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Abstract

The Harvard-Yale-ACS GCI Green Chemistry Project is investigating the overall question of the circumstances under which firms can enact innovations that have both economic and environmental benefits, through a focused examination of the implementation of green chemistry. The research project has taken up three fundamental, interrelated questions: What factors act as barriers to the implementation of green chemistry? What actions can be taken by the government, academia, NGO's and industry that will help alleviate these factors? What are the policy implications of these barriers and potential actions, for all of the involved stakeholders?

During its initial phases, through interviews with a dozen green chemistry leaders from industry and academia, and through a multi-stakeholder workshop, the project has focused on the first two questions, and is working towards the third. Overall, we determined that there are six major classes of barriers to the implementation of green chemistry: economic, regulatory, technical, organizational, cultural and definition and metrics. From the workshop participants, six major action themes emerged to address these. They are: create incentives for the development and implementation of innovations; consider policies to shift focus to hazard reduction; facilitate linkages, networks and collaborations; act as a facilitator for multi-stakeholder initiatives; promote actions that make environmental and health impacts a larger part of the decision calculus; and support research, knowledge creation, and educational efforts to support green chemistry across a range of disciplines and problem areas.

Keywords: green chemistry, innovation, chemical policy, environmental technology

JEL codes: O14, O31, O33, O38, Q56

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It is available at http://www.cid.harvard.edu/cidwp/155.htm. Comments are welcome and may be directed to the corresponding author, kira_matus@ksgphd.harvard.edu.

The Sustainability Science Program at Harvard's Center for International Development seeks to advance basic understanding of the dynamics of human-environment systems; to facilitate the design, implementation, and evaluation of practical interventions that promote sustainability in particular places and contexts; and to improve linkages between relevant research and innovation communities on the one hand, and relevant policy and management communities on the other. See http://www.cid.harvard.edu/sustsci.

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Kira JM Matus[1], Paul T Anastas[2], William C Clark[1], Kai Itameri-Kinter[3]

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The Harvard-Yale-ACS GCI Green Chemistry Project is investigating the overall question of the circumstances under which firms can enact innovations that have both economic and environmental benefits, through a focused examination of the implementation of green chemistry. The research project has taken up three fundamental, interrelated questions: What factors act as barriers to the implementation of green chemistry? What actions can be taken by the government, academia, NGO's and industry that will help alleviate these factors? What are the policy implications of these barriers and potential actions, for all of the involved stakeholders?

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Table of Contents

I. Executive Summary: The Harvard-Yale-ACS GCI Green Chemistry Project

What We Asked

For fifteen years, green chemistry advocates have touted the benefits of a set of guiding principals which confer both environmental and economic advantages for industry and society. There have been a number of noteworthy successes in this endeavor across a number of sectors, which have served as examples to the larger chemical community. Yet for all of the movement on the scientific front, and for all of the truly innovative work done by some firms, green chemistry has yet to become a fundamental operating strategy in the majority of chemical firms. Why is this the case? Is it simply another example of the generic difficulties of implementing technological innovation? Are there aspects of the chemical enterprise that make this particular challenge unique? What is the impact of the environmental aspect of green chemistry that makes its implementation different from other chemical innovations?

The Harvard-Yale-ACS GCI Green Chemistry Project's goal is to investigate the overall question of the circumstances under which firms can enact innovations that have both economic and environmental benefits, through a focused examination of the green chemistry case. The research project has taken up three fundamental, interrelated questions.

1. What factors act as barriers to the implementation of green chemistry?
2. What actions can be taken by the government, academia, NGO's and industry that will help alleviate these factors?
3. What are the policy implications of these barriers and potential actions, for all of the involved stakeholders?

During its initial phases, through interviews with a dozen green chemistry leaders from industry and academia, and through a multi-stakeholder workshop, the project has focused on the first two questions, and is working towards the third. The process is highly iterative- initial work has been focused on these questions within the domestic, United States context. The preliminary responses to the three basic questions within this limited, United States scope, will in turn inform future investigation into the larger, global outlook.

What We Found

For each phase of the research, we have been able to construct preliminary answers to the questions being addressed. The project began with a focus on the historical barriers to the implementation of green chemistry. Those who had successfully adopted green chemistry provided descriptions of the process, including the many challenges that had to be overcome. Many of them, in the course of successfully implementing green chemistry, had also experienced less positive outcomes. Through interviews, we were able to probe these experiences, and correlate between cases that spanned a range of sectors. Overall, we determined that there are **six major classes of barriers** to the implementation of green chemistry.

1. **Economic and Financial:**
    a. High capital costs
    b. Uncertainty of future benefits
    c. Reluctance to abandon sunk capital in mandated mitigation technologies
2. **Regulatory**
    a. Regulatory emphasis on exposure reduction, not hazard reduction
    b. Regulatory disincentives (i.e. recertification)
    c. Lack of regulatory incentives (i.e. fast-tracking or fee reduction) for greener alternatives
    d. Lack of funding for research
3. **Technical**
    a. Lack of available substitutes for problematic reactions, solvent systems
    b. Difficulty in accessing existing technical and scientific knowledge
    c. Difficulty in sharing information across industry
    d. Lack of chemists and engineers with appropriate training
4. **Organizational**
    a. Intraorganizational conflicts between divisions, plants, products, etc…
    b. Lack of support at executive or technical level
    c. Lack of understanding in sales and marketing
5. **Cultural**
    a. Not enough awareness in larger chemical community
    b. Not enough awareness on the part of consumers and the general public
    c. Negative connotations associated with "green:"
        i. More expensive
        ii. Less effective
        iii. Not rigorous science
6. **Definition and Metrics**
    a. Confusion as to what defines something as being "green chemistry"
    b. Difficulty with optimizing over multiple dimensions
    c. Lack of widely applicable metrics for measuring level of "green"

Once these barriers had been identified, we then asked thirty workshop participants to consider what actions each of four stake-holder groups (academics, regulators, NGO's and industry) could take in order to mitigate these barriers not just for themselves, but for other groups as well. From the broad list of actions proposed (see Section VII), six major action themes emerged.

1. Create **incentives for the development and implementation** of innovations- and avoid dictating required technologies or approaches.
2. Consider policies to **shift focus to hazard reduction-** not just exposure control.
3. **Facilitate linkages, networks and collaborations** that positively impact the exchange of information, expertise, tools, etc…
4. **Act as a facilitator for multi-stakeholder initiatives** to create and enforce green chemistry metrics and standards.
5. **Promote actions that make environmental and health impacts a larger part of the decision calculus.**
6. **Support research, knowledge creation, and educational efforts** to support green chemistry across a range of disciplines and problem areas.

