disseminating information about green chemistry business, economic, and health benefits, as well as opportunities and funding.
5. ***Track Progress*** by improving green chemistry metrics and periodically gathering and reporting data on progress.

The GC3 has developed six key actions, based on the above strategies, that it will take to reach its short-term goals, including:

- supporting the proposed federal "Sustainable Chemistry Research and Development Act of 2015," or similar legislation that meets the GC3's criteria for "smart policies" described in this document;
- expanding the development and use of innovative tools that support green chemistry research and adoption;
- convening a national summit on green chemistry research and education;
- building agreement on the priority metrics needed to measure progress in green chemistry and ways to gather such information;
- engaging with public and private sector funding entities to target critical green chemistry needs; and
- continuing to advance collaborative supply-chain partnerships.

The *Agenda to Mainstream Green Chemistry* is the result of literature reviews, in-depth original research, interviews, a survey of GC3 members, lessons from the GC3's first decade of bringing together practitioners and enablers (policy-makers, researchers, and advocates) of green chemistry, and input from an advisory committee comprised of business, government, academic, and not-for-profit leaders.

There is a clear business and economic case for green chemistry, the barriers to increasing its practice are becoming better understood, and the opportunities for collaboration in accelerating green chemistry research, adoption, and scale are growing. The GC3 will continue to play a convening and supporting role to overcome barriers and take advantage of these opportunities in the coming years.

DEFINING GREEN CHEMISTRY

Green chemistry is the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances throughout their lifecycles: design, manufacture, use, and end of life. Green chemistry is a growing field of practice that builds on conventional chemistry and engineering by applying 12 fundamental principles that guide the molecular design of sustainable chemical products and processes.[1] Adhering to these principles prevents pollution and waste, leads to synthesis of chemicals in less hazardous and more efficient ways, promotes the use of renewable feedstocks, and leads to the design of safer chemicals.

HOW GREEN CHEMISTRY IS PRACTICED

Green chemistry incorporates every element of business, from product design to feedstock selection through manufacturing to finished products, including the ways that companies manage their businesses and engage their customers throughout the supply chain.

While green chemistry is practiced primarily at the chemical discovery, development, and formulation levels, product developers, manufacturers, brands, and retailers all play an important role in its implementation. Several ways they do this are by changing design specifications, sourcing materials and products that incorporate green chemistry practices, changing manufacturing practices to substitute or reduce the use of hazardous chemicals, and developing and implementing policies that restrict chemicals of concern in the products they source, make, and/or sell.

Green chemistry can be an iterative process where products are improved incrementally over time, or it can yield a disruptive innovation and offer entirely new technologies and approaches for making safer products.

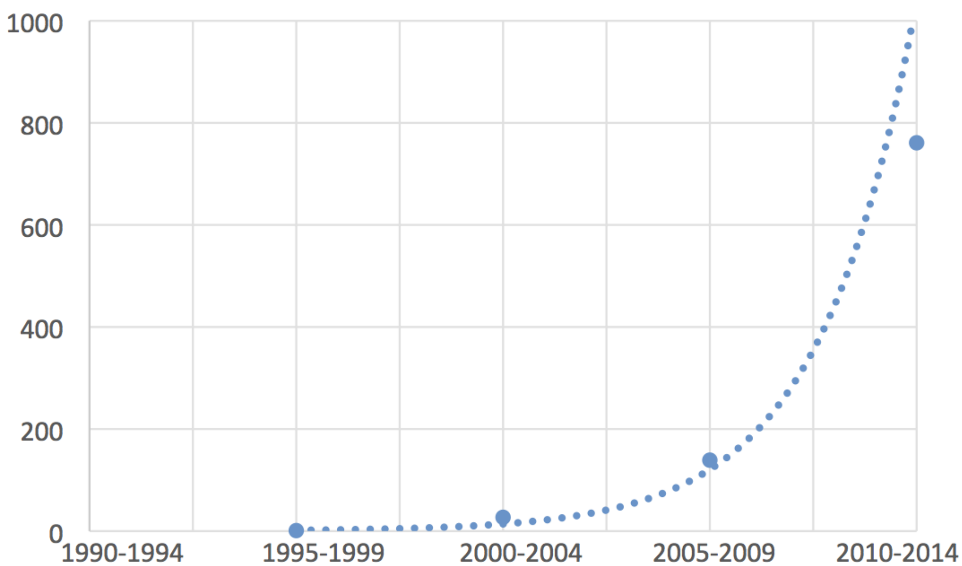
THE GROWTH OF GREEN CHEMISTRY

A report from Pike Research, a consulting firm that analyzes global clean tech markets, estimates that green chemistry is a market opportunity that will grow from $2.8 billion in 2011 to $98.5 billion by 2020, while also saving over $65 billion in direct costs and reduced liabilities.[2] The report identifies three major themes driving the growth in green chemistry: waste minimization in the chemical production process, replacement of existing products with less toxic alternatives, and a shift to renewable (non-petroleum) feedstocks. Market growth in green chemistry has occurred across a range of sectors—e.g., building materials, chemicals, and personal cleaning products—more quickly than that of conventional chemistry.[3]

In the short period of time since the field of green chemistry has emerged, there have been significant and ever-increasing strides in its adoption:

- the Presidential Green Chemistry Challenge, a federal government awards program, has been recognizing innovative green chemistry research initiatives in business and academia since 1996;
- an increasing number of green chemistry research and education conferences are bringing together researchers from around the world to share knowledge and experiences;
- the number of University and K-12 green chemistry research, education, and training programs is growing significantly;
- several states have established green chemistry programs that engage industry, academia, non-profit organizations, and government in building a foundation for green chemistry research, education, and adoption;
- business adoption of green chemistry is expanding: companies across industry sectors are integrating green chemistry into research, design, and development decisions, groups of industries are collaborating to advance the application of green chemistry principles, and the number of innovative, green chemistry- and biomaterials-based start-up companies is on the rise;
- major scientific bodies, such as the President's Cancer Panel and the Centers for Disease Control and Prevention's National Conversation on Chemical Exposures, now acknowledge the need to develop green chemistry solutions to prevent chemical risks;
- new toxicological screening approaches and tools to support designers in developing and selecting safer chemistries are emerging;

FIGURE 1: US Patents Issued for Sustainable Chemistry



Source: Trucost, *Making the Business Case for Safer Chemistry*[4]

- business and institutional purchasers are increasingly specifying products with safer chemistries and finding more products to meet their needs; and
- there has been a significant growth in investments as well as patents relating to sustainable chemistry, of which green chemistry is a subset (see Figure 1, page 7).

Examples abound of companies around the world, both established and emerging, big and small, developing new innovations using green chemistry, and GC3 members and affiliates are leading the way:

- International chemical industry leaders **Dow** and **BASF** together developed a way to synthesize propylene oxide, one of the top 30 chemical intermediates sold worldwide, utilizing green chemistry principles. Their new process reduces wastewater production by 70 to 80% and energy use by 35%, while also reducing the cost of production facilities by 25%.

- California-headquartered outdoor clothing pioneer, **Patagonia**, has invested in the Swiss firm **Beyond Surface Technologies** to develop a water repellant for clothing that is free of perfluorocarbons, which are persistent and bioaccumulative. Beyond Surface Technologies has developed three alternative products that can replace or significantly reduce fossil-based raw materials, have lower toxicity than their alternatives, and in some cases use less water and electricity to produce.

