Integrating Green Chemistry and Green Engineering into the Revitalization of the Toxic Substances Control Act

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Executive Summary

Introduction

The Toxic Substances Control Act (TSCA) was enacted in 1976, and its core provisions have not been significantly amended in the more than three decades since its inception. As United States policy, TSCA established 1) the requirement that manufacturers develop data on the impact of chemicals on health and the environment, 2) that those chemicals that posed an "unreasonable risk of injury to health or the environment" should be regulated,[2] and 3) that such regulation should not create unnecessary economic barriers to innovation.[3]

When the EPA announced its essential principles for TSCA reform in 2009, it highlighted green chemistry as a key approach to advancing the mission of TSCA. Similarly, the Center for Green Chemistry and Green Engineering at Yale University is interested in the potential future impact of any TSCA reform efforts on innovation, especially in the areas of green chemistry and green engineering[4]. The current reform efforts present a unique and critical opportunity to create a regulatory structure that proactively encourages the development and implementation of techniques to decrease the intrinsic hazard of chemicals. TSCA should actively promote, through provision of incentives throughout its regulatory framework, the design, generation and use of chemicals and technologies that are greener, safer, and less resource intensive throughout the chemical industry and its broader supply chain.

Incorporation of Green Chemistry into TSCA

Green chemistry and engineering (GC&E) are systems-based approaches that promote design for reduced hazard across the entire life cycle of chemicals, from design, manufacture, and use to end of life. They integrate knowledge from across chemistry, engineering, environmental science, and toxicology in order to reduce and, ideally, eliminate adverse impacts on health and the environment. GC&E provide a framework for a preventative approach based on innovation that improves technical performance, profits, and social benefit. If the principles of GC&E were broadly deployed, both in the scientific research community and in industry, they would be a powerful, market-oriented, economically favorable approach to protecting human health and the environment from the potential adverse impacts of chemical substances throughout their life cycle.

[2] 15 U.S.C 2601

[3] *ibid*

[4] Green Chemistry can be defined as "the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances." Anastas and Warner, *Green Chemistry: Theory and Practice.* Green chemistry and green engineering are guided by the 12 Principles of Green Chemistry and the 12 Principles of Green Engineering (see Appendix)

Reformed TSCA legislation can incorporate GC&E into its overall regulatory framework by leveraging three types of resources available to the EPA and other agencies involved in chemical regulation. These three types of resources are:

1. **Technical:** The development and deployment of metrics, tools, education, knowledge sharing and communication to support the continuous development and implementation of GC&E based innovations.
2. **Policy:** The use of regulatory authorities in a variety of ways, including (but not limited) to help remove market distortions that protect or favor more hazardous alternatives, to provide incentives for GC&E based alternatives, and to engage in voluntary agreements and collaborations.
3. **Financial:** The designation of federal funds to support green chemistry and engineering research, development, and implementation both internally and externally.

The Center for Green Chemistry and Green Engineering at Yale has developed six specific strategic policy recommendations for inclusion in reformed TSCA legislation based on its own policy analysis and discussions with thirteen experts (see Appendix) at a workshop held at Yale University in October 2009.[5] Table 1 lists these policies and what types of resources they each would leverage. All of the recommended policies are specific to GC&E, which would support TSCA by reducing hazard by supporting the development and implementation of GC&E technologies throughout the economy. The first three (1-3) are policy elements which should be woven throughout the core provisions of the bill, such as the larger process of safety determination, or the list of possible regulatory responses to chemicals of concern. The second three (4-6) are specific, stand-alone policies that should be included in a reformed TSCA, but constitute separate programmatic elements from the core provisions.

[5]The views, analysis and recommendations in this document are those of the authors. Workshop participants contributed their expertise and insights during the workshop, but this is not a consensus document, and does not claim to represent the views of the participants or the organizations with which they are affiliated.