What We Do Next

The project has several important tasks remaining in order to reach its goal of answering its three core questions. The first is to build upon the action themes that emerged from the workshop, in order to **construct a framework for effective green chemistry policy** in the United States. This will be accomplished through small, focused brainstorming meetings. One will be with regulators from the state and federal levels, and will concentrate on identifying the most useful policy tools available at different regulatory levels. The other meeting will bring together members of the industrial community in order to map out what existing policies and regulations act as considerable disincentives to the implementation of green chemistry innovations. Once we have completed the construction of a policy framework based on the results of these meetings and the previous work, we will have preliminary answers in hand for all three of the core questions.

The second task remaining for the project is to broaden the outlook beyond the United States context, to take into account the international nature of the chemical enterprise, and the important impacts of globalization on the future outlook for green chemistry. We have begun conducting interviews with members of the academic, industrial, and regulatory communities involved with green chemistry in China, and will be expanding to include India in this effort within the year. As two of the largest emerging players in the chemical enterprise, understanding how the answers to the three core questions change for each differing geographic context will provide a more robust answer to the project's underlying goal of understanding how to successfully implement innovations for sustainable development.

II. Introduction to the Harvard-Yale- ACS Green Chemistry Institute's Green Chemistry Project

The Harvard-Yale- ACS Green Chemistry Institute's Green Chemistry Project is working to elucidate the underlying causes of the barriers to the implementation of green chemistry technologies in the United States, with a view towards using its findings to inform the design of future policies.

There has recently been increasing attention focused on the need to deal with the challenges of sustainability. Sustainability as defined by the Brundtland Commission calls for meeting the needs of the current generation while preserving the ability of future generations to meet their needs. The role of scientists, engineers, and policymakers on all scales is central and essential to determining if and how quickly we move towards a sustainable future. Green chemistry, along with the complimentary fields of green engineering, industrial ecology, and sustainability science represent examples of the critical emerging disciplines necessary to realize this goal. Each of these disciplines/ meta-disciplines works at different scales and with different focus areas to make fundamental contributions to advancing sustainability. Green chemistry, however, is one of the most fundamental of these fields in that it focuses on the molecular level to design chemicals and materials to be inherently non-hazardous. Given the expansive use of chemicals throughout the economy and society, creating benign chemicals will have far reaching effects by providing engineers and industrial ecologists with the necessary building blocks in the design of sustainable products, processes, and systems.

The challenge of promoting greater adoption of green chemistry innovations is substantial because green chemistry is a disruptive emerging technology embedded in a complex scientific, political, regulatory, economic, industrial and cultural framework. Innovations in green chemistry are innovations in a large system that spans borders between nations, between industries, and between scientific disciplines. This project seeks to elucidate the underlying causes of the barriers to the implementation of green chemistry technologies in the United States, with a view towards using its findings to inform the design of future policies.

Background and History of Green Chemistry

In 1991, the US Environmental Protection Agency (EPA) launched the US Green Chemistry Program with the first research initiative in Green Chemistry. This Program has served as a focal point for major activities within the United States, such as the Presidential Green Chemistry Challenge Awards and the annual Green Chemistry and Engineering Conference. In subsequent years, Italy, the United Kingdom, Japan and Australia have launched major initiatives in green chemistry.

Most often, Green Chemistry initiatives are launched by cooperative groups of non-governmental organizations (NGO), academic institutions and the private sector. The single largest effort is by the Green Chemistry Institute (GCI), which was incorporated in 1997 with the mission of promoting and advancing green chemistry and has chapters in 27 countries.

Green chemistry has also made progress in the area of education. The training of next generation of scientists and engineers in the methodologies, techniques, and principles that are central to green chemistry is vital to its success. To this end, professional societies, private industry, and the educational community have worked together to develop textbooks, case studies, laboratory experiments, and training opportunities for students, teachers, and faculty. Additionally, private industry has also begun to retrain their current workforce, encouraging green chemistry innovations through in-house award programs and salary bonus incentives (e.g. Pfizer, Rohm and Haas).

Current State of Implementation of Green Chemistry

The research, development, and implementation of green chemistry has already led to significant economic gains for many private firms with accompanying environmental, health and safety benefits for society. The breadth of Green Chemistry's applicability can be seen through its many areas of accomplishment spanning agriculture, energy, materials, electronics, automotive, and consumer goods. Several industrial sectors have been true pioneers in their adoption of green chemistry principles by recreating the approach to designing the next generation of chemicals and materials. These include polymer manufacturers, textile producers, and pharmaceuticals developers. Some illustrative examples of Green Chemistry accomplishments include[4]:

- a dramatically more effective fire extinguishing agent that eliminates halon and utilizes water in combination with an advanced surfactant;
- production of large scale pharmaceutical active ingredients without the typical generation of thousands of pounds of toxic waste per pound of product;
- elimination of arsenic from wood preservatives that are used in lumber applied to decks and playground equipment;
- higher performance automotive coatings that remove the substantial lead content and replace it with the relatively benign element yttrium;
- introduction of the first commodity bio-based plastic that has the performance qualities needed for a multi-million pound application as a food packaging for Wal-Mart;
- a new solvent system that eliminates large scale ultra-pure water usage in computer chip manufacture, replacing it with liquid carbon dioxide which allows the production of the next generation of nano-based chips;
- a class of pesticides that focus exclusively on the unique characteristics of the target pest and biodegrading to innocuous bioproducts after use in the environment.

Research Vision

While the benefits of Green Chemistry have been and continue to be demonstrated across the chemical enterprise, the widespread penetration and implementation of green chemistry has been impeded by its fundamental and disruptive nature.

Analysis of the impediments to Green Chemistry is an important aspect to understanding its potential for widespread adoption. Candidates include key regulatory impediments,

[4] For details about award-winning Green Chemistry accomplishments, see http://www.epa.gov/greenchemistry

knowledge impediments, metrics impediments, and impediments that are the result of the institutions, culture and infrastructure particular to the chemical sector. This project will examine the role that all these have played in bringing about the current state of Green Chemistry, and what that implies for the future. This will allow us to construct a framework for the circumstances under which the implementation of Green Chemistry is in fact viable.

Given the breadth and depth of the importance of chemicals to the economy and society, Green Chemistry provides an ideal platform for the analysis of innovation for sustainable development. Currently, the chemical enterprise presents challenges to the environment, economy, and society, but it also offers unique opportunities to advance the goal of sustainability through innovations in chemical product and process design. It represents a promising area of emerging technologies in terms of potential contributions to sustainability. The findings of this work will be used to inform the scientific, policy, and business community of a framework for how and under what conditions adoption of radical innovations for sustainable development is most viable and can be most effective.