- **The Warner Babcock Institute for Green Chemistry**, based in Massachusetts, has developed and recently introduced to the market Hairprint, a non-toxic, vegetable-based product that restores gray hair to its original color while also improving hair structure. Hairprint uses 9 food-grade vegetable ingredients and avoids the chemicals found in traditional semi-permanent hair dyes that have been linked to allergies, skin irritation, and cancer.

- **Elevance Renewable Sciences, Inc.**, headquartered in Illinois, uses a proprietary Nobel-prize winning technology that turns natural oils into high-performance chemicals that have benefits of both petroleum and bio-based products. This process creates a product with functional attributes that were previously only achievable by blending petro-chemicals and bio-based oleochemicals, reducing source pollution, production costs, and capital expenditures compared to petrochemical refineries.

- **Johnson & Johnson**, headquartered in New Jersey, reaps significant environmental and economic benefits through the use of green chemistry principles in designing and reformulating its active pharmaceutical ingredients (API). The company reduced its raw material use by 64%, water use by 78%, and hazardous waste produced by 87% by applying green chemistry principles to the synthesis of Zytiga®, an API used for patients with prostate cancer. With another API, buprenorphine, the company reduced process mass intensity by 43%, water use by 71%, hazardous waste by 28%, and energy use by 23%.

- **Verdezyne, Inc.**, based in California, has developed a proprietary technology that can ferment a variety of renewable, non-food, plant-based feedstocks to create chemical intermediaries commonly used in nylons and other plastics. Verdezyne's preferred feedstocks cost less than other plant or petroleum inputs, and are not subject to the same types of price volatility and uncertainty of supply. Verdezyne's production methods are expected to generate less CO_2 than petroleum-based processes, offering a reduced carbon footprint.

- Montreal-based company **BioAmber** has partnered with **Bayer MaterialScience** to provide renewable feedstocks for Bayer MaterialScience's new bio-based polyurethane dispersions under the Impranil® eco brand. Impranil® eco can contain up to 65 percent renewable content. These are the first synthetic materials and coated fabrics with a high renewable content. Their bio-based source does not compete with food production.

These examples represent a small number of the many breakthroughs that share a common basis in green chemistry and are transforming how we make products in a more sustainable manner, starting from the chemical building blocks.

THE CASE FOR GREEN CHEMISTRY

A report by the sustainability research firm Trucost entitled *Making the Business Case for Safer Chemistry*,[5] commissioned by the GC3 and the American Sustainable Business Council, identified a number of risks that companies take by not transitioning to safer chemistries. These include the risk of NGO and/or shareholder activism, regulatory risks, costs of incidents and accidents from hazardous materials, product liability, and lost market opportunities. Conversely, companies that pursue safer chemistry can have higher growth rates than conventional markets, increased capital flows, greater market opportunities, and job growth. A 2011 McKinsey survey of 500 executives around the world found that over 80% see green attributes as an important trend that will generate value; low toxicity was one of the top two green attributes mentioned.[6]

A 2014 PricewaterhouseCoopers survey of chemical company CEO attitudes[7] identified a number of CEO concerns that could be addressed through adoption of green chemistry and engineering:

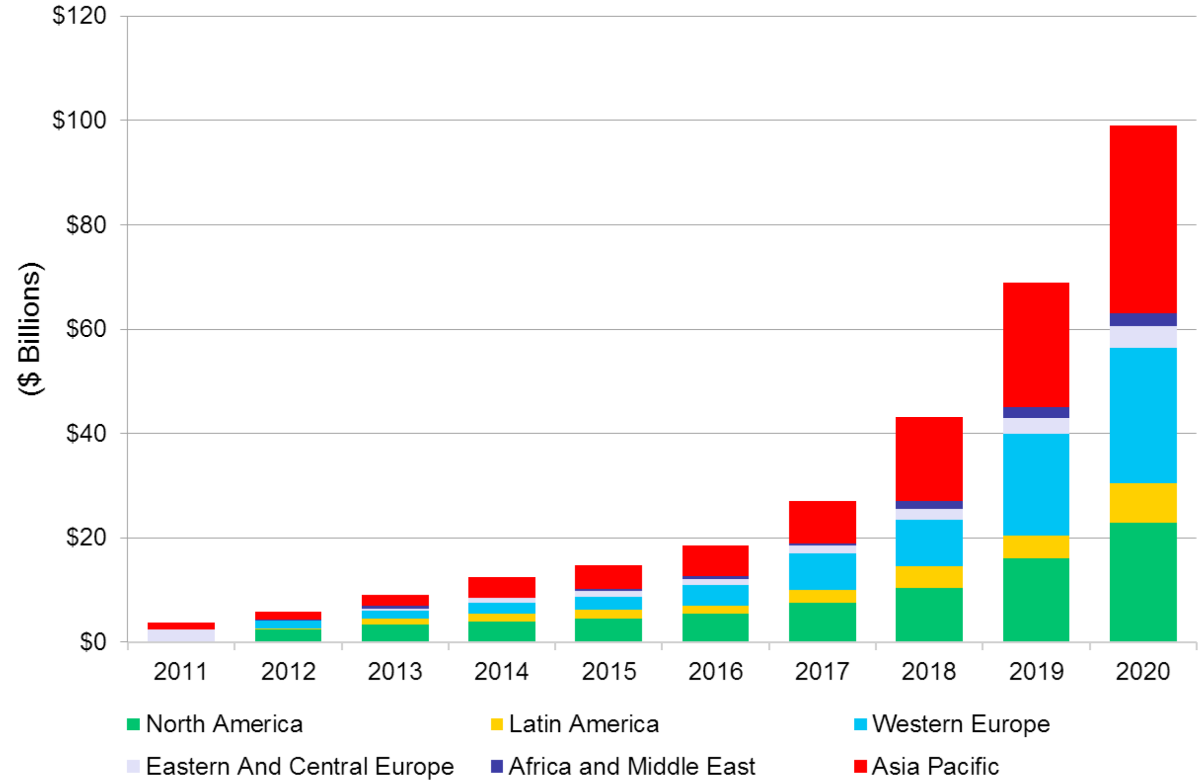
- 91% feel it is important for their companies to measure and reduce their environmental footprints (compared to 81% of all CEOs);
- close to 90% have as a priority altering their R&D and innovation capacity and changing their technology investments;
- 82% worry about high and volatile raw materials prices;
- 75% are concerned about high and volatile energy costs; and
- 61% expect that climate change and resource scarcity will dramatically transform their business environment in the next five years.

Numerous studies have shown that green chemistry provides economic benefits. From 2010 to 2011, the number of US chemical manufacturing jobs classified as "Green Goods and Services" (GGS) positions grew by 7%, whereas total employment in the chemical manufacturing sector decreased by 4%.[8] The US Department of Labor defines GGS as "goods and services produced by an establishment that benefit the environment or conserve natural resources."

A study[9] of the economic benefits of a green chemical economy by the Political Economy Research Institute (PERI) at the University of Massachusetts found that jobs in the chemical industry (not including pharmaceutical companies) have been reduced by 48% between 1992 and 2010 due to off-shoring. The researchers estimate, however, that if 20% of U.S. production were to shift from petrochemical to bio-based plastics (one of the principles of green chemistry), 104,000 jobs would be created in the US, keeping the same production levels. The study finds that green chemistry will make the US chemical industry more competitive by:

- lowering handling and disposal costs,
- opening up access to global markets,
- reducing wastes through efficient inputs,
- meeting demands for safer products more efficiently,
- protecting shareholder value, and
- encouraging research & development.