Table 1 - Policy Recommendations

POLICY CONSIDERATIONS TO CREATE A MORE EFFECTIVE TSCA FRAMEWORK	Financial	Technical	Policy
1. Data used to evaluate chemicals should make use of green chemistry concepts and metrics.		x	
2. Create incentives for better performance on health, safety and environmental criteria, and/or switching to less hazardous alternatives.	x		x
3. Use information collected by the EPA to help drive GC&E forward.		x	
4. Implement a coordinated research and development fund overseen by funding from a variety of agencies.	x		x
5. Provide funding and support for states that implement technical outreach programs for GC&E implementation in small and medium sized firms.	x	x	x
6. Recognize and broaden Design for the Environment (DfE) and other cooperative programs between industry and government, in order to increase the impact of partnership programs for development of less hazardous products.	x	x	x

Conclusions

Green chemistry and green engineering have the potential to provide technologically sound, socially preferable and economically competitive alternatives to current chemicals of concern and enhance the likelihood of designing safer chemicals in the future. The Center for Green Chemistry and Green Engineering at Yale is recommending a set of policy considerations that would incorporate these concepts directly into reformed TSCA legislation. Some of these policies explicitly direct funding or other resources to GC&E; others are meant to correct policy and market distortions and failures that currently favor older, more hazardous chemical substances over newer, safer alternatives across the life cycle. The overall goal of the Center's recommended policy considerations is to leverage the power and promise of GC&E as upstream, systemic, life cycle based innovation tools to provide a long-term solution reconciling the need for and value of chemical substances with the need for protection of human health and the environment.

NOTE: Green Chemistry & Engineering and the Safer Chemicals Act of 2010

On April 15, 2010, Senator Frank Lautenberg (D-NJ) introduced the "Safe Chemicals Act of 2010" in the United States Senate. On the same day, Representatives Henry Waxman (D-CA) and Bobby Rush (D-Ill) released a discussion draft of a similar bill. These bills present an important and much needed modernization of the country's approach to managing and regulating chemical hazards.

Both versions of the bill, picking up on EPA Administrator Jackson's inclusion of green chemistry as one of the EPA's core elements of TSCA reform, explicitly mention the need to "spur innovation in green chemistry." They address this with a series of proposals under the title of "Safer Alternatives and Green Chemistry and Engineering." The programs included in this section are laudable. They would provide incentives for the creation of greener, less hazardous alternatives through research funding, expedited review processes, awards, labeling programs, and the creation of four national green chemistry and engineering research centers.

While these provisions represent a strong beginning for integrating GC&E innovation into TSCA reform, there is more that can and should be done. GC&E goes beyond the development of safer alternatives. It is fundamentally a series of guidelines for designing chemicals to reduce, and ideally eliminate, hazard. GC&E is a preventative approach based on innovation that improves technical performance, profits, and social benefit. It takes into account long-term, life cycle thinking.

GC&E is at its most powerful as a tool for the development of the next generation of chemical innovations. For new chemicals and materials, it is much more efficient if they are as benign as possible from the outset, eliminating the need to develop safer alternatives later. Deployed throughout the scientific community and the chemical enterprise, the principles of GC&E provide the foundation for a powerful, market-oriented, economically favorable approach to protecting human health and the environment from the potential adverse impacts of chemical substances before any impacts could even occur. Not only would this improve safety, but it would enhance the broader sustainability of the chemical enterprise in the United States.

Twenty-First Century TSCA

I. Introduction

The Toxic Substances Control Act (TSCA) was first enacted in 1976, and has not been significantly reformed in the more than three decades since its inception. As United States policy, TSCA established 1) the requirement of manufacturers to develop data on the impact of chemicals on health and the environment, 2) that those chemicals that posed an "unreasonable risk of injury to human health or the environment" should be regulated,[6] and 3) that such regulation should not create unnecessary economic barriers to innovation.[7]

However, in recent years, the public and regulators at a variety of levels have voiced concern that TSCA is not fulfilling its role of protecting human health and the environment from the adverse impacts of toxic chemicals. In the light of similar concerns expressed in Europe with regard to regulations governing chemicals, new and intensive regulation in the form of the Registration, Evaluation, Authorization and Restrictions of Chemicals (REACH) framework has been developed, which governs all chemicals imported to or manufactured in the European Union. Finally, controversy around chemicals such as bisphenol-A, phthalates, and brominated flame retardants has led to a lack of public confidence in the ability of the current version of TSCA to fulfill its mission. In response, the chemical industry has joined other stakeholders in calling for TSCA reform.[8]

When the EPA announced its six essential principles for TSCA reform in 2009, it highlighted green chemistry as a key approach to advancing the mission of TSCA. The Center for Green Chemistry and Green Engineering at Yale University is interested in the potential future impact of any TSCA reform efforts on innovation, especially in the areas of green chemistry and green engineering.[9] The current reform efforts present a unique and critical opportunity to create a regulatory structure that proactively encourages the development and implementation of techniques to decrease the intrinsic hazard of chemicals. TSCA should actively promote, through provision of incentives throughout its regulatory framework, the design, generation and use of chemicals and technologies that are greener, safer, and less resource intensive throughout the chemical industry and its broader supply chain.