Plan of Action- Phase I

This project will build on expertise at Harvard's Kennedy School of Government in tackling issues surrounding implementation of innovations in related fields, such as energy and metals, as well as on the subject-specific knowledge of the Green Chemistry Institute and its connections with the chemical enterprise. In order to undertake this study, the authors have assembled a steering committee with expertise in sustainability, science, and technology. The steering committee generated a list of another dozen key individuals that are leaders in industry with knowledge of Green Chemistry, who were then engaged in an initial investigation of the barriers to implementation, the findings of which are reported in Section III of this report. This team of collaborators worked with the authors in an initial exploration of the impediments to the more extensive adoption of green chemistry innovations.

The information gleaned from this initial exploration was the basis of a document that the authors prepared and presented to a workshop of approximately thirty interested and qualified individuals from industry, academia, government, and non-governmental institutions[5]. The workshop, which took place on February 22nd and 23rd, 2007, provided an opportunity for focused reflection on the initial findings of the study. This report of the interviews and workshops reflects the desired goals of greater understanding of the unique impediments to implementing Green Chemistry in industry, the underlying causes of these impediments, policy levers that can be used to address these issues, and the appropriate next steps both for the participants, and the research project overall.

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[5] The lists of members of the steering committee, the participants in the interviews, and the workshop participants can all be found in the Appendix 2.

III. Report from Interviews: The Barriers to the Implementation of Green Chemistry in the United States

Introduction to the Barriers

What are the barriers that slow or prevent the implementation of green chemistry? In particular, which of these barriers are the most particular to the chemical enterprise, as opposed to the more general problems associated with implementing technical innovations in well established industries?

Preliminary research indicates that there are a complex set of intertwined issues that act as barriers to the effective implementation of green chemistry within the chemical enterprise. They broadly fall into the categories of economic and financial, regulatory, technical, organizational, cultural, and even definition and measurement. These categories themselves have significant interactions and overlaps between them. Increasingly, the research is demonstrating that one of the problems unique to the widespread implementation of this (and most likely other) innovations in the chemical enterprise is the sheer complexity and diversity of the industry itself.

The Chemical Enterprise: Complex and Intertwined

The sectors of industry that fall under the chemical enterprise umbrella are both large and diverse. They range from pharmaceuticals to textiles, from pesticides to paper, from petroleum products to specialty chemicals, plastics, and just about everything in-between. It is not unusual for a company that specializes in a consumer product like sporting goods to evaluate its processes and discover that it is also in the business of large-scale chemical production. The variety and ubiquitousness of the use and production of chemicals within industry represents the first barrier. Many firms that fall into the chemical umbrella may not see themselves as such, which makes the dissemination of information to these arenas much more difficult.

Furthermore, diversity within industry extends beyond product lines, but also includes the particular kinds of barriers that different firms face when they decide to implement green chemistry. There is a huge variety of technical knowledge within the industry, much of it highly contextual. There are also very different experiences with regulations. Pharmaceutical firms are concerned that they may have to deal with the costly and time-consuming process of FDA recertification every time that it changes a production process. Other firms may need to recertify with the EPA or other environmental agencies abroad if they change the formulation of a pesticide. Still other sectors may not have to deal with any regulatory re-certifications due to changes in their process. This is just one aspect in which diversity in the broader chemical enterprise affects how and where green chemistry is easy (and difficult) to implement. Similar diversity can be found between the particular cultures, organizational structures, and financial situations throughout the chemical enterprise. This means that any particular sector, or even any particular firm, may find itself facing a unique group of barriers, depending on its suite of products, which makes it difficult for learning and knowledge transfer to take place between firms and across sectors.

Many of the sectors in the industry are highly intertwined, which means that firms within the chemical enterprise occupy a variety of positions along the supply chain, from primary production (i.e. petrochemicals) all the way to consumer products. Some firms face demand from the consumer market, others are focused on industrial and business to business (B2B) markets, and some firms may deal with both. The needs of these very different markets add to the complexity of evaluating potential barriers to green chemistry.

Despite this diversity, there are many barriers which appear to be common to many sectors of the chemical enterprise. They include economic, financial, regulatory, technical, organizational, cultural, and barriers that arise from differing opinions as to what constitutes green chemistry, and how it should be measured (metrics).

Economic and Financial

Within the chemical enterprise, a new product or process based on green chemistry must meet two criteria- economic and environmental performance. The product or process must not only represent an improvement for health and the environment, but it must also be more profitable, without sacrificing efficacy or quality. In the case of an existing product, changes in the production process or formulation must represent enough of a potential cost savings that the short-term costs are outweighed. For example, Pfizer has saved millions of dollars to date from Presidential Green Chemistry Award winning changes to the process to synthesize sertraline, the active ingredient in Zoloft. The resulting revenue increase was enough to overcome the costs, which went beyond capital investment and included all of the costs associated with the time-consuming process of recertifying the drug with the FDA. A small decrease in costs associated with waste, or the use of less dangerous or more efficient processes, may not be enough to justify large changes, which can be a significant barrier to implementation, especially when exact savings are uncertain or hard to quantify.

There are also other financial barriers. Many chemical enterprises are highly capital intensive, and firms will be reluctant to abandon their previous investments. The costs of shuttering an old, inefficient plant can be very high, leaving firms without the resources to then re-invest in new technologies. Building new chemical infrastructure can also be very expensive, and the high upfront costs can be a significant barrier to implementation of greener chemical processes. Depending on the sector, many operations that are under the chemical umbrella fall under the commodities classification, or may not enjoy high-enough margins to overcome the financial and economic barriers to change.

Regulatory Barriers

The significant growth in environmental regulations over time has had an important impact on the chemical enterprise. And given the increasing globalization of the chemical enterprise, many firms must also cope with regulations (which may differ significantly) in all of the nations where they produce and sell their products. While green chemistry is interested in reducing inherent risk through the reduction of hazard, most environmental, health and safety regulations focus instead on reducing risk through reductions in exposure. This means that many firms find themselves in situations where they must spend precious resources on regulatorily mandated, and often expensive, end-of-pipe technologies, instead of investing in research and development to move towards inherently safer products and processes. The focus on risk control, rather than risk prevention, can be a serious barrier. Under control-oriented regulation, firms have little incentive to invest in prevention, and may be forced to divert resources to control instead.

There are also regulatory barriers that emerge from the particular details of a given set of regulations, such as those that surround the certification of drugs. If a pharmaceutical company wishes to change certain parts of its method of production for a product on the market in the United States, it must undergo a time-consuming and expensive recertification process with the FDA. If a company develops a pesticide that is safer, or produced in a less hazardous or more environmentally friendly manner than one in current production, it must go through the process of certification with the EPA under TSCA. These regulations, while meant to protect, do not offer any benefits (such as a fast-track for processes that provide environmental or health benefits) and often take enough time, money, or both, to create a significant barrier to the implementation of green chemistry.