FIGURE 2: Global Green Chemicals Market by Region: 2011–2020

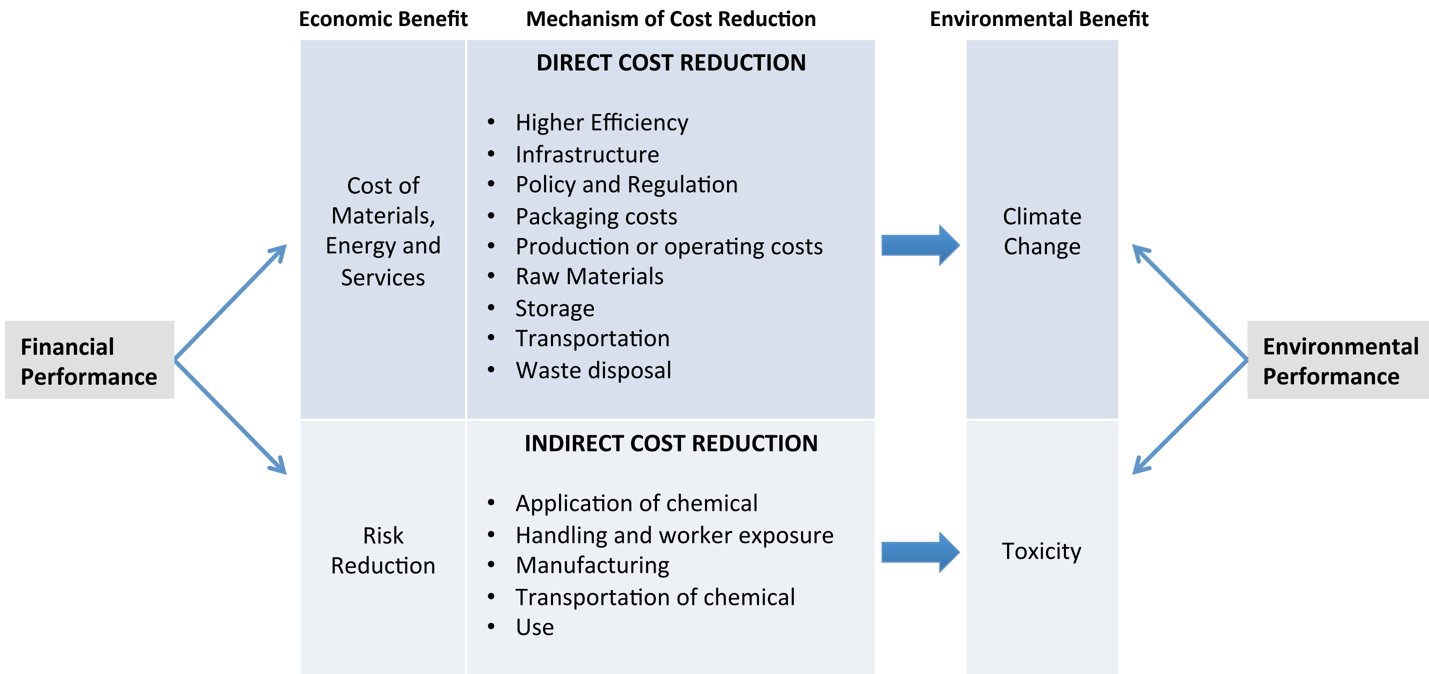


Source: Pike Research, *Green Chemistry Bio-based Chemicals, Renewable Feedstocks, Green Polymers, Less-toxic Alternative Chemical Formulations, and the Foundations of a Sustainable Chemical Industry*[10]

An estimated 90% of all manufactured goods are linked to the global chemical industry.[11] As a result, green chemicals markets around the world have been increasing by tens of billions of dollars per year, with Asia Pacific, Western Europe, and North America as key growth regions (Figure 2).

An analysis of the winners of the U.S. Presidential Green Chemistry award between 2001 and 2010 by researchers at McGill University illustrates both the environmental and business benefits of green chemistry. It found that for these awardees, green chemistry investments reduced the costs of materials, energy, and/or services, and reduced risks. The wide range of industries represented in the awards shows that green chemistry is not just isolated in one part of the economy, but has a place in almost every industry, including agriculture, automotive and transportation, buildings and architecture, bulk and commodity chemicals, electronics, food, fuels, medical devices, paints and coatings, pharmaceuticals, plastics, printing and imaging, pulp and paper, soaps and detergents, and textiles and fibers. Each of the 21 industries identified in the research had from 1 to 18 award-winning innovations, with stated benefits that included reductions in greenhouse gas generation, endocrine disruptors, carcinogens, skin irritants, and wildlife and aquatic toxicants. The business benefits realized were improved performance, cost savings, reduced regulatory burdens, and reduced risk (Figure 3, page 11).[12]

FIGURE 3: Environmental and Economic Benefits Associated with Green Chemistry Investments



Source: Milne, I. and Maguire, S. 2011. *The Business Cases for Green Chemistry*.

GREEN CHEMISTRY DRIVERS

Consumer demand (both individual and institutional) for safer products, as noted in research conducted for the GC3 by Trucost and Tess Fennelly & Associates, is one of the most important drivers for green chemistry.[13] The results of a 2014 survey of 29 GC3 member companies[14]—chemical and product manufacturers, product brands, and retailers—reinforce this finding. The survey also indicates that the most important reasons GC3 member companies pursue green chemistry are concern for worker health and safety and concern for the environment. Other drivers for GC3 companies are competitive advantage, brand fit, and risk avoidance. In Table 1 (page 12), note that the priority of these drivers vary slightly based on business sector.

GC3 businesses want to see green chemistry become the norm because this will help open new markets—both domestically and internationally—for their products, support their concern for worker and environmental safety, make it easier to find qualified workers, and bolster their ability to be innovation leaders.

Well-designed government policies can also be effective drivers of green chemistry activity. Thirty percent of companies receiving Presidential Green Chemistry Awards explicitly stated that regulations were one of their drivers for investing in green chemistry.[15] The nonprofit Center for International Environmental Law (CIEL), has documented that patents in green chemistry tend to increase with chemical regulation.[16] A 2011 survey of 146 chemists from firms with headquarters in 22 countries performed by the Yale Center for Green Chemistry and Green Engineering, the London School of Economics and Political Science, and the OECD Environment Directorate supports the importance of good policy in driving green chemistry in firms. It found that government regulation is a driver in decisions to invest in research and development in green chemistry, and that regulatory structure is the most important policy factor that drives firm behavior. Traditional regulatory requirements and product standards were considered by respondents of that survey to be very important in driving businesses towards more involvement with green/sustainable chemistry, along with mandatory testing and product labeling. Incentive-related policies, such as government R&D financing, were also found by firms to be important drivers of green chemistry.[17]

TABLE 1: Top Ranked Drivers of Green Chemistry by Business Type for GC3 Members

	Chemical Mfr	Product Mfr	Product Brand	Retailer
Concern for Worker Health/Safety	✔	✔	✔	✔
Concern for Environment	✔	✔	✔	✔
Competitive Advantage	✔	✔	✔	✔
Fits Our Brand	✔	✔	✔	✔
Customer Demand	✔	✔	✔	✔
Risk Avoidance/Reduction		✔	✔	✔
Profits Generated	✔			
Cost Savings		✔		
Opens New Markets	✔			

BARRIERS: WHY GREEN CHEMISTRY IS NOT YET MAINSTREAM

Even though green chemistry yields such a wide range of important benefits, there are many reasons why it has not yet become mainstream practice and why it needs more support to become so. A number of surveys and investigations have been conducted by business and academic organizations, including the GC3, to understand green chemistry barriers.[18] These barriers, detailed below, fall into the following categories:

- Development, identification, and evaluation of green chemistry innovations;
- Supply chain alignment;
- Education; and
- Metrics.