II. Incorporating Green Chemistry and Green Engineering into TSCA

Green chemistry and engineering (GC&E) are systems-based approaches that consider the entire life cycle of a chemical from design, manufacture and use to end of life. They integrate knowledge from across chemistry, engineering, environmental science, and toxicology in order to reduce and, ideally, eliminate adverse impacts on health and the environment.

[6] 15 U.S.C 2601

[7] *ibid*

[8] American Chemistry Council, "10 Principles for Modernizing TSCA."

[9] Green Chemistry can be defined as "the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances." Anastas and Warner, *Green Chemistry: Theory and Practice*. Green chemistry and green engineering are guided by the 12 Principles of Green Chemistry and the 12 Principles of Green Engineering (see Appendix)

There are many approaches to making production and use of chemicals more sustainable. Traditionally, environment and safety controls focused on reducing exposure to hazardous chemical substances. But these exposure reduction practices result in increased costs, and when they fail, the resulting incidents can be catastrophic.[10] An alternative approach is to return to the underlying science and engineering in order to build in greater sustainability from the outset, both in how chemicals are produced, and also in the molecular design of chemicals themselves. If risk is most easily conceptualized according to the relationship

$$\text{RISK} = f(\text{HAZARD}, \text{EXPOSURE}),$$

then the application of GC&E reduces risk through the reduction of the intrinsic hazards of the chemicals themselves, and the engineering processes used to produce them. For GC&E, hazard encompasses not only the potential to cause harm to humans or ecosystems, but also encompasses other areas, such as the inefficient use of energy and natural resources, creation of excess and/or persistent waste products, and contributing to global environmental challenges like climate change (see Box 1). These upstream, preventative approaches work to eliminate risk from the chemical enterprise by reducing or eliminating hazards while preserving, or ideally enhancing, the desired functions of the chemicals.

Box 1 -Types of Hazard

Physical Hazards: flammability, explosivity, corrosivity, high reactivity

Toxicological Hazards: human, animal, and ecotoxicity, acute & chronic

Global Hazards: resource depletion, waste generation, and environmental degradation or destruction (acid rain, climate change, ozone depletion, water scarcity, etc.)

Green chemistry and engineering provide a framework for an approach based on innovation that improves technical performance, profits, and social benefit. If the principles of GC&E are broadly deployed throughout the scientific research community and industry, they would be a powerful, market-oriented, economically favorable approach to protecting human health and the environment from the potential adverse impacts of chemical substances throughout their life cycle.

Incorporating green chemistry and engineering approaches, which are forward-thinking and long-term, into TSCA will make the legislation more responsive and adaptive to both current and yet-unknown future challenges. The development and use of alternatives developed through GC&E principles will fundamentally reduce risk by replacing many of the current, problematic chemical substances with alternatives that are intrinsically less hazardous. The principles also drive innovations to use resources more efficiently (e.g., atom economy) which provide additional benefits. It is critical to include the principles of green chemistry and green engineering when providing guidance and structuring policies to achieve the full potential of the approach.

[10]One of the most tragic examples occured in India in 1984, when an accidental release in Bhopal killed more than three thousand people as they slept, and thousands more were seriously injured. There have been many other incidents worldwide that have harmed workers, communities and the environment. An extensive review of chemical accidents can be found in Matlack, *Introduction to Green Chemistry.*

Reformed TSCA legislation can incorporate GC&E into its overall regulatory framework by leveraging three types of resources available to the EPA and other agencies involved in chemical regulation. These three types of resources are:

1. **Technical:** The development and deployment of metrics, tools, education, knowledge sharing and communication to support the continuous development and implementation of GC&E based innovations.
3. **Policy:** The use of regulatory authorities in a variety of ways, including (but not limited) to help remove market distortions that protect or favor more hazardous alternatives, to provide incentives for GC&E based alternatives, and to engage in voluntary agreements and collaborations.
3. **Financial:** The designation of federal funds to support green chemistry and engineering research, development, and implementation both internally and externally.