Finally, there are financial regulations that can also create a barrier. Many of these involve details of the accounting systems, and how and when a company can write-off old infrastructure. There are also financial complexities that come from the regulations governing the liability of firms for the land where their facilities are cited, should any health or environmental problems that result from these facilities arise in the future. Even if companies are able to shutter old plants, they face a significant potential future financial liability (such as Superfund), that makes it much more attractive to continue with the status quo than to make investments in new infrastructure.

Technical Barriers

The science behind green chemistry is often complex and multi-disciplinary. While the underlying chemistry has made great progress, there are many reactions and processes for which greener substitutes remain unknown. Even where academic or industrial research has devised a new reaction or synthetic pathway to a given chemical, this knowledge may not be readily available to the chemists within industry. Some of it remains in the firms that develop it, protected as trade secret for competitive advantage. Some of it is buried within the vast chemical literature, and may not even be labeled anywhere as being a "green" alternative. As of yet, there is no formal collection and dissemination (such as a large-scale green chemistry database), although the Green Chemistry Institute has started to work on this problem with its GreenChemEx database. But as of yet this is still very small, and does not solve the problem of a comprehensive reference.

Additionally, even when tools are generated by one firm, or within one industry, they can be very difficult to implement elsewhere. For example, S.C. Johnson, Inc. has been very successful in its implementation of its Greenlist program. But the very flexibility to absorb detail and context that makes it effective also makes it very difficult to transfer to other firms. It requires a significant technical effort to adjust it for the products of other formulators, and even more fundamental adjustment would be required if it were to be transferred to other sectors, especially those that are involved in the production, as opposed to the formulation, of chemical products.

The number of disciplines involved in green chemistry also creates a technical barrier. Organic chemists typically do not have a working knowledge of toxicology, chemical engineering, or ecology. Similarly, toxicologists are not trained as synthetic chemists, and the engineers usually do not have extensive knowledge of environmental systems. This makes it difficult for chemists to anticipate, or take into account, the potential downstream effects of a product or a synthetic pathway, unless they are provided with a tool-set to aid them in a more systematic evaluation. The lack of a broader technical background in the training of chemists, including the ability to think on a more global, systems level, has emerged as an important barrier to the integration and implementation of green chemistry within industry.

Organizational Barriers

Within firms, the implementation of green chemistry can run into problems that are the result of the organization's structure. For example, a division may be reluctant to change to a greener production process that may produce costs for their own bottom-line, even if the results benefits the firm as a whole, since this could negatively impact evaluations of the division's performance. The same problem can occur even more locally, when a particular facility is reluctant to implement a change which would be good for a division overall, but that would be locally costly.

There can also be occasions where the development of a greener product in one part of a company will hurt the sales of another product, leading to conflicts and difficulty in implementation. These kinds of organizational clashes are especially likely to occur if the overall business plan and evaluation structure does not explicitly include environmental and health metrics.

Another kind of organizational barrier can occur when the "champions" of a greener product or process are not in positions of power. If support does not exist at the very top, then implementing green chemistry becomes less of a priority, and it is difficult to secure the necessary resources for implementation. Like any other project, green chemistry can fall prey to the power struggles within any given company. Besides the importance of support at the top of the firm, it is also important for there to be buy-in from those who actually are in charge of the research and production processes. The absence of a common environmental goal across the organization can be a significant hurdle to implementation.

Cultural Barriers

Within firms, the regulatory community, academia, and even the general public, there are barriers that could best be classified as cultural. One of the most important of these is awareness. While green chemistry has made significant progress, it is unknown or misunderstood by a large number of chemists. It is not part of the standard curriculum in most schools, although this is beginning to change. And while awareness is low among chemists, it is even lower within industry. People whose jobs revolve around sales, marketing, and operations have even less exposure to the concepts and potential benefits of green chemistry. Some may harbor misconceptions regarding the actual nature of green chemistry, and may consider it to be just green washing, or a part of the "environmental agenda," as opposed to a set of practices grounded in rigorous science. Or, they just may have no idea that the science itself is available, and could have important benefits.

There are also cultural barriers that are the result of previous experiences with the environmental movement. These include, from the corporate standpoint, the idea that all environmentally friendly changes are expensive and not particularly worthwhile. This is a legacy of the largely command-and-control policies typical of environmental regulation through the 1980's, which often mandated costly technologies. For the general public, there has been a variety of often less than successful "green" products over the years. The general perception remains that products labeled as "green" are more expensive and less effective, which lowers demand and limits the effectiveness of green as a marketing strategy.

There are also cultural barriers that arise from the separation of academia from industry. Academia is concerned with providing an education that produces first-rate chemists, and the definition of what that education includes have remained remarkably constant since the end of World War II. Changes in chemical education have been difficult, and incorporation of green chemistry into the curriculum, while gaining ground, is hardly universal. Academia is also focused on its own particular research goals, which are not necessarily the same as the research agendas that would be useful to industry. The differences between the research interests of academics, whose careers depend on publications in peer-reviewed journals and their image in the academic community as serious researchers, can be very different from the research interests of chemists within industry. These chemists are concentrated on particular problems which they are attempting to solve, in an arena where speed, effectiveness and cost-efficiency are important to their personal success.

Finally, there are cultural barriers within the chemical enterprise that deal with innovation more broadly. Some sectors are highly innovative, constantly rework their products and processes, and place great value on being as efficient and cutting-edge as possible. This is often the case with consumer products firms, who face a constantly shifting market demand, and must innovate to stay competitive. However, there are other sectors that are less open to innovation. The pharmaceutical industry has been confronted with its resistance to change. This has also been the case with bulk chemicals, and other sectors whose products are (or are very much like) commodities. The degree to which the culture of a sector or firm shuns innovation in general can create a significant barrier to the implementation of green chemistry.

Barriers from Disagreements Regarding Definitions and Metrics

Green chemistry, unlike many other elements of sustainability, consists of a rigorous definition and design framework, which is embodied in the Twelve Principles of Green Chemistry[6]. Nonetheless, a final important barrier emerges from questions about what exactly constitutes green chemistry. The term is often used interchangeably with chemical sustainability, and can easily be grouped in with green engineering and sustainable development in general. It is unclear to some whether green chemistry is its own branch of chemistry, like organic or physical chemistry; whether it is a method for analyzing and thinking systematically about chemistry; or whether it is something else entirely. This kind of definitional fuzziness can be both positive and negative. It has allowed for a fair amount of longitude in developing the science, but it has also

[6] Anastas, P. T. and J. C. Warner (1998). Green chemistry : theory and practice. Oxford [England] ; New York, Oxford University Press.

led to confusion and argument about whether a given reaction, product, or process really represents green chemistry.