Key barriers experienced directly by GC3 members include the high cost to scale up new products, including the time and resource costs it takes to get these to market; the lack of technically and/or economically feasible alternatives; the high cost to research alternatives; and the perceived high cost of alternatives.[19]

Table 2 shows how the priority of these barriers may vary depending on where in the supply chain a company is situated. For example:

- the lack of chemical ingredient disclosure and lack of information about safer alternatives are key barriers for retailers,
- the high cost to scale up is a significant barrier for chemical and product manufacturers, and
- the lack of availability of technically and economically feasible safer alternatives is an important barrier for product manufacturers and brands.

GC3 chemical company members report that bringing new chemical innovations to market can take 5 to 10 years. Time is needed for research and development, testing, regulatory compliance, raising funds, and scaling up a production facility. As a result, according to the 2011 Pike Research study, many manufacturing facilities applying green chemistry principles are still at laboratory or pilot scale, with production-scale plants not expected to be running at capacity for several more years.[20]

The lag time from idea to incorporation of a new substance or material into a product is also a factor. Sometimes chemical companies develop a new product but there is not a strong enough market demand, or no market at the desired price; years later the market may open and it can become more economical to scale up a plant. Many

TABLE 2: Top Ranked Barriers to Implementing Green Chemistry by Business Type for GC3 Member Companies

	Chemical Mfr	Product Mfr	Product Brand	Retailer
High Cost to Scale Up	✔	✔	✔	
Lack of Economically Feasible Alternatives	✔	✔	✔	✔
Lack of Technically Feasible Alternatives		✔	✔	
High Cost to Research Alternatives		✔		
Perceived High Cost of GC Alternatives	✔			
Low Cost of Existing Options	✔			
Lack of Disclosure About Chemicals, Materials, and/or Products Sourced From Suppliers			✔	✔
Lack of Info re: Safer Alternatives				✔
Lack of Available Safer Alternatives			✔	
Perceived Lack of Value in GC	✔			
Lack of Customer Demand	✔			
Conflicting Info re: Chemical Hazards				✔

green chemistry companies are also targeting large, existing chemical markets so adoption can be limited by the lack of ability to feed these markets at required levels of supply, cost, and performance.

Investment in new chemical development is also expensive, ranging from hundreds of millions to over a billion dollars, depending on the type of chemical; chemical companies do extensive research into market trends before making this investment. However, as confirmed by stakeholder dialogues the GC3 has convened between major retailers and chemical companies, chemical companies do not always get a clear message from consumers or their supply-chain customers about the demand for safer alternatives. Even if they do, there are other issues in the supply chain that can slow adoption, such as the need for manufacturers to redesign, reformulate, or test products to incorporate a new alternative.

Other supply chain barriers, described by Tess Fennelly & Associates in research commissioned by the GC3,[21] relate to the number and complexity of supply chains, which can fragment customer demand for a particular chemical. For example, a chemical may be used in a host of different applications, each with different industry requirements, standards, regulations, and customer perceptions and demands. Fennelly identifies six supply chain challenges that are magnified by this fragmentation:

- ***Incumbency:*** The chemical industry is anchored by multi-billion dollar petroleum-based companies with global capabilities. Their products have optimized and proven process economics, well-understood performance data, and well-established customers and markets. This well-embedded infrastructure makes it difficult for new entrants.

- ***Confusion and Switching Risk:*** Confusion exists in the marketplace about what constitutes a toxic or safer chemical, and whether a "better bad" is worth the risk of switching from what is known and understood.

- ***Price/Performance:*** Green chemistry innovations are targeting markets with well-established chemicals with known performance and price. While the full cost profiles of green chemistry products may in fact be better (reduction in hazard handling, disposal costs, etc), they are not necessarily drop-in replacements and there can be additional costs of reformulation and production, as well as changes in product performance.

- ***Supply & Demand:*** Building scale is costly, and processors and producers, key to building demand, are often reluctant to change, and incur transition costs, and rely on a sole source of a chemical.

- ***New Technology Access and Placement:*** Finding a home for new technology is not a guaranteed success. Suppliers struggle to find early adopters of their products, and customers don't know where to find safer products beyond their existing supply chain.

- ***Transparency:*** The increased demand for transparency from manufacturers, retail customers, and others can slow innovation, as the need to protect trade secrets and intellectual property is important in developing new products.

The positive side of the drive to increase transparency, however, is that it improves information flow in the supply chain, making it easier for customers to identify where chemical hazards exist and where market opportunities for green chemistry may be found, thereby supporting the development of safer alternatives.[22]

While there are federal and state incentives for R&D, these are often not leveraged for green chemistry. There are also few federal, state, or local government incentives to support commercial-scale green chemistry companies. Some GC3 member companies have located or are planning to locate outside the U.S. to Canada, France, Thailand, and Indonesia due to attractive location incentives and/or proximity of bio-feedstocks.

Regulations, which can drive green chemistry activity, can also create barriers. One way is by creating uncertainty—the concern that regulations are unclear or may change—which adds risk to industry.[23] In addition, depending on the product, certification of new chemicals or ways of producing them must go through an expensive and time-consuming process of registration with the federal government, even if the product is safer than its predecessor. Some regulations, which focus on risk management rather than risk prevention, do not offer incentives for greener alternatives (such as a fast track for processes that provide environmental or health benefits) and can create a barrier to the implementation of green chemistry.[24]

Green chemistry represents a significant cultural shift in how chemicals are designed and how materials and products are made. It requires a different way of thinking that would evolve from changes in the types of training that chemists, engineers, product designers, and environmental health and safety professionals receive. Building a workforce trained in green chemistry principles, toxicology, life cycle thinking, and sustainability is key. However, while the number of green chemistry academic and continuing education programs is growing, it is still a small number and not enough to transform an industry by providing workers at every skill level—from bench chemists to entrepreneurs. More education is needed, from elementary school through post-graduate, to build the green chemistry ecosystem.

Another reason why green chemistry is not yet mainstream is that the costs of public health and environmental assessment, monitoring, and damage resulting from some conventional chemistry practices are largely externalized and not always borne by individual firms. Therefore, investments in green chemistry that can reduce such impacts, while benefitting society, do not necessarily accrue directly to a company, making it harder to justify new investments that might lessen or eliminate these externalities. In addition, the externalization of these costs artificially lowers the cost of conventional chemistry.

A final barrier to the growth of green chemistry is the lack of good metrics that benchmark progress, ensure movement in the right direction, and track the impact of policies and investments. Because green chemistry isn't a simple checklist of activities or outcomes, it can be challenging to measure what products or processes qualify as green chemistry. Developing key indicators, such as health benefits, can be challenging. This can make it difficult to create support for such activities in firms.[25] Needed as well are metrics that help make the case for green chemistry, for example jobs (numbers, growth, and required skills), business value and growth, actual costs to businesses and society of conventional chemistry, reduction in volume of toxic chemicals used (and increase in safer ones), and research outcomes.

While there is a clear definition of green chemistry, the complexity in its implementation can make it difficult to know what or how to measure, and also makes it difficult to have a common language about its practice. For example, how many or which of the 12 Principles must a company follow for their product or company to be considered as utilizing green chemistry, or what toxicological endpoints should be considered to define an inherently safer molecule? The American Chemical Society's Green Chemistry Institute Chemical Manufacturers Roundtable surveyed its members to identify which green chemistry principles they are implementing and found that companies may only be engaged in implementing some of them, depending on the type of company and breadth of operations.[26] In addition, these principles refer primarily to actions undertaken at the chemical research and development level, while all parts of the supply chain play a role in green chemistry development and adoption; metrics must be developed that encompass all parts of the supply chain. Finally, green chemistry is often a process of continuous improvement and therefore lacks a clear mile marker letting a company know it has "achieved green chemistry."