The Center for Green Chemistry and Green Engineering at Yale has developed six specific strategic policy considerations for inclusion in reformed TSCA legislation based on its own policy analysis and discussions with thirteen experts at a workshop held at Yale University in October 2009. The goal of these items is to explicitly incorporate GC&E approaches and the subsequent benefits into chemical regulatory strategies. This requires an explicit commitment of the resources and capabilities (including, e.g., regulatory, incentive, and collaborative capabilities) necessary to move beyond aspirational statements of support[11] in order to realize the use of reduced hazard and sustainability as design criteria throughout the chemical enterprise.

III. Analysis

In order to address the many complex elements of TSCA reform, in October 2009 the Center for Green Chemistry and Green Engineering at Yale convened a one and a half day workshop that was attended by 13 experts[12] (see Appendix). The attendees had a range of affiliations, including academia, consulting, government, industry, and NGOs. The goal of the workshop was to access a range of perspectives regarding TSCA, including its history, its current status, successes and failures, and challenges for the future. The workshop discussions, in conjunction with additional analyses from a range of sources,[13] were the basis for more targeted analysis of what role green chemistry and engineering should play in a reformed TSCA, and what policies are needed to support this role.

[11]For example, 1991's Pollution Prevention Act

[12]The views, analysis and recommendations in this document are those of the authors. Workshop participants contributed their expertise and insights during the workshop, but this is not a consensus document, and does not claim to represent the views of the participants or the organizations with which they are affiliated.

[13]Peer-reviewed analyses, articles and opinion pieces in the popular press, Congressional testimony, government publications and other documents published by NGOs and trade associations (see Bibliography for selected references).

To arrive at a set of strategic policy recommendations, answers to six key questions about TSCA reform were compiled and analyzed to define the role of GC&E in the broader context of TSCA reform. The six questions are listed in Table 2. The first four questions (1-4) were the basis for analyzing which kind of regulatory framework a reformed TSCA requires to be successful at addressing the challenges posed by chemical hazards. Their analysis provided a foundation for better understanding how TSCA has functioned, in order to develop strategies for integrating green chemistry and green engineering into future regulation. Questions five and six were designed to stimulate discussion and analysis about what, specifically, innovation in GC&E could add to the discussions of TSCA reform, and how it could best be integrated into the larger policy framework. Analysis of these two questions was the main goal of the workshop, and is discussed in more detail below.

Table 2- Key Questions about TSCA Reform to Develop a GC&E Strategy

1.	**What are the drivers behind the movement for TSCA reform?**
2.	**What are the goals of a "reformed TSCA"?**
3.	**What are the key lessons from the last 30 years of TSCA in practice?**
4.	**What does it take to construct an adaptive, flexible, resilient chemicals policy?**
5.	**How can, or should, "reformed TSCA" impact innovation?**
6.	**How can green chemistry and green engineering be critical parts of resilient, forward-looking chemical risk management, and how should they be built into the regulatory system?**

A. The Role of GC&E Innovation in a Reformed TSCA

There are two core questions regarding the role of innovation in TSCA reform and its implementation. One question is how the system could have direct, as well as unintended or indirect adverse impacts on innovation, and whether it should actively attempt to promote innovation of safer, greener alternatives. The second is how GC&E, as part of a strategy to reduce hazard through the development and use of safer alternatives, fits into the overall strategy for TSCA reform, and ways in which direct support could be integrated throughout the regulatory system.

1. *How can, or should, "reformed TSCA" impact innovation?*

One of the goals of the original TSCA is to regulate chemicals without creating undue barriers to innovation. There are a number of ways that a reformed TSCA could encourage or stifle innovation,

both directly and indirectly. Direct impacts include any rules that affect the cost or time required to bring an innovation to market, such as high fees or extensive data reporting requirements. Reformed TSCA could also impact innovation positively and directly by providing incentives for or resources in support of particular categories of innovation, such as less hazardous alternatives to chemicals of concern. There is also the possibility for adverse and indirect impacts on innovation. For example, the fact that TSCA currently does not hold chemicals that were manufactured prior to 1976 to the same review process as new chemicals provides an incentive for firms to continue to use older, sometimes more hazardous substances, rather than incur the costs and risks associated with innovating a greener alternative.