Part of this last problem is compounded by the absence of a metric or certification for green chemistry. Green chemistry is highly contextual, and thus open to a great deal of debate. The ability to have a process for certification, such as is found with organic food products, creates a way for firms to express to their markets that a product is more environmentally friendly by some well-defined (though possibly still contestable) measure. This could be much more difficult with green chemistry, since a careful reading of the Twelve Principles reveals that green chemistry is a process for thinking about chemistry from a systems perspective, as opposed to set of goals or standards of what makes something green. One of the barriers that emerges from the loose definition and current lack of metrics is that it is hard to point to a given product and declare it "green." Because the Twelve Principles define a complex, multi-parameter system that often involves making trade-offs between its elements, it is very difficult to create bright-line standards that would make green chemistry certification and labeling effective. This can mean trouble for support in firms, limits for potential marketing opportunities, and it may end up causing too much focus on debating what is "in" and what is "out," as opposed to working on the underlying science.

Conclusions

These are just some of the barriers, and some of the strategies that have been identified to overcome them. The goal of the Harvard-GCI Green Chemistry Project, and of this workshop, is to continue to identify these barriers, to probe them more deeply, and to consider what strategies are best suited to helping the chemical enterprise move forward in the area of green chemistry.

IV. The Workshop: Organization and Working Group Tasks

Organization

After a brief introductory plenary session, where Kira Matus and Dr. Buzz Cue reviewed the research on the barriers to implementation up to that point, the workshop participants were divided into four working groups. Participants were mixed so that each group had individuals who had worked in each of the four stakeholder groups represented- industry, regulatory/government, academia and NGO. Each group was then assigned a leader and the role of a stakeholder group, according to the following table:

Stakeholder Group	**Leader**
Industry	Dr. Buzz Cue
Regulatory	Dr. Robert Israel
Academia	Dr. William Clark
NGO	Dr. Paul Anastas

Tasks

Dr. Clark laid out the overview of the working groups' task for the first day of the workshop. The challenge to the groups was to move beyond the discussion of barriers, and to consider which barriers were the most pressing, and what actions each stakeholder group could undertake in order to lower, or remove them. In particular, the groups were encouraged to spend their time considering not just actions that would be beneficial for their own group (i.e. what academics could do to lower barriers for other academics), but the actions that they could take that would have a significant positive impact on other groups (i.e. what academics could do to lower barriers for industry). The morning session was set aside for brainstorming, while in the afternoon, groups were encouraged to choose two to three actions to develop more thoroughly, for reporting back to the entire group the next morning.

V. Reports from the Working Groups

Academia Working Group

The Academia working group reported that they focused on addressing three major barriers during their brainstorming. The first was the lack of certification methods or metrics for Green Chemical products or processes. The group identified as its second barrier inadequate curriculum materials and lack of knowledge among students, educators, and industrial chemists. Finally, the group analyzed the title Green Chemistry as a possible barrier to adoption or acceptance of Green Chemistry innovations and processes.

In response to the barrier stemming from lack of certification or metrics, the group proposed that Academia use its perceived independent status to lend authority to the development of uniform green standards for Industry in collaboration with Government and Industry. Academia could especially inform this process by pointing out similarities to other certification programs, and perhaps developing industry-specific standards.

For the problems associated with inadequate curriculum materials and training, the Academic group proposed the creation of summer term courses on Green Chemistry for educators leading to the creation of a comprehensive textbook and curriculum, along with mid-career courses for executives, chemists, and engineers. They also suggested creating a case-study curriculum for non-chemists or -chemistry majors which integrates business, legal, and scientific concerns in the Green Chemistry design and manufacturing process. Additionally, it was perceived that it would be useful to consult with Industry leaders to create a standard set of classes outside of chemistry required for sustainability or Green Chemistry work.

Finally, a major change suggested by the group was to change the name “Green Chemistry” because of the connotations of green as ineffective and expensive and because chemistry is often seen as foreign. Changing the name to, for example, Green Design or Clean Technology could also decrease other academic disciplines’ aversion to taking on Green Chemistry work. Members of the group suggested that a relatively quick, inexpensive market-research survey could be used to measure the effectiveness of candidate names, and to quantify both the negative and positive connotations associated with the term “green chemistry,” in order to understand whether such a dramatic action would actually be useful.

Industry Working Group

The Industry working group chose to address seven barriers to broader adoption of Green Chemistry. They were the stifling effect of short-term thinking and ROI timelines on innovation, the need for further industry promotion and provision of Green Chemistry education along with increased funding and support for research, the lack of broadly available Green Chemistry tools, the need for increased collaboration across chemical sectors and industries, the realization that Industry was not bearing the life-cycle costs of its products, so there was little incentive to incorporate cradle-to-cradle design into manufacturing processes, and the barriers that arose from comfortable supplier relationships inhibiting firms from changing to greener suppliers.

To overcome short-term thinking the group proposed that alternate accounting systems be developed with standardized sustainability reporting. More financially-oriented remedies included the establishment of "futures" groups, working with investment advising organizations like Innovest and insurers/reinsurers to increase understanding of investor risk from not pursuing Green chemistry.

They also saw the need for the inclusion of Green Chemistry in continuing education programs and the advantage of partnering with educators to provide case studies and other curricula. Additionally, establishing more industry consortia at university centers for joint Academia-Government-Industry pre-competitive research, endowing chairs, and funding post-docs/research fellows were identified as major steps towards increasing industry workforce and general knowledge.

After the research produces results, the group saw the need to create or designate an organization to oversee a Green Chemistry toolbox and related database of reactions, materials, LCA, TCA, and toxicology information. In order to further collaboration within Industry, a series of sector- or technology-based roundtables were proposed to identify pre-competitive research platforms and publicize large R&D challenges and organize Grand Challenge programs. Roundtables could also be organized around one issue which brings in various Industry sectors and Academia to initiate discussion and collaboration.

Regulatory Working Group

The Regulatory working group approached three barriers which the government deals with in encouraging Green Chemistry. The largest was the lack of a clear methodology for measuring green, and thus the inability to make determinations about the greenness of products or processes. The second was a lack of trust in green as a positive change and a lack of trust among stakeholders (e.g. business and NGOs), which were also seen as inhibiting factors. This stemmed from the observation that business often does not share opportunities for Green Chemical innovation and its own needs with academia and regulators, perhaps due to indifference or a lack of awareness in the business community. The third barrier was the heavy-handed, prescriptive nature of regulation and its focus on managing exposure instead of designing to reduce hazard, which makes design-focused Green Chemistry less attractive. However, when addressing regulatory reform, it was recognized that an additional major barrier still exists, in that there is most likely no one size fits all regulation, so there will have to be extensive work and specialization or flexibility put into new policy.