A summary of barriers can be found in Appendix II.

Five Key Strategies

THE GC3 HAS IDENTIFIED THE FOLLOWING FIVE STRATEGIES AS CENTRAL TO ACCELERATING innovation in and adoption of green chemistry. These strategies will help continue to build an understanding of green chemistry markets and opportunities, lead to policies that overcome barriers and drive innovation, create partnerships that will yield new breakthroughs and markets, shift the marketplace towards safer products, and generate data to track progress and ensure and celebrate positive movement.

1. Enhance Market Dynamics

The GC3 calls for continuing research and dialogue among stakeholders to keep an up-to-date understanding of the changing market factors driving and holding back green chemistry innovation and adoption, and to use this understanding to grow green chemistry practice.

While GC3 members are leaders in green chemistry and understand their individual business drivers and constraints, ongoing dialogue across the supply chain is key to understanding ever-changing market factors. Such market intelligence will help identify the best ways to mainstream green chemistry—from overcoming barriers to growing accelerators. Such market factors include:

- specific and varied barriers faced by companies throughout the value chain
- key leverage points for green chemistry
- how demand can be built for green chemistry solutions domestically and internationally
- models to reduce the high cost of scaling up and to share market and other risks
- critical green chemistry needs or priority challenges to be solved
- where chemicals of concern are being substituted and why
- how the innovation challenges facing companies practicing green chemistry are similar to or different from those in other industries and what lessons can be learned
- why certain chemicals, materials, and finished products designed applying green chemistry principles have succeeded or failed in the marketplace
- how to fulfill the workforce needs of green chemistry employers
- places where transparency demands and need to keep business information confidential are supporting or limiting green chemistry
- identifying where there is a lack of common understanding regarding definitions

2. Support Smart Policies

The GC3 calls for and will support smart state and federal policies that accelerate and enhance green chemistry innovation and adoption.

The right kinds of policies—at the local, state, and federal levels—can drive new technology availability, demand, and adoption. For example, green chemistry education and research funding can lead to new innovations and encourage universities to integrate the teaching of green chemistry principles and practices into their curricula. Policies can drive demand by calling for the purchase of less toxic products and services.

Tax policies favoring green chemistry investment and manufacturing will help companies expand their green chemistry efforts domestically. Smart policies should:

- create and/or support green chemistry research or manufacturing centers
- support collaborative research among universities, industry, and nonprofit organizations
- offer funding, incentives and/or prizes for green chemistry research and commercialization
- support demonstration projects
- provide tax credits for chemistry that uses renewable feedstocks
- track market forces, barriers, and opportunities
- spur government, contractor, and grantee purchasing of products with safer chemistries
- streamline permitting for green chemistry chemical and product manufacturers
- increase education and job training in green chemistry
- provide marketing and technical support to firms through existing federal and state programs
- help market U.S. green chemistry innovations to overseas markets
- foster international collaboration through UNEP and other international green chemistry initiatives
- increase information flow about supply-chain chemical use, toxicity, and alternatives
- responsibly "Fast-Track" patent applications and permitting for green chemistry technologies
- create regulatory frameworks that help reduce uncertainty for industry

3. Foster Collaboration

The GC3 supports efforts that help create collaborations within and among supply chains and industry sectors, and which involve other key stakeholders, for the purposes of growing demand, building capacity, stimulating innovation, and improving information flow.

The GC3 has a history of fostering collaborations that build the green chemistry marketplace. These partnerships have brought together companies in various sectors to accelerate innovation and build the supply of green chemistry products to meet customer demand. GC3 member companies have stressed the importance of such partnerships in developing new innovations and markets. Needed collaborations should:

- create opportunities for companies with chemistry challenges to connect with those who can develop green chemistry solutions
- improve information flow (e.g., about chemicals, demand) up and down the supply chain
- come to a common understanding of goals and terminology
- help understand and address barriers and needs
- identify opportunities and deploy pre-competitive strategies to jointly develop design criteria and green chemistry solutions
- foster alignment within supply chains for new technologies
- build demand for new green chemicals and materials
- identify organizations that want to use new products and technologies
- increase the teaching of green chemistry and hiring of workers with green chemistry expertise
- help integrate green chemistry and green engineering best practices into the fabric of firm culture
- define and communicate opportunities that could significantly improve the ability to effectively implement green chemistry and engineering in chemical manufacturing

4. Inform the Marketplace

The GC3 supports the dissemination of information to the marketplace that supports green chemistry education, research, and practice.

A key way to help markets grow is to get the right kind of information to the people who need it: supply-chain players, policy-makers, academic institutions, advocates, and the general public. Information should be shared that fosters information flow among researchers and companies about green chemistry challenges, needs, opportunities, resources for R&D and scale-up, and new products and innovations. Such information should include:

- available state and federal funding and location incentives
- quantitative data on benefits of green chemistry to businesses, public health, and the environment
- workforce needs of green chemistry employers
- case studies of green chemistry successes
- information on green chemistry alternatives for specific chemical functions
- data on economic indicators of the green chemistry economy, such as number of jobs, revenues, health and other societal indicators, etc.
- information on the cost to society of accidents and incidents from hazardous chemicals use

5. Track Progress

The GC3 supports the development and use of metrics to track and understand green chemistry benefits and progress.

Green chemistry is not always a simple yes/no proposition, but one of continuous improvement, yielding benefits to the economy, environment, and public health. It is therefore important to ensure that metrics at the chemical, material, product, firm, sector, and societal levels encourage forward movement and track progress towards a future where high performing, cost-effective chemicals that minimize negative impacts on humans and ecosystems are the norm. These metrics should:

- measure green chemistry progress at firm, industry, and economy levels
- build on existing, effective economic and sustainability tools and criteria
- set benchmarks that lead to more benign chemistries, materials, products, and processes
- help to understand and build the business and policy cases for green chemistry, such as quantifying business risk from conventional chemistry, revenues, job growth, economic benefits, trends in capital flows, and more
- be periodically evaluated for their effectiveness and usefulness

Taking Action

THE GC3 HAS SET THREE KEY SHORT-TERM GOALS TO GUIDE ITS EFFORTS TO MAINSTREAM green chemistry:

- scale green chemistry innovation;
- elevate the importance of green chemistry in education and research; and
- develop and pass smart policies that support markets, research, and innovation.

To achieve these goals, the GC3 will, in the next two years:

Support the proposed federal "Sustainable Chemistry Research and Development Act of 2015," [27] ***or similar legislation that meets the GC3's criteria for "smart policies"***

The Sustainable Chemistry R&D Act of 2015 contains many of the components that the GC3 considers smart policy, directing the President to establish an interagency Sustainable Chemistry Program to promote and coordinate federal sustainable chemistry research, development, demonstration, technology transfer, commercialization, education, and training activities. This legislation helps to address barriers relating to the perceived lack of value in green chemistry, and the high cost of researching and developing safer alternatives. It would lead to more technically and/or economically feasible safer alternatives. Parts of this legislation have also been integrated into the current draft of Senate Bill 697, the Frank R. Launtenberg Chemical Safety for the 21st Century Act.[28]

Expand the development and use of innovative tools and resources to accelerate green chemistry

The GC3 is launching two new web-based portals to support green chemistry research, development, adoption, and workforce development. The Innovation Portal helps practitioners identify needs and opportunities for green chemistry innovations, links research and business communities, and educates the market about existing green chemistry solutions and R&D efforts. The Safer Chemistry Training for Business website contains tools for continuing education that enhance practitioners' understanding of green chemistry. The GC3 will also revamp its Retailer Portal, a compendium of tools and resources that helps retailers source and sell safer products, speeding their development and expansion into the marketplace. The GC3 will create tools that its members can use to engage with their communities (alma maters, supply chains, colleagues) about green chemistry.

