Green Chemistry Guide

POLLUTION PREVENTION
A CORNERSTONE OF SUSTAINABILITY
National Pollution Prevention Roundtable

Collaborated on by renowned university professors, industry professionals and City of Los Angeles's engineers

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POLLUTION
PREVENTION
A CORNERSTONE OF SUSTAINABILITY

GREEN CHEMISTRY GUIDE

This manual provides state agencies and technical assistance providers with tools and resources to better serve their clients who are looking for information and to support greening their operations, supply chains, processes, and products.

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Preface

By DAVID CONSTABLE

We look forward to the day when there is no need to add a modifier to chemistry like green or sustainable because the way in which all chemicals are thought about, synthesized, manufactured and used in products is greener and more sustainable. This transition has already begun and there are many dedicated persons, like the people who wrote this manual, who are committed to making greener and more sustainable chemistry a practical, functional reality. There has been considerable progress over the past 20 years or so and I would expect that in the next 20 years, the practice of chemistry and chemical engineering will mostly be where it needs to be.

I very much enjoyed reading this manual. It provides the reader with the background and context of how green chemistry grew out of the pollution prevention movement of the 1980's and how it is the ultimate form of source reduction. It clearly places green chemistry in the context of systems thinking and the need to look at greener and more sustainable chemistry from a broad life cycle perspective. It points the reader towards useful tools and gives practical advice on how to craft a business case. It firmly recognizes that implementing greener and more sustainable chemistry is more about helping people make different kinds of decisions in their everyday work than only considering technical barriers.

Implementing green chemistry is firmly rooted in the very best possible science and engineering and goes beyond traditional approaches to consider broader impacts and opportunities. Green chemistry is about encouraging what will ultimately be seen as disruptive innovation. Green chemistry is seeing what is possible beyond a heavy reliance on the status quo and many practices that have the potential to be harmful to business, people and the planet.

I would encourage you to read and use this manual. It is timely, practical and comprehensive. It will help you to implement greener and more sustainable practices and sustain those practices over time. It is clearly worth your time and effort to read.

Larger than the world thanks goes to the David Constable, Ph.D. Director of American Chemical Society (ACS) – Green Chemistry Institute in Washington, D.C., for writing this preface.

"Green Chemistry is the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical products."

Anastas, P. and Warner, J. 1998. Green Chemistry: Theory and Practice. Oxford University Press

Chapter 1

Introduction

As more and more companies, businesses, and industries begin to look for ways to improve their environmental footprint, there will be an increasing need for state environmental quality and pollution prevention agencies to be able to offer the resources and information their clients are seeking. While a high level of expertise currently exists at the state level with regard to pollution prevention strategies, resources, and measurement, there is less experience with and knowledge of the newer landscape of green chemistry and what that means for front-of-pipe changes, life-cycle analysis, and demands for change along different points along the supply chain.

This manual provides state agencies and technical assistance providers with tools and resources to better serve their clients who are looking for information and support on greening their operations, supply chains, processes, and products. The manual is organized into ten chapters and three appendices of supporting resources:

Chapter 1 is an inspiration for the manual and the introduction to the principles and tenets of green chemistry.

Chapter 2 describes how green chemistry drives the pollution prevention (P2) strategy, discusses the interconnectedness of sustainability with green chemistry and P2, and introduces the concept of life-cycle thinking.

Chapter 3 discusses the supporting principles for green chemistry and explains the components of a product life-cycle analysis.

Chapter 4 explains green engineering and green chemistry principles, relates green engineering principles to P2 concepts, and provides case studies of green engineering being incorporated into manufacturing processes.

Chapter 5 appraises the green chemistry mindset from different vantage points and explains the beneficial outcomes for companies that embrace green chemistry principles.

Chapter 6 presents an overview of software tools and guidance documents that can be used for implementing Green Chemistry principles.

Chapter 7 builds the business case for Green Chemistry and describes the steps needed for initiating a successful program.

Chapter 8 describes implementation of sustainability practices into business models, integrating Pollution Prevention and Green Chemistry strategies into the models.