Actions proposed to overcome these barriers included developing a universally applicable, common understanding of green chemistry using the twelve principles. This could include recognition or adoption of the twelve principles by governments, industry, and NGOs and the development of clearly articulated criteria or metrics for measuring green.

Regime change or a strong governmental focus on Green Chemistry was identified as a major step in building trust, focused on an accelerated schedule of practical trust-building exercises between sectors. In this vein, a separate, stakeholder-created program focused on building and celebrating trust was seen as a possible solution, perhaps including sabbatical exchange programs between Industry, Academia, Government, and NGOs.

The need for broad reforms in order to integrate environmental regulation into a single holistic unit was identified, including reforms within the EPA itself. Additionally, a number of incentives were proposed in order to reward green innovation through reforming regulatory processes, including: tax incentives for costly redesign of manufacturing processes or capital replacement, reduced registration fees and timelines for green innovations, product patent life extensions for redesign of manufacturing processes, and increased public recognition of green developments. Also, a redirection of funds from regulatory fines away from exposure control towards green chemistry (such as those from SEP), and targeted, voluntary regulatory programs to encourage awareness and innovation were proposed. Involving Industry in encouraging research in Academia through tax-incentivized grants or other tools was listed as a possible driver of broader implementation of green chemistry.

NGO Working Group

The NGO working group brainstormed actions to address four barriers to the implementation of Green Chemistry. They began with the determination that current methods of cost and risk accounting are unsatisfactory because they fail to reflect true product costs and instead spread the costs of a product out over organizational costs. A second barrier that they focused on was what they saw as the focus on green products to be distracting from improvements in manufacturing processes. Greenwashing was identified as a cause of consumer confusion, which along with unclear green certifications/seals was seen as decreasing the ability of the market to drive demand for green products. A third barrier that received attention was that a tight regulatory interpretation of recyclable materials was identified as a major force in reducing recycling rates in industry. And finally, more generally, an unclear problem statement, inertia to maintain the status quo, and poor recognition for urgency were also seen as significant barriers.

To deal with these hurdles, the group proposed action steps. One was a clearinghouse for toxicology data and requiring journals to publish toxicological data for new compounds. Specifically, creating a limited low-cost toxicology test kit and allowing broader chemical model characterizations were seen as critical steps in this venture. Similarly, the group also discussed increasing access to life-cycle analysis data of chemical products if possible.

To overcome cultural barriers, they brainstormed on actions related to scientific education within the NGO community and more inter-sector involvement, possibly including foreign collaborations. In order to use NGO leverage to encourage Green Chemistry, they saw the need to support and recognize the accomplishments and early successes of other stakeholders, especially refraining from shooting down rising champions who are in the process of greening. This arose from the observation that organizations that declare themselves to be green are often overly scrutinized and a small misstep or slow development, even if positive, can draw political and media attention and hamper these efforts. Finally they discussed that although it is difficult, establishing or modifying a green evaluation and certification program with effective criteria would be a major tool to overcome market difficulties.

VII. Plenary Session

The workshop concluded with a final plenary session. At this session, each working group presented the actions which they had formulated in the greatest detail during the first day of the workshop (see Appendix 1 for the full summaries of actions presented to the group). Three topics were chosen by the group for greater discussion- "Stocking the Toolbox"/information exchange/data clearing-house for information on toxics; incentivizing different research and development; and institutionalizing multi-stakeholder collaboration.

"Stocking the Toolbox"

One theme that struck a chord with a large number of participants was the need to make information and data more easily accessible to all stakeholders, but especially to chemists in the lab. This is true for a number of areas, but concern was especially acute in regards to the availability of toxicology data, which is needed to assess the human health and environmental impacts of chemical processes and products. Unlike other data needs, which may be very particular to a given sector, there is a broad-based understanding of what kinds of toxicology data are required to assess impacts. There is a great deal of such information currently in existence- what is needed is an efficient way to put it all together to be accessible from one location. Furthermore, such data does not confer a competitive advantage to any particular firm or group, which makes it a strong candidate for a collaborative project. There was also agreement that any large-scale database of toxicology information must be widely and publicly available.

In order to realistically embark on such a project, participants recognized several factors that would have to be addressed in greater depth:

- Development of a framework for the data – for example, three key pieces of information on each compound
- Incentive mechanisms for manufactures to make, locate, and make available their in-house toxicology information
- A location where the database could be publicly housed
- The ability to link to existing publicly available toxicology data, such as through a meta-search engine
- Process and methods for data evaluation and certification
- Development of new testing mechanisms, so that a global database does not result in driving testing in a certain (and possibly very expensive) direction
- Need for the ACS Board of Publishing to require that toxicology information to be included in ACS Publication guidelines.

Building on this, it was also suggested that a group of participants could work together to identify what other, similar tools are most needed to enhance the ability of chemists in industry and academia to assess the toxicity of new compounds. This could include modeling tools and the development new kinds of assays. The goal of this overall action is to assemble a system such that industry and academia have access to what is currently available, while at the same time, creating the incentives and resources to work to develop additional data, methods and tools.

Creating Incentives for Research and Development

Green Chemistry is still a very new discipline, and nearly all participants recognized the need for greatly expanded research and development programs with accompanying incentives to make this type of research possible. Without increased basic science and implementation methods, Industry cannot effectively incorporate Green Chemistry into business practice on a large scale. Simple actions towards this end focus on increased public celebration of successes in Green Chemistry, while several larger scale programs and actions were proposed.

There were many regulatory reforms proposed, beginning broadly with redefining environmental protection as a holistic program legitimized by NGO involvement. More specific regulatory changes focused on reducing fees, speeding up timelines, providing tax incentives for new technology development and implementation, and encouraging Industry-funded research. All of these initiatives incentivize the development of green technologies and make Industry involvement more attractive in order to drive basic research and new product development. In addition to new incentives, it was also recognized that existing regulations created barriers, resulting in the proposition that the Green Chemistry community compile a list of regulations it found to be pernicious, counter-intuitive, and contradictory to be submitted to regulators and decision-makers. The goal would be to illustrate how the current process can have negative effects in order to remove these major impediments.

Academic involvement was also identified as a key component in encouraging research, including:

- Encouraging an increased level of Industry-funded research
- Increased Industry-Academia development of relevant curricula
- Providing incentives for increased academic development of Green Chemistry education
- Development of standard Green Chemistry education guidelines
- Promoting Green Chemistry as a necessary part of any engineer or chemist’s education
- Extending Green Chemistry education from the undergraduate level through doctoral work and on to MBA-level and mid-career training

Another common point for encouraging competition and innovation was developing metrics or a uniform system of evaluation and certification of Green Chemistry, whether it be an absolute approval/disapproval system or a differentiated rating system such as LEED ratings.