Convene a National Summit on Green Chemistry Research and Education

Similar to the National Dialogue on Climate Change and Health,[29] the GC3 will work with key legislators, federal agencies, academic leaders, and other key stakeholders to convene a National Summit on Green Chemistry Research and Education that will identify needs, develop a vision, and establish priorities for green chemistry research and education. The Summit will amplify efforts already underway by the American Chemical Society's Green Chemistry Institute, Beyond Benign, the Green Chemistry Education Network and others to build a roadmap, curricula, and strategies to enhance green chemistry education, leading to a workforce trained for the economy of tomorrow. Understanding green chemistry is critical for anyone working with supply chains, in product design or development, institutional purchasing, and many other functions in business, government, and academia,

Build agreement on the priority metrics needed to measure progress in green chemistry and ways to gather such information

The GC3 commissioned a white paper, published in 2015,[30] that identifies the landscape of current and potential types of metrics that could be used to measure progress in green chemistry—from the molecular and product levels to the firm and societal levels. In addition, there are other types of metrics, such as numbers of jobs, patents, and revenues, which can track the economic benefits of green chemistry. Metrics comparing safety and health statistics, hazardous waste compliance costs, and workers' compensation claims of conventional versus green chemistry can be used to make the business case for green chemistry. The GC3 will convene key stakeholders to identify priority metrics to measure green chemistry progress in the short and longer terms, and identify needed steps to support the gathering of such information. This will enhance market dynamics by providing information about the impact of policies and programs, and the business case for green chemistry.

Engage with public and private sector funding entities to target critical green chemistry needs

Numerous federal agencies that provide funding for research and development, workforce training, and scaling up of production facilities can direct money towards green chemistry projects, while private venture funders can be helpful in supporting green chemistry start-ups. The GC3 will engage with federal agencies such as the National Science Foundation; Environmental Protection Agency; Departments of Commerce, Defense, and Agriculture; the National Institute of Standards and Technology; and the National Institute of Occupational Safety and Health, as well as policy-makers, in order to open funding channels that support green chemistry needs and yield environmental, public health, and economic benefits. It will also work to inform venture funders of the opportunities in green chemistry, and to identify models and approaches to finance the commercialization of new technologies.

Advance collaborative supply-chain partnerships

The GC3 has had great success bringing together companies to work on pre-competitive collaborations to address pressing market needs. Its Plasticizer Project brought together companies in the electronics supply chain to collaboratively assess the hazards of alternative plasticizers. The assessments, which were made public, have become the basis for company decisions on which plasticizers to select for their products, and have informed the work of stakeholders interested in these materials. The Retailer Leadership Council is engaging major retailers with chemical companies to identify ways to accelerate the supply of products of green chemistry to meet customer demand. The Preservatives Project has convened 12 formulators to identify new green chemistry-based preservatives for use in personal care and household products and accelerate their scale-up. The GC3 will convene at least one new collaborative supply-chain project that will focus on another class of chemicals for which new, safer alternatives are needed, or that will address a critical supply-chain barrier.

A summary of these actions and associated barriers and strategies can be found in Appendix III.

Conclusion

THIS IS A UNIQUE MOMENT IN TIME TO ACCELERATE THE GROWTH OF GREEN CHEMISTRY. OVER THE past decade, concerns about public and environmental health have increased, consumer demand for safer products has grown, and there is uncertainty in petroleum markets, the traditional building block of chemicals. There has also been unprecedented growth in collaborations between sectors and within supply chains to advance safer, more sustainable chemicals and products, and green chemistry research and education. Worldwide, demand for green chemistry is growing and is not expected to change. The business and economic cases for green chemistry have become increasingly clear, while the barriers to green chemistry, still significant, are better understood. The needs and opportunities for partnership in green chemistry research, adoption, and growing scale are not going away.

The GC3 looks forward to working with industry, government, researchers, and advocates that share the goals and vision outlined in this Agenda, and that wish to take meaningful actions with the GC3 to mainstream green chemistry.

APPENDIX 1

The 12 Principles of Green Chemistry[31]

1. POLLUTION PREVENTION

It is better to prevent waste than to treat and clean up waste after it is formed.

2. ATOM ECONOMY

Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.

3. LESS HAZARDOUS SYNTHESIS

Whenever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

4. DESIGN SAFER CHEMICALS

Chemical products should be designed to preserve efficacy of the function while reducing toxicity

5. SAFER SOLVENTS AND AUXILIARIES

The use of auxiliary substances (solvents, separations agents, etc.) should be made unnecessary whenever possible and, when used, innocuous.

6. DESIGN FOR ENERGY EFFICIENCY

Energy requirements should be recognized for their environmental and economic impacts and should be minimized. Synthetic methods should be conducted to ambient temperature and pressure.

7. USE OF RENEWABLE FEEDSTOCKS

A raw material or feedstock should be renewable rather than depleting whenever technically and economically practical.

8. REDUCE DERIVATIVES

Unnecessary derivatization (blocking group, protection/deprotection, temporary modification of physical/chemical processes) should be avoided whenever possible.

9. CATALYSIS

Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

10. DESIGN FOR DEGRADATION

Chemical products should be designed so that at the end of their function they do not persist in the environment and instead breakdown into innocuous degradation products.

11. REAL-TIME ANALYSIS FOR POLLUTION PREVENTION

Analytical methodologies need to be further developed to allow for real-time in-process monitoring and control prior to the formation of hazardous substances.

12. INHERENTLY SAFER CHEMISTRY FOR ACCIDENT PREVENTION

Substance and the form of a substance used in a chemical process should be chosen so as to minimize the potential for chemical accidents, including releases, explosions, and fires.

APPENDIX II

Summary of Key Barriers to Implementing Green Chemistry

Development, Identification, and Evaluation of Green Chemistry Innovations
High cost and long time frame to research, develop, test, and scale up safer alternatives
Perception of lack of value in pursuing green chemistry
Lack of sufficient information available to assess chemical hazards
Lack of financial and policy support for green chemistry research and companies
Regulatory uncertainty
Externalization of costs (public health, environmental degradation) of conventional chemistry
Supply-Chain Alignment
Lack of technically and/or economically feasible safer alternatives
High cost, time, and risk of incorporating alternatives (performance, testing, regulatory, product redesign, etc.)
Perceived high cost of green chemistry alternatives
Lack of transparency in supply chain
Requirements for supply-chain transparency
Incumbency of existing chemicals and markets
Multiple complex supply chains for any given chemical
Risks of switching not shared across supply chain
Supply and demand not in sync
Lack of communication within supply chains
Education
Lack of green chemistry-trained chemists and chemical engineers
Lack of alignment of industry need and academic workforce
Inertia and incumbency of traditional chemistry education
Metrics
Lack of agreement on what should be “counted” as green chemistry
Lack of data to measure progress and make the case for green chemistry benefits