Chapter 9 concludes the manual with a discussion on how to maintain success, and the value of recognition and award programs and provides examples of such programs for Green Chemistry/Green Engineering.

Chapter 10 presents the Green Chemistry checklist, courtesy of Michigan Green Chemistry Roundtable.

Chapter 11 the Appendix, contains three sub-sections: Subsection A is a brief history of Green Chemistry, Subsection B contains resources for Green Chemistry and Green Engineering and complements Chapter 4, and Subsection C presents a case study of safer chemical substitution and Complements Chapter 7.

Definition of Green Chemistry for the Guide:

"Green Chemistry is the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical products." † Appendix A presents a brief history of the Green Chemistry movement. Green chemistry was developed as a new model for the creation of chemical molecules in which the primary design objective is that the chemical be inherently non-hazardous. As the twelve principles (Figure 1) became better known, many scientists in fields related to chemistry such as pollution prevention, public health, occupational health and safety, and the environment came to recognize that these principles incorporated many of the core values of these fields as well. Looking at the pollution prevention hierarchy, as established by the U.S. Congress in the Pollution Prevention Act of 1990 (Figure 2), the highest tier is "prevention and reduction". These are also at the center of green chemistry, and are reflected throughout all of the twelve principles. While all pollution prevention is not green chemistry, all green chemistry is pollution prevention.

The 12 Principles of Green Chemistry

Provides a framework for learning about green chemistry and designing or improving materials, products, processes and systems.

1. **Prevent Waste**
2. **Atom Economy**
3. **Less Hazardous Synthesis**
4. **Design Benign Chemicals**
5. **Benign Solvents & Auxiliaries**
6. **Design for Energy Efficiency**
7. **Use of Renewable Feedstocks**
8. **Reduce Derivatives**
9. **Catalysis (vs. Stoichiometric)**
10. **Design for Degradation**
11. **Real-Time Analysis for Pollution Prevention**
12. **Inherently Benign Chemistry for Accident Prevention**

Green Chemistry Definition: The design, development and implementation of chemical products and processes that reduce or eliminate the use and generation of hazardous substances.

Green chemistry is doing chemistry the way nature does chemistry-using renewable, biodegradable materials which do not persist in the environment.

Green chemistry is using catalysts and biocatalysts to improve efficiency and conduct reactions at low or ambient temperatures.

Green chemistry is a proven systems approach.

Green chemistry reduces negative human health and environmental impacts.

Green chemistry offers a strategic path way to build a sustainable future.

Figure 1: The Twelve Principles of Green Chemistry

Pollution Prevention Hierarchy
as establish by Congress in the Pollution Prevention Act of 1990