Institutionalizing Collaboration

The need for increased collaboration on Green Chemistry issues across all sectors was recognized, requiring the development of a safe forum for discussion. Many groups were identified that were working on similar issues, but there was little apparent organization or cooperation. No clear model emerged which would be perfectly suited for this emerging sector, but a multi-faceted system of roundtables built around common sectors or technologies was proposed. The goal would be to have a series of roundtables which are administered in a synergistic way so that lessons can be learned and a sustained effort can be made at advancing cooperation to produce long-term results. Part of this sustained effort would focus on maintaining the “toolbox” discussed above. The eventual goal would be to raise awareness and implementation across all sectors to ensure that Green Chemistry rises to prominence in business and academic discussions and that a new generation of academic and industrial scientists, businesspeople, and NGO leaders develop accustomed to Green Chemistry as a normal part of design and planning processes. More thought as to how this would be specifically organized and what partnering groups could run the network would have to occur, but the first necessary step is to get relevant stakeholders discussing the creation of this group as an initial step in establishing and then institutionalizing new relationships and flows of information.

VIII. Conclusions

A Broad Policy Framework for Green Chemistry

From the content of the initial set of interviews, as well as the proceedings of the workshop, it is clear that the implementation of green chemistry cannot be moved forward by government action alone. It will take the involvement of a variety of actors, working in concert in order to lower the barriers that have been identified. However, if approached properly, well-constructed policies could have a significant positive impact. While the workshop was focused on delving into particular actions that could be taken by stakeholder groups, alone or in concert, the discussions pointed to the nature of policies that would facilitate and incentivize these actions. While many particular policy interventions, such as increased research funds and tax incentives were mentioned, six broader themes emerged. Put together, they create a broad policy framework for the promotion of green chemistry. Such a framework is a useful guide to move from the realm of discussion and suggestion to the actual formulation of sensible, useful, and effective green chemistry policies.

The six themes that emerged were:

- Create incentives for the development and implementation of innovations- and avoid dictating required technologies or approaches
- Consider policies to shift focus to hazard reduction- not just exposure control
- Facilitate linkages, networks and collaborations that positively impact the exchange of information, expertise, tools, etc…
- Act as a facilitator for multi-stakeholder initiatives to create and enforce green chemistry metrics and standards
- Promote actions that make environmental and health impacts a larger part of the decision calculus
- Support research, knowledge creation, and educational efforts to support green chemistry across a range of disciplines and problem areas.

With these themes in place, it is possible to move forward by linking them to the barriers that they address via many of the actions suggested by the workshop participants. Table 1 presents a matrix of the actions presented at the workshop, and how they can be classified according to the major barriers and policy themes. From this visual presentation, it is clearer which barriers can be addressed by different classes of policies. It also provides guidance for future policy development. For example, most of the actions presented did not significantly impact the economic barriers. With this in mind, future efforts to address green chemistry policy could explicitly work towards identifying policy interventions aimed at this particular barrier. It is important to stress, as was done throughout the workshop, that the actions of one set of stakeholders (for example, those involved with the regulatory and policy processes) can have a significant impact on barriers for all those involved. Policy in this case can be thought of as being broader in scope than just traditional public policy, to include the strategic decisions and actors of players from other sectors, who can identify areas in which they are able to have an impact, and proceed accordingly. This workshop, through the use of broad, multi-sectoral participation and brainstorming, demonstrated the types of useful, action-oriented approaches that can emerge from this framing. And it is these sorts of actions that will be needed to move the implementation of green chemistry forward, beyond the many barriers in its path.

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Table 1- Actions Sorted by Policy Theme and Barrier Addressed

		Barriers					
		Economic	**Regulatory**	**Technical**	**Organizational**	**Cultural**	**Definition and Metrics**
Policy Themes	**Incentives to Innovate**	• Tax Incentives	• Streamlined approval • Fee reduction • IP Protection	• Tax incentives	• Awards programs • Alternate accounting schemes (long term)	• Awards programs	
	Hazard Reduction Focus		• Use of fines towards green chemistry improvements				
	Linkages and Networks			• Shared tools, databases, information exchange		• Trust building	
	Standards, Metrics and Certifications	• Certification/ Standards efforts	• Certification/ Standard efforts • Metrics	• Metrics			• Certification/ Standards efforts
	Increase Prominence of Environment in Decision Making			• Inclusion of toxicology data in articles	• Alternate accounting schemes (long term)	• New green chemistry terminology	
	Support for Research, Education			• Research funding, • Sabbatical programs, • Curriculum development, • Training programs • Industry roundtables		• Research funding • Sabbatical programs • Curriculum development • Course integration • Education for NGO's	

Appendix 1 – Summary of Actions Presented by Working Groups at the Final Plenary Section

Industry Group

Actor: Industry

Barrier: Short-term thinking stifles/impedes innovation

Affected Group(s): Industry

Action: To expand decision timelines for innovations with longer-term ROIs
- Development of alternate accounting systems
- Systemization/standardization of sustainability reporting
- Establish "futures" groups
- Undertake discussions with SAM or Innovest organizations to establish greater understanding of investor risk from not pursuing Green Chemistry
- Undertake discussions with insurance/reinsurance industry to establish greater understanding of loss prevention related to not pursuing Green Chemisty

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Actor: Industry

Barrier: Don't have sufficient GC tools available

Affected Group(s): Industry, Academia

Action: To stock the Green Chemistry toolbox
- Use the US EPA Presidential GC Challenge Awards categories as a guide; e.g., alternative synthetic strategies, designing safer chemicals, etc.
    - Real options analysis
    - Tox / eco-tox
    - Fate
    - LCI/A
    - TCA
    - Materials
- Create a database of reactions, vetted materials, etc
- Identify an organization to own the tool box including stocking, maintaining and disseminating the tools.
    - Create an organization for each chemical sector to oversee tool box
- Collaborating with academia, government agencies; e.g., NIH, EPA, etc
- Challenge grants and funding

Actor: Industry

Barrier: Inadequate funding for Green Chemistry in Industry and Academia

Affected Group(s): Industry, Academia

Action: To make funds available

- Promote in-house basic research
- Greater funding of academic research by industry
- Joint funding programs, e.g., between DOE / DOD / NSF / etc., and industry to fund pre-competitive research.

Actor: Industry

Barrier: Lack of Green Chemistry education and educated workforce

Affected Group(s): Academia, Industry, current and future workforce

Action:

- Form Industry-Academia task force to identify actions needed to move Green Chemistry education forward for workforce
    - Provide case studies and curricula to Academia
    - Endow university chairs
    - Fund post-docs and research fellows
    - Fund more Industry consortia i.e. fund more Green Chemistry university centers (interdisciplinary producers of education materials, white papers)
- Include Green Chemistry in continuing education programs
- Develop industry-specific journals with Green Chemistry reporting requirement

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Actor: Industry

Barrier: Lack of cooperation in/across chemical sectors due to antitrust, cultural issues etc.