APPENDIX III

GC3 Actions, Barriers Addressed, and Strategies Used

Action	Barriers Addressed	Key Strategies Addressed
Support the proposed federal "Sustainable Chemistry Research and Development Act of 2015," or similar legislation that meets the GC3's criteria for "smart policies"	• Perception of lack of value in pursuing green chemistry • High cost and long time frame to research, develop, test, and scale up safer alternatives • Lack of technically and/or economically feasible alternatives • Lack of green chemistry-trained chemists and chemical engineers	• Enhance Market Dynamics • Support Smart Policies
Expand the development and use of innovative tools and resources to accelerate green chemistry	• High cost and long time frame to research, develop, test, and scale up safer alternatives • Incumbency of existing chemicals and markets • Supply and demand not in sync • Lack of green chemistry-trained chemists and chemical engineers	• Foster Collaborations • Inform the Marketplace
Convene a National Summit on Green Chemistry Research and Education	• Lack of green chemistry-trained chemists and chemical engineers • Lack of alignment of industry need and academic workforce • Inertia and incumbency of traditional chemistry education	• Enhance Market Dynamics • Inform the Marketplace
Build agreement on the priority metrics needed in the short term to measure progress in green chemistry and ways to gather such information	• Lack of agreement on what should be "counted" as green chemistry • Lack of data to measure progress and make the case for green chemistry benefits	• Enhance Market Dynamics • Track Progress
Engage with federal agencies to open funding channels targeted at critical green chemistry needs	• High cost and long time frame to research, develop, test, and scale up safer alternatives • Lack of financial and policy support for green chemistry research and companies • Lack of technically and/or economically feasible safer alternatives • Incumbency of existing chemicals and markets	• Enhance Market Dynamics • Support Smart Policies
Advance Collaborative Supply-Chain Partnerships	• Lack of technically and/or economically feasible safer alternatives • Lack of communication within supply chains	• Enhance Market Dynamics • Foster Collaborations

About the Green Chemistry & Commerce Council (GC3)

THE GREEN CHEMISTRY & COMMERCE COUNCIL (GC3) IS A BUSINESS-TO-BUSINESS FORUM THAT works collaboratively to accelerate the application of green chemistry across industry sectors and supply chains. The GC3 provides an open setting for companies to share information and experiences about the challenges to and opportunities for safer, more sustainable chemicals and products.

Established in 2005, the mission of the GC3 is to make green chemistry standard practice, contributing to innovation, improved public health, and protection of the environment.

The GC3:

- Develops and promotes tools, policies, and business practices to drive the application of green chemistry throughout supply chains;
- Fosters collaboration among businesses, government, non-governmental organizations, and academic researchers; and
- Undertakes cutting edge research, model partnership projects, and outreach and education to leverage development and adoption of green chemistry solutions.

The GC3 works through project groups that may vary from year to year based on the priorities of its members. For a list of current GC3 projects, visit *www.greenchemistryandcommerce.org*.

The GC3 also holds educational webinars, facilitates dialogues, publishes a monthly newsletter, and hosts an annual Innovators Roundtable that brings together experts to explore solutions to green chemistry challenges. GC3 reports and articles, webinars, and meetings provide critical background to support efforts to mainstream green chemistry.

GC3 businesses range from major international corporations to small start-up firms, from those whose business model is based entirely on green chemistry approaches to those that are developing or expanding the green chemistry side of their business practices. Virtually all GC3 companies have formal policies on green chemistry or on restricting certain types of hazardous chemicals, and include green chemistry as an explicit business priority.

GC3 members include chemical companies; product brands; manufacturers that design and/or make items such as apparel and footwear, personal care products, furniture, building products, and electronics; and retailers. Representatives from academic institutions, non-governmental organizations, and government are also members.

Individuals participating in the GC3 work in a wide variety of functions within their companies, including product stewardship, sustainability, research and development, environmental health and safety, and regulatory affairs. GC3 member company revenues account for approximately 7% of US GNP.

The GC3 is coordinated by the Lowell Center for Sustainable Production at The University of Massachusetts, Lowell.

Green Chemistry & Commerce Council Members

(As of November 2015. For an updated list, visit www.greenchemistryandcommerce.org)

3M

ACS Green Chemistry Institute

Advancing Green Chemistry

AkzoNobel Inc.

Aubrey Organics

Avon Products, Inc.

BASF Corporation

Battelle

Beautycounter

Behr Paint

Best Buy Company, Inc.

BioAmber Inc.

Bioindustrial Innovation Canada

Biomimicry 3.8

Bose Corporation

Center for Environmental Health

Chemours

Christ Supplies, LLC

Clean Production Action

Colgate-Palmolive

Community Playthings

Connora Technologies

Construction Specialties, Inc.

Covestro

Cradle to Cradle Products Innovation Institute

Designtex

Dow Chemical Company

DuPont

Eastman Chemical Company

Elevance Renewable Sciences

Environmental and Public Health Consulting

Environmental Defense Fund

Environmental Protection Agency

Forsythia Foundation

Green Advantage Consultants

Green Depot

Green Electronics Council

Green Futures Unlimited

Green Seal, Inc.

GreenBlue

GreenCentre Canada

Herman Miller

Hewlett Packard Company

Investor Environmental Health Network

Johnson & Johnson

L'Oréal

Levi Strauss & Co.

Method Products, Inc.

Minnesota Pollution Control Agency

Naturepedic

NatureWorks LLC

New Balance

NEWMOA

Nike, Inc.

NSF International

NYS Pollution Prevention Institute

Patagonia

Pepper Hamilton LLP

Procter and Gamble Company

Pure Strategies, Inc.

Reckitt Benckiser

Resinate Materials Group

SABIC

San Francisco Department of the Environment

Schneider Electric

Seventh Generation

Shaw Industries Inc.

Solazyme

Staples, Inc.

State of Oregon, Department of Environmental Quality

Steelcase Inc.

Target

Tetrahedron

The Wercs Ltd

thinkstep

Timberland

Toxics Use Reduction Institute (TURI)

ToxServices, LLC

UL Environment

University of Toledo

Valspar Corporation

Verdezyne

VF Corporation

Washington State Department of Ecology

Endnotes

1 U.S. EPA. 2015. Basics of Green Chemistry. Accessible at: *http://www2.epa.gov/greenchemistry/basics-green-chemistry*; Warner Babcock Institute for Green Chemistry. 2015. About Green Chemistry. Accessible at: *http://www.warnerbabcock.com/green-chemistry/about-green-chemistry*; Center for Green Chemistry and Green Engineering at Yale. 2015. Green Chemistry and Green Engineering Defined. Accessible at: *http://greenchemistry.yale.edu/green-chemistry-green-engineering-defined*.