There are two approaches to how a reformed TSCA should handle innovation. The first is in line with the current legislation: that TSCA should not create large barriers to innovation in the chemical industry. The reality is that firms have a limited quantity of human and economic resources, and the more these have to be devoted to testing protocols, evaluations and applications, the less there is available to engage in research and development of new products and processes. This does not mean that there is not a need to determine the associated hazards. Clearly having an efficient, predictable, and timely process is important.

Secondly, TSCA should explicitly favor innovations that improve safety or reduce environmental impact. If the goal is to protect human health and the environment, then it is in the interest of firms and society to encourage the development of these alternatives. Support could include direct funding towards research and development, but could also incorporate incentives such as preferential fee schedules or timelines in order to help these alternatives capture some of their social benefit by speeding their time and lowering their costs to market. Furthermore, evaluating and regulating the universe of existing chemicals according to a triaged prioritization process would remove the current disincentive to invest in alternatives to chemicals in commerce as of 1976. Overall, the two main ways that a reformed TSCA should impact innovation are that it:

1. Must not stifle innovation generally with unnecessary resource burdens, and
2. Should favor innovations that improve safety and reduce environmental impacts.

2. *How can green chemistry and green engineering be critical parts of resilient, forward-looking chemical risk management, and how should they be built into the regulatory system?*

From the workshop discussions regarding the strengths and weaknesses of the current TSCA system, it is clear that it is important for the EPA to have a diverse and flexible portfolio of policy options and assessment tools so that it may adapt effectively to innovation and emerging scientific knowledge.

Building GC&E into a reformed TSCA will provide several benefits in this regard. First, it will increase availability of more benign chemical alternatives and reduce the overall TSCA workload. Second, it will encourage the development of advanced life cycle assessment and modeling tools by both industry and EPA. Most importantly, it will contribute to fundamental solutions that are robust over the long term, regardless of how assessment methods and regulatory regimes may evolve.

In addition, the EPA should collaborate with, support and learn from the state level efforts in this arena. Several states have developed innovative and effective programs to advance green chemistry and green engineering. State run programs can be especially helpful in outreach to SMEs, in developing local academic-industrial collaborations to resolve key technical challenges, and in providing support for education and training. Reformed TSCA should recognize the importance of these programs for learning, and as ways to incentivize innovation within industry. The EPA can use its expertise to support these efforts, and also to act as a central repository for many of the tools and resources developed and implemented on the state level.

Given the long-term societal benefits that GC&E can realize, a reformed TSCA should include a range of incentives to encourage application of GC&E in the innovation process. Providing these incentives will require explicit dedication of financial and technical resources, and a supportive regulatory framework. Explicit inclusion of GC&E into a reformed TSCA should have two elements:

1. Adoption of an anticipatory, preventative approach to chemicals management which includes an effort to reduce hazards, as opposed to focusing solely on exposure control mechanisms.
2. Mechanisms and incentives to provide financial, technical and policy support for GC&E innovation, including:
    a. Incentives for GC&E in any review process in the form of reduced fees, timelines, and data requirements (with evolving standards to prevent spurious claims and to drive continuous improvement),
    b. Direct support of programs like EPA's Design for Environment or other collaborations based on priority areas,
    c. Support GC&E curriculum development and retraining programs needed to develop a workforce with the skills required to develop and implement GC&E innovations,
    d. R&D funding by EPA to establish the foundation for a pipeline of green innovations, and
    e. Large-scale development funding modeled after DARPA and ARPA-E to help bridge the gap between the lab/pilot scale and full commercial scale.

IV. Policy Recommendations

The overall goal of the recommended policies is to leverage the power and promise of GC&E as an upstream, systemic, life cycle based innovation tool to provide long-term solutions to simultaneously advancing innovative chemical substances and the protection of human health and the environment. Some of these policies explicitly direct funding or other resources to GC&E; others are meant to create market incentives for GC&E innovations over older, potentially more hazardous technologies.