Affected Group(s): Industry

Action:

- Establish sector- or technology-based roundtables
- Define and administratively support interaction between roundtables
- Identify pre-competitive research platforms
- Identify and publicize large R&D problems and administer Grand Challenge program

Academia Group

Actor: Academia

Barrier: Lack of certification scheme and accompanying metrics for Green Chemistry

Affected Group(s): Industry, Academia, possibly NGOs

Action:

- Use perceived independent status to convene inclusive meetings to establish metrics
  - Involve industry to establish uniform standards
  - Include provisions for continuous improvement
  - Contribute a historically-informed strategic perspective to better design a scheme in light of other certification programs
  - Determine whether universal or industry-specific programs are best

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Actor: Academia

Barrier: Inadequate curriculum materials for Green Chemistry, chemists lack knowledge of green processes

Affected Group(s): Industry, Academia, NGOs, Regulatory

Action: Curriculum reform to address interdisciplinary nature of Green Chemistry

- Teach a summer or other short course for those in chemistry profession
  - Eventually develop comprehensive curriculum and textbook
  - Focus on mid-career professionals, open dialogue with Industry to determine appropriate material
- Form an integrated case study model of education for non-majors
  - Include business, R&D, engineering, legal, and other aspects
- Approach Industry to create standard for courses outside of chemistry in business, government, etc. that would be required of chemistry students (like pre-med)

Actor: Academia

Barrier: Green Chemistry name may be ineffective or alienating

Affected Group(s): Industry, Academia

Action: B/C green considered ineffective, expensive, radical; chemistry seen as foreign; other departments shy away from chemistry research; chemists can consider Green Chemistry not "real chemistry"

- Rename Green Chemistry to, for example, Green Design, Clean Technology
    - Conduct market research to determine how Green Chemistry is viewed and to explore effective alternatives

NGO Group

Actor: NGOs

Barrier: Methods of cost and risk accounting do not reflect true costs of products (spread out over organizational costs)

Affected Group(s): Industry, Academia, NGOs

Action: To collect toxicology data for specific products

- Establish a clearinghouse for toxicology data
- Require journals to publish toxicology data for new compounds/syntheses

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Actor: NGOs

Barrier: Lack of clearly articulate problem to rally around, inertia to maintain status quo, poor recognition of urgency for change

Affected Group(s): NGOs, Academia, Industry

Action: To increase awareness and action

- Scientific education for the NGO community
- Formation of strategic alliances with Green chemistry educators, Industry

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Actor: NGOs

Barrier: Early successes not advertised/promoted enough; need champions

Affected Group(s): Industry, NGOs

Action:

- Recognize accomplishments of other stakeholders, get NGOs to support positive developments not just target enemies
- Develop awards or other public mechanisms to accomplish recognition

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Other Barriers:

- Greenwashing leads to consumer confusion
- Too much emphasis on product, not on better manufacturing/engineering
- Tight regulatory interpretation of recyclable materials reduces recycling rates

Regulatory Group

Actor: Regulatory

Barrier: No clear method for measuring green

Affected Group(s): Industry, Academia, NGO, Regulatory

Action: Develop a multi-stakeholder understanding of Green Chemistry
- Based on Twelve Principles
- Defining different levels of green
- Universally applicable to chemical and related industries
- Challenge stakeholders to develop metrics

Actor: Regulatory

Barrier: Lack of trust in green and among stakeholders

Affected Group(s): Industry, Academia, NGOs, Regulatory

Action: Build trust
- Focus on an accelerated schedule of small trust-building exercises
- Regime change or new strong governmental focus on Green Chemistry
- Establish Green Chemistry collaboration program designed by stakeholders
    - Celebrate trust and reward collaboration/partnerships
    - Build a cross-sectoral sabbatical exchange program

Actor: Regulatory

Barrier: Current focus is on exposure control rather than hazard prevention

Affected Group(s): Industry, Regulatory, Academia

Action: Reward green innovation - incentives
    - Tax incentives for replacing old technology
    - Reduced product registration fees and approval timelines for green innovations
    - Product patent life extension for green improvements in manufacturing
    - Increased public recognition for innovation
- Target funds from environmental fines towards hazard reduction instead of exposure control (e.g. SEP)
- Establish targeted voluntary regulation programs

Appendix 2: Harvard-Yale-ACS Green Chemistry Institute Green Chemistry Project: Steering Committee and Project Participants

Steering Committee:

Dr. Paul Anastas

Dr. William C. Clark

Dr. Buzz Cue

Dr. Charles Kolb

Dr. Peterson Myers

Dr. Karen Peabody O'Brien

Expert Interviews:

Dr. Martin Abraham, University of Toledo, September 11, 2006

Dr. John Carberry, DuPont, February 22, 2007

Dr. Joseph DeSimone, University of North Carolina Chapel Hill, September 13, 2006

Mr. John Frazier, Nike, October 24, 2006

Dr. James Hutchison, University of Oregon, September 12, 2006

Dr. Robert Israel, JohnsonDiversey, Inc., November 1, 2006

Dr. Charles Kolb, Aerodyne Research, Inc., September 10, 2006

Dr. Pam Marrone, AgraQuest/Marrone Organic Innovations, September 12, 2006

Dr. James Solyst, Navigant, September 10, 2006

Dr. John Warner, University of Massachusetts-Lowell, September 6, 2006

Green Chemistry Workshop: February 22nd-23rd, 2007

Dr.	Paul	Anastas	Yale University
Mr.	Ben	Anderson	Lilly
Mr.	Steve	Bradfield	Shaw Industries
Ms.	Mary	Buzby	Merck
Dr.	William	Clark	Harvard University
Mr.	David	Constable	GlaxoSmithKline
Dr.	Berkeley	Cue	Consultant
Dr.	Richard	Engler	United States Environmental Protection Agency
Dr.	Cassandra	Fraser	GCI/UVA
Mr.	John	Frazier	Nike
Dr.	Robert	Frosch	Harvard University, WHOI
Dr.	Edeltraud	Guenther	Dresden University
Dr.	Rich	Gurney	Simmons College
Dr.	Patricia	Hogan	Suffolk University
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Dr.	Andrea	Larson	University of Virginia
Dr.	Robert	Lee	United States Environmental Protection Agency
Dr.	CJ	Li	McGill
Dr.	Richard	Liroff	IEHN
Mr.	David	Long	S. C. Johnson & Son, Inc.
Ms.	Julie	Manley	GCI
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