2 Atkinson, Andrew and Wheelock, Clint. 2011. Green Chemistry Bio-based Chemicals, Renewable Feedstocks, Green Polymers, Less-toxic Alternative Chemical Formulations, and the Foundations of a Sustainable Chemical Industry. Executive Summary. Pike Research. Accessible at: *http://www.navigantresearch.com/wp-content/uploads/2011/06/GCHEM-11-Executive-Summary.pdf*

3 Trucost. 2015. Making the Business & Economic Case for Safer Chemistry. April 24, 2015, "Theme 1, Market Growth." Accessible at: *http://www.greenchemistryandcommerce.org/documents/trucost_gc3_report_april2015.pdf*

4 Trucost. 2015. Making the Business & Economic Case for Safer Chemistry. April 24, 2015, "Theme 2, Trends in Capital Flow."Accessible at: *http://www.greenchemistryandcommerce.org/documents/trucost_gc3_report_april2015.pdf*

5 Trucost. 2015. Making the Business & Economic Case for Safer Chemistry. April 24, 2015. Accessible at: *http://www.greenchemistryandcommerce.org/documents/trucost_gc3_report_april2015.pdf*

6 McKinsey and Company. 2012. McKinsey on Chemicals, Number 4, Spring 2012. Exhibit 2, Industry Executives regard recyclability and low toxicity as the most important green attributes. Accessible at: *http://www.mckinsey.com/client_service/chemicals/latest_thinking/mckinsey_on_chemicals_issue_4*

7 PwC, 17h Annual CEO Survey, 2014. Fit for the Future, Capitalizing on Global Trends, Accessible at *http://read.pwc.com/i/243985-pwcs-17th-annual-global-ceo-survey*

8 Trucost. 2015. Making the Business & Economic Case for Safer Chemistry. April 24, 2015. "Theme 4, Job Growth." Accessible at: *http://www.greenchemistryandcommerce.org/documents/trucost_gc3_report_april2015.pdf*

9 Heintz, James and Robert Pollin. 2011. The Economic Benefits of a Green Chemical Industry in the United States Renewing Manufacturing Jobs While Protecting Health and the Environment. Political Economy Research Institute (PERI) University of Massachusetts, Amherst, May, 2011. Accessible at: *http://www.peri.umass.edu/fileadmin/pdf/other_publication_types/green_economics/Green_Chemistry_Report_FINAL.pdf*

10 Atkinson, Andrew and Wheelock, Clint. 2011. Green Chemistry Bio-based Chemicals, Renewable Feedstocks, Green Polymers, Less-toxic Alternative Chemical Formulations, and the Foundations of a Sustainable Chemical Industry. Executive Summary. Pike Research. Accessible at: *http://www.navigantresearch.com/wp-content/uploads/2011/06/GCHEM-11-Executive-Summary.pdf*

11 ING Investment Management. 2013. ING Sustainable Investments, Report Q4 2013. Amsterdam

12 Milne, I. and Maguire, S. 2011. The Business Cases for Green Chemistry. 15th Annual Green Chemistry Conference and Engineering Conference, in concert with the 5th International Conference on Green and Sustainable Chemistry, Washington, D.C. June 21-23

13 Tess Fennelly & Associates. 2015. Advancing Green Chemistry: Barriers to Adoption & Ways to Accelerate Green Chemistry in Supply Chains. March 2015. Accessible at: *http://greenchemistryandcommerce.org/assets/media/images/Publications/Advancing-Green-Chemistry-Report-15-June-2015.pdf*

14 Green Chemistry and Commerce Council. 2014. GC3 Mainstreaming Green Chemistry Business Member Survey. Accessible at: *http://greenchemistryandcommerce.org/projects/mainstreaming*

15 Milne, I. and Maguire, S. 2011. The Business Cases for Green Chemistry. 15th Annual Green Chemistry Conference and Engineering Conference, in concert with the 5th International Conference on Green and Sustainable Chemistry, Washington, D.C. June 21–23.

16 Tuncat, Baskut. 2013. Driving Innovation: How Stronger Laws Help Bring Safer Chemicals to Market. The Center for International Environmental Law. February, 2013. Accessible at: *http://www.ciel.org/Publications/Innovation_Chemical_Feb2013.pdf*

17 Organisation for Economic Co-operation and Development, Environment. 2012. The Role of Government Policy in Supporting the Adoption of Green/Sustainable Chemistry Innovations. OECD Health and Safety Publications, Series on Risk Management No. 26, Paris. ENV/JM/MONO(2012)3. Accessible at: *http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2012)3&doclanguage=en*

18 Matus, K et al. 2012. Barriers to the Implementation of Green Chemistry in the United States. Environmental Science and Technology, 6 (20), pp 10892–10899; Giraud, Robert et al. 2014. Implementing Green Chemistry in Chemical Manufacturing: A Survey Report. ACS Sustainable Chemistry and Engineering, 2 (10), pp 2237–2242; Green Chemistry and Commerce Council. 2014. GC3 Mainstreaming Green Chemistry Business Member Survey. Accessible at: *http://greenchemistryandcommerce.org/projects/mainstreaming*; Leger, Lynn. 2014. Perceptions and Experiences of Practitioners, March 26, 2014 webinar for Green Chemistry and Commerce Council. Accessible at *http://www.greenchemistryandcommerce.org/assets/media/images/leger%20gc%20mainsrtreaming%203-26-14%20webinar%20slides.pdf*

19 Green Chemistry and Commerce Council. 2014. GC3 Mainstreaming Green Chemistry Business Member Survey. Accessible at: *http://greenchemistryandcommerce.org/projects/mainstreaming*

20 Atkinson, Andrew and Wheelock, Clint. 2011. Green Chemistry Bio-based Chemicals, Renewable Feedstocks, Green Polymers, Less-toxic Alternative Chemical Formulations, and the Foundations of a Sustainable Chemical Industry. Executive Summary. Pike Research. Accessible at: *http://www.navigantresearch.com/wp-content/uploads/2011/06/GCHEM-11-Executive-Summary.pdf*

21 Tess Fennelly & Associates. 2015. Advancing Green Chemistry: Barriers to Adoption & Ways to Accelerate Green Chemistry in Supply Chains. March 2015. Accessible at: *http://greenchemistryandcommerce.org/assets/media/images/Publications/Advancing-Green-Chemistry-Report-15-June-2015.pdf*

22 Green Chemistry and Commerce Council. 2011. Meeting Customers' Needs for Chemical Data: A Guidance Document for Suppliers. Accessible at: *http://www.greenchemistryandcommerce.org/downloads/GC3_guidance_final_031011.pdf*

23 Organisation for Economic Co-operation and Development, Environment. 2012. The Role of Government Policy in Supporting the Adoption of Green/Sustainable Chemistry Innovations. OECD Health and Safety Publications, Series on Risk Management No. 26, Paris. ENV/JM/MONO(2012)3. Accessible at: *http://www.oecd.org/officialdocuments/public displaydocumentpdf/?cote=env/jm/mono(2012)3&doclanguage=en*

24 Matus, K et al. 2012. Barriers to the Implementation of Green Chemistry in the United States. Environmental Science and Technology, *6* (20), pp 10892–10899.

25 Matus, K et al. 2012. Barriers to the Implementation of Green Chemistry in the United States. Environmental Science and Technology, *6* (20), pp 10892–10899.

26 Giraud, Robert et al. 2014. Implementing Green Chemistry in Chemical Manufacturing: A Survey Report. ACS Sustainable Chemistry and Engineering, *2* (10), pp 2237–2242.

27 S.1447 - Sustainable Chemistry Research and Development Act of 2015, 114th Congress (2015-2016). Accessible at: *https://www.congress.gov/bill/114th-congress/senate-bill/1447*

28 S.697—Frank R. Lautenberg Chemical Safety for the 21st Century Act, 114th Congress (2015-2016). Accessible at: *https://www.congress.gov/bill/114th-congress/senate-bill/697/text*

29 The White House. 2015. FACT SHEET: Obama Administration Announces Actions to Protect Communities from the Health Impacts of Climate Change at White House Summit, Accessible at: *https://www.whitehouse.gov/the-press-office/2015/06/23/fact-sheet-obama-administration-announces-actions-protect-communities*

30 Blake, Ann. 2015. Measuring Progress Towards Green Chemistry: A White Paper Commissioned by the Green Chemistry and Commerce Council. October, 2015. Accessible at *http://greenchemistryandcommerce.org/projects/mainstreaming*

31 Warner Babcock Institute for Green Chemistry. 2015 12 Principles of Green Chemistry. Accessible at: *http://www.warnerbabcock.com/green-chemistry/the-12-principles*

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