All of these policies are specific to GC&E, which would support TSCA in reducing hazard by supporting the development and implementation of GC&E technologies throughout the economy. The first three (1-3) are policy elements which should be woven throughout the core provisions of the bill, such as the larger process of safety determination, or the list of possible regulatory responses to chemicals of concern. The second three (4-6) are specific, stand-alone policies that should be included in a reformed TSCA, but constitute separate programmatic elements from the core provisions. Based on the current analysis, Table 3 lists the Center's policy recommendations and what types of resources that each would leverage. Further details are provided below.

Table 3 - Policy Recommendations

POLICY CONSIDERATIONS TO CREATE A MORE EFFECTIVE TSCA FRAMEWORK	Financial	Technical	Policy
1. Data used to evaluate chemicals should make use of green chemistry concepts and metrics.		x	
2. Create incentives for better performance on health, safety and environmental criteria, and/or switching to less hazardous alternatives.	x		x
3. Use information collected by the EPA to help drive GC&E forward.		x	
4. Implement a coordinated research and development fund overseen by funding from a variety of agencies.	x		x
5. Provide funding and support for states that implement technical outreach programs for GC&E implementation in small and medium sized firms.	x	x	x
6. Recognize and broaden Design for the Environment (DfE) and other cooperative programs between industry and government, in order to increase the impact of partnership programs for development of less hazardous products.	x	x	x

A. POLICY RECOMMENDATIONS

1. Data used to evaluate chemicals should make use of green chemistry concepts and metrics in order to take into account health, safety, and environmental impacts across the entire life cycle for various intended uses of a chemical.
   a. The EPA should have the authority to compel submission of green chemistry metrics as part of its data required for chemical evaluations.
   b. The EPA should set up a program for public reporting of green chemistry information submitted by firms (such as green chemistry score cards).
   c. The EPA should use submitted green chemistry data as a baseline when considering whether a chemical or substance should be eligible for awards, incentives, expedited review, and other programs that are preferential towards “greener” alternatives.

2. Create incentives for better performance on health, safety, and environmental criteria, and/or to switch to less hazardous alternatives.
   a. Establish and consistently enforce standards for manufacture and use of hazardous chemicals.
   b. Design preferential pre-manufacture notice timelines and information requirements for “greener” alternatives.
   c. Make use of a variety of positive incentive mechanisms, including tax incentives for R&D expenditures, patent life extensions, capital loan funds and grants, and recognition and awards.

3. Use information collected by the EPA to help drive GC forward.
   a. Accumulate data on impacts, and deploy it to help develop tools to improve the design and analysis of chemicals (i.e. systems to aid with molecular design, information for use in LCA, etc.).
   b. Act as a center for the communication of information regarding impacts of chemicals in use and potential alternatives.

4. Implement a coordinated research and development fund overseen by funding from a variety of agencies (including the EPA, NSF, NIH, DOE and others as appropriate) as is common in developing solutions to large-scale, interdisciplinary challenges. Include:
   a. Basic R&D funding for major, pre-competitive platforms and technologies, and long term, fundamental research areas.

b. Support GC&E curriculum development and retraining programs needed to develop a workforce with the skills required to develop and implement GC&E innovations.

c. Large scale funding (like DARPA, DOE) to help green innovations in key areas transition from the laboratory to full-scale industrial use.

5. Provide funding and support for states that implement technical outreach programs for GC&E implementation in small and medium sized firms.

6. Recognize and broaden Design for the Environment (DfE) and other cooperative programs between industry and government, in order to increase the impact of partnership programs for development of less hazardous products.

V. Conclusion

Plans to develop a reformed TSCA legislation must explicitly include green chemistry and engineering in the overall regulatory structure. By acting across a chemical's life cycle, with a focus on hazard prevention, they are robust, long term, and preventative approaches to guarding against harm to human health and the environment. Since GC&E innovations must also provide the same technical and economic performance as the alternatives that they replace, they provide competitive options which reduce the cost of regulatory compliance on chemical firms and the wider economy. For these reasons, GC&E have the potential to be powerful tools for chemical risk management.

The Center for Green Chemistry and Engineering at Yale has developed a set of six policy recommendations to guide policy-makers in how to effectively incorporate this growing field into TSCA. Support for GC&E in a reformed TSCA must be more than rhetorical; as is clear from the policy recommendations, promotion of GC&E as part of a chemical risk management strategy requires the government to commit to the provision of financial and technical resources (see Table 3). The reformed legislation should provide the EPA with a range of policy tools that can be employed to create positive incentives for GC&E based innovations, while also incorporating life cycle and GC&E based analysis throughout the chemical enterprise. Inclusion of these policies will allow the EPA to leverage the power and promise of GC&E as an upstream, systemic, life cycle based innovation tool to provide a long term solution to reconciling the need for chemical substances with the protection of human health and the environment.