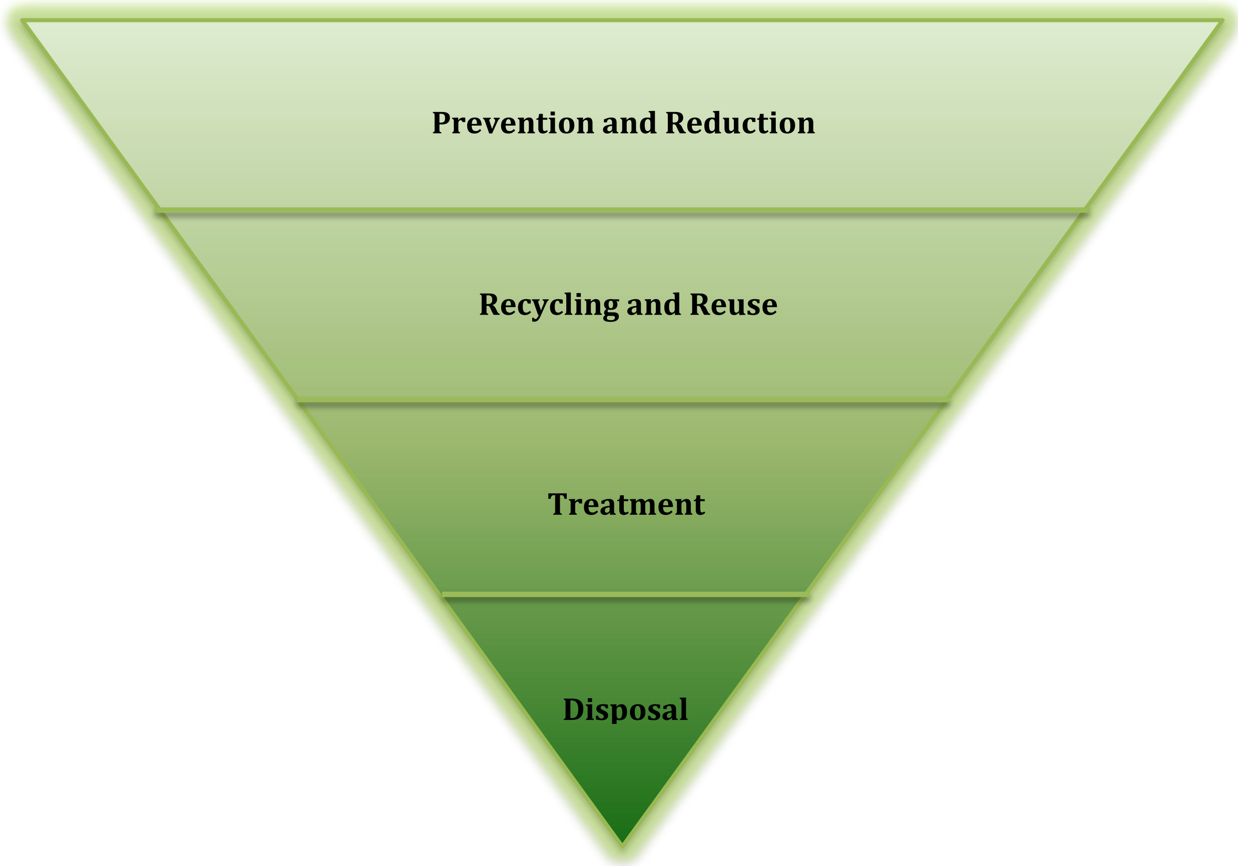

Figure 2: *EPA Pollution Prevention Hierarchy*

The use of green chemistry allows businesses to not only reduce or eliminate negative environmental impacts, but oftentimes creates a competitive advantage as well. Green chemistry applies across the life cycle of a product, including its design, manufacture, and use. Green chemistry practitioners design and implement new products and processes that reduce or eliminate the use or generation of hazardous substances in several phases:

- Extraction of materials.
- In the molecular design of new chemicals.
- In the formulation of new chemicals/applications.
- In the manufacture of products (e.g., when companies manufacture their products).
- When consumers use the products.
- At the end of the cycle when the products (and their packaging) are disposed of.

One of the most important benefits of green chemistry is its inherent ability to drive innovation and a new way of thinking about chemistry and its applications from “cradle to grave.” Green chemistry encourages what its creators call “innovation for success,” that is, the opportunity for companies to create new products and new processes, and in doing so:

- Differentiate them from the competition.
- Meet rising consumer demand for safer and healthier products.
- Stay ahead of tightened regulations and meteoric market changes.

The long-term goal of this effort is that someday there will be no such thing as "green chemistry" – something distinguishable from the rest of chemistry – but that all chemistry will inherently be green, practiced according to the twelve principles as a matter of course and the term "green chemistry" will have become unnecessary and obsolete.

What this means now is that companies that position themselves as market leaders can increase profits using green chemistry concepts as a strategic guidepost. Firms pioneering innovative extraction, feedstock processes, and product redesign and reuse around green chemistry protocols are developing an increased market share that positions them favorably for future sales growth. Green chemistry offers the private sector an opportunity for cutting-edge chemical-related breakthroughs in the move toward more benign production methods and products that bring improved efficiency, and as a result, greater profitability.

"Pollution Prevention is The New Environmental Ethic" "...Pollution should be prevented or reduced at the source whenever feasible."

- Carol M. Browner, former EPA Administrator

Chapter 2

How Green Chemistry Drives P2 Strategy

The establishment of the **Pollution Prevention Act** of 1990 mobilized the development of strategies for reducing pollution in original and innovative ways by reducing the generation of pollutants. Carol M. Browner, then United States Environmental Protection Agency (EPA) Administrator said on June 15, 1993: "Pollution Prevention is *The New Environmental Ethic*"……"the Pollution Prevention Act establishes a bold national objective for environmental protection"…..and "that pollution should be prevented or reduced at the source whenever feasible." EPA defined pollution prevention as "source reduction"[1] as well as protecting natural resources through conservation or increased efficiency in the use of energy, water, or other materials.

When EPA was created in the early 1970's, pollution reduction focused primarily on "control" – containing/minimizing releases after pollutant generation ("end-of-pipe" technologies) – and remediating accidental discharges. Those efforts yielded major reductions in pollution. However, traditional "end-of-pipe" approaches can be expensive, less than fully effective, and sometimes transfer pollution from one medium to another (for example, from water to air). Additional improvements to environmental quality required a move "upstream" to prevent pollution from occurring in the first place. Preventing pollution also offers important economic benefits, as pollution elimination avoids expensive waste management or cleanup. Pollution prevention has the exciting potential for both protecting the environment and strengthening economic growth through more efficient manufacturing and use of raw materials.

The effectiveness of pollution prevention is influenced by a number of factors:

- EPA regulations and state programs.
- Collaborative efforts offering recognition and technical assistance.
- Public data.
- Availability of clean technologies.
- Practices and policies of large public agencies.

Despite its many influences, the Pollution Prevention Act made it clear that pollution prevention is not the only strategy for reducing risk but is the preferred one.

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[1] *Source reduction is explained under the Pollution Prevention Act*

How Sustainability, Green Chemistry, and Pollution Prevention Interconnect

Pollution prevention (P2) describes activities that reduce the amount of pollution generated by a process, whether it is end user consumption, or industrial production. Most pollution control strategies seek to manage a pollutant after it is formed and reduce its impact on the environment. However, the pollution prevention approach seeks to increase the efficiency of a process or use a less toxic alternative to reduce the amount of pollution generated at its source. Pollution prevention (P2) encompasses more specialized sub-disciplines including green chemistry and green engineering.

Green chemistry, often considered synonymous with the term "sustainable chemistry," is a philosophy of chemical research and design that encourages the development of products and processes that minimize the use and generation of hazardous substances. Green chemistry seeks to reduce and prevent pollution at its source.

"Sustainability" For this manual, sustainability is a concept that is used to distinguish methods and processes that can ensure the long-term productivity of the environment, so that subsequent generations can continue to live on this planet. Earth's resources are finite. While new discoveries, innovative ways to extract resources, and uses of substitute materials will certainly extend resources, the time will come where no more remains and modern civilization will face an uncertain future. Unfortunately, the conventional economic view of resources often fails to consider the environmental harm done in exploiting additional resources. Fossil fuels provide an excellent example.

The key is sustainability. Although sustainability has many definitions, it simply means living in ways that do not deplete Earth's vital support systems, or as *Barbara J. Lither, J.D.* put it "…sustainability is really the study of the interconnectedness of all things." The great challenges to sustainability are:

- Population growth beyond Earth's carrying capacity
- Potentially disruptive changes in global climate
- Provision of adequate food
- Depletion of Earth's resources
- Supply of adequate energy
- Contamination of Earth's environment with toxic and persistent substances

It will not be easy to overcome these challenges and achieve sustainability and it is by no means certain that humankind will ultimately succeed or even survive on Earth. But we have to try; the alternative of a world population reduced to just a few million people surviving in poverty and misery on a sadly depleted planet under conditions hostile to higher life forms is too grim to contemplate. The achievement of sustainability will require adherence to some important principles. These can be condensed into Ten Commandments of Sustainability,[2] which are listed below:

1. Human welfare must be measured in terms of quality of life, not just acquisition of material possessions, which demands that economics, governmental systems, creeds, and personal life-styles must consider environment and sustainability.
2. Since the burden on Earth's support system is given by the relationship: *Burden = (number of people) × (demand per person)*, it is essential to address both numbers of people on Earth and the demand that each puts on Earth's resources.
3. Given that even at the risk of global catastrophe, *technology will be used* in attempts to meet human needs, it is essential to acknowledge the astrosphere as one of the five basic spheres of the environment and to design and operate it with a goal of zero environmental impact and maximum sustainability.
4. Given that energy is a key to sustainability, the development of efficiently used, abundant sources of energy that have little or no environmental impact is essential.
5. Climate conducive to life on Earth must be maintained and acceptable means must be found to deal with climate changes that inevitably occur.
6. Earth's capacity for biological and food productivity must be maintained and enhanced, considering all five environmental spheres.
7. Material demand must be drastically reduced; materials must come from renewable sources, be recyclable and, if discarded to the environment, be degradable.
8. The production and use of toxic, dangerous, persistent substances should be minimized and such substances should not be released to the environment; any wastes disposed to disposal sites should be converted to nonhazardous forms.
9. It must be acknowledged that there are risks in taking no risks.
10. Education in sustainability is essential; it must extend to all ages and strata of society, it must be promulgated through all media, and it is the responsibility of all who have expertise in sustainability.

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[2] *Green Chemistry and the Ten Commandments of Sustainability*, Stanley E. Manahan, ChemChar Research, Inc., 2006

Sustainability has environmental, economic, and social dimensions, also sometimes called spheres (Figure 3).

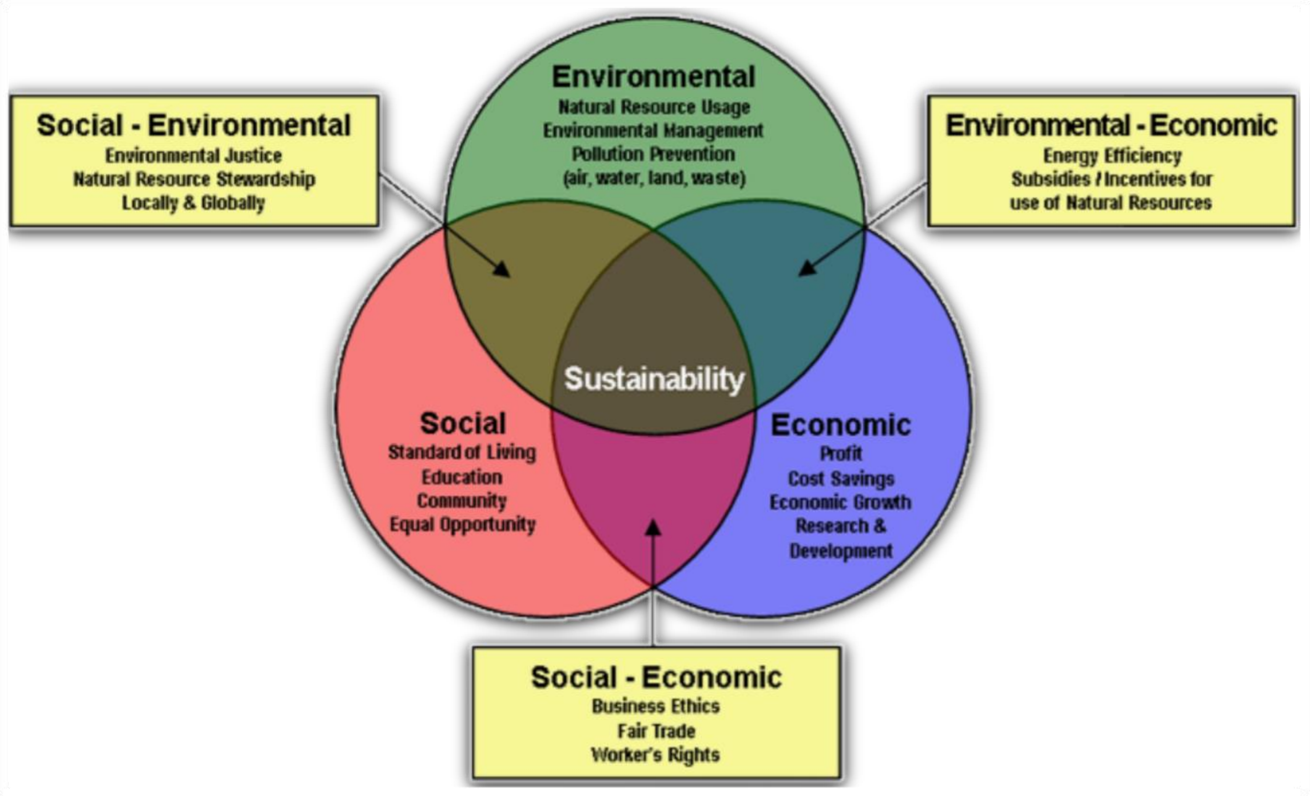

Figure 3. *The Three Spheres of Sustainability*

Life-cycle Thinking is necessary to reduce the environmental footprint. The life-cycle concept will become the backbone in a new industrial culture named sustainable production. Sustainability, in regards to products, means that products are designed for their whole life cycle (i.e., production, distribution, usage, and disposal) with minimized (acceptable) influence on the environment, occupational health, and use of resources. A key element in this new engineering life-cycle approach is a method/tool, termed "life-cycle assessment," to evaluate environmental, occupational health, and resource consequences in all life-cycle phases at the product development stage.

Both green chemistry and green engineering (see Chapter 4) rely on lifecycle thinking to bring their concepts to fruition (Figure 4). All three serve to achieve the ultimate goal of a sustainable economy and society.[3]

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[3] *California Green Chemistry Initiative Science Advisory Panel Report, May 2008*

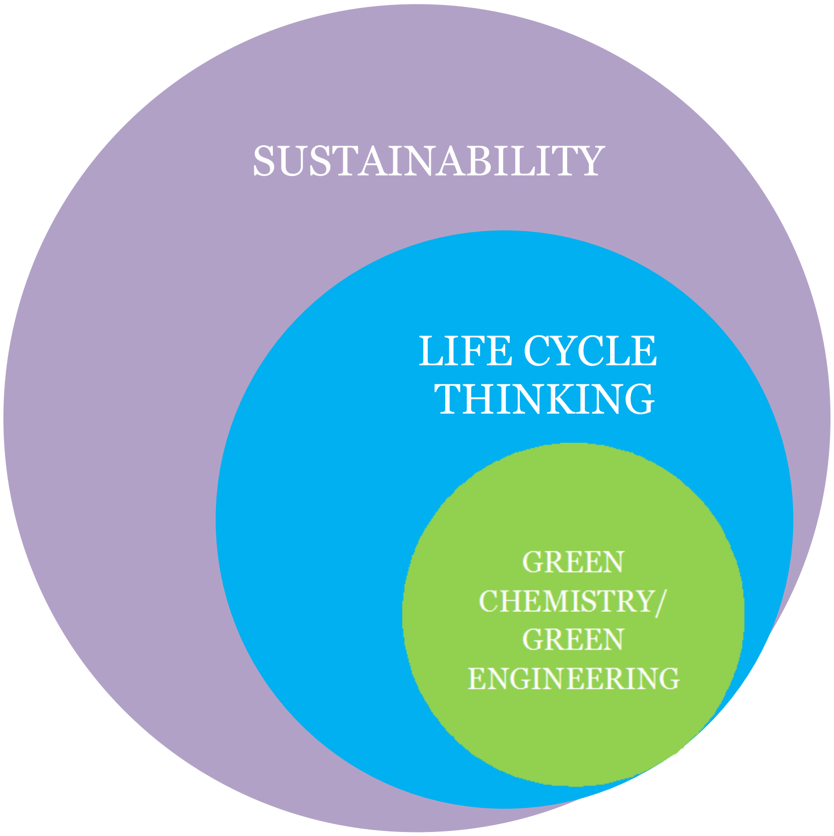

Figure 4. *Green Chemistry: An Essential Component of Sustainable Production*

Sustainability, and the chemical life cycle are considered to go hand-in-hand in developing approaches for making existing and new chemicals safer and more environmentally acceptable. Sustainability is important in ensuring that we have and will continue to have, the water, materials, and resources to protect human health and our environment.