NOTE: Green Chemistry & Engineering and the Safer Chemicals Act of 2010

On April 15, 2010, Senator Frank Lautenberg (D-NJ) introduced the "Safe Chemicals Act of 2010" in the United States Senate. On the same day, Representatives Henry Waxman (D-CA) and Bobby Rush (D-Ill) released a discussion draft of a similar bill. These bills present an important and much needed modernization of the country's approach to managing and regulating chemical hazards.

Both versions of the bill, picking up on EPA Administrator Jackson's inclusion of green chemistry as one of the EPA's core elements of TSCA reform, explicitly mention the need to "spur innovation in green chemistry." They address this with a series of proposals under the title of "Safer Alternatives and Green Chemistry and Engineering." The programs included in this section are laudable. They would provide incentives for the creation of greener, less hazardous alternatives through research funding, expedited review processes, awards, labeling programs, and the creation of four national green chemistry and engineering research centers.

While these provisions represent a strong beginning for integrating GC&E innovation into TSCA reform, there is more that can and should be done. GC&E goes beyond the development of safer alternatives. It is fundamentally a series of guidelines for designing chemicals to reduce, and ideally eliminate, hazard. GC&E is a preventative approach based on innovation that improves technical performance, profits, and social benefit. It takes into account long-term, life cycle thinking.

GC&E is at its most powerful as a tool for the development of the next generation of chemical innovations. For new chemicals and materials, it is much more efficient if they are as benign as possible from the outset, eliminating the need to develop safer alternatives later. Deployed throughout the scientific community and the chemical enterprise, the principles of GC&E provide the foundation for a powerful, market-oriented, economically favorable approach to protecting human health and the environment from the potential adverse impacts of chemical substances before any impacts could even occur. Not only would this improve safety, but it would enhance the broader sustainability of the chemical enterprise in the United States.

APPENDIX

I. Twelve Principles of Green Chemistry[14]

1. It is better to prevent waste than to treat or clean up waste after it is formed.
2. Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3. Wherever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
4. Chemical products should be designed to preserve efficacy of function while reducing toxicity.
5. The use of auxiliary substances (e.g. solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.
6. Energy requirements should be recognized for their environmental and economic impacts and should be minimized. Synthetic methods should be conducted at ambient temperature and pressure.
7. A raw material or feedstock should be renewable rather than depleting wherever technically and economically practicable.
8. Reduce derivatives - Unnecessary derivatization (blocking group, protection/ deprotection, temporary modification) should be avoided whenever possible.
9. Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. Chemical products should be designed so that at the end of their function they do not persist in the environment and break down into innocuous degradation products.
11. 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. Substances and the form of a substance used in a chemical process should be chosen to minimize potential for chemical accidents, including releases, explosions, and fires.

II. Twelve Principles of Green Engineering[15]

1. Designers need to strive to ensure that all material and energy inputs and outputs are as inherently nonhazardous as possible.
2. It is better to prevent waste than to treat or clean up waste after it is formed.
3. Separation and purification operations should be designed to minimize energy consumption and materials use.
4. Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.
5. Products, processes, and systems should be “output pulled” rather than “input pushed” through the use of energy and materials.

[14]Anastas and Warner, *Green Chemistry: Theory and Practice.*

[15]Anastas and Zimmerman, *“Design Through the 12 Principles of Green Engineering.”*

6. Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.
7. Targeted durability, not immortality, should be a design goal.
8. Design for unnecessary capacity or capability (e.g., “one size fits all”) solutions should be considered a design flaw.
9. Material diversity in multicomponent products should be minimized to promote disassembly and value retention.
10. Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.
11. Products, processes, and systems should be designed for performance in a commercial “afterlife”.
12. Material and energy inputs should be renewable rather than depleting.

III. Participant List

The following individuals contributed their expertise and insights to the authors. However, this is not a consensus document, and it does not purport to represent the views and positions of these individuals and the organizations with which they are affiliated. The recommendations, views and analysis herein are those of the authors.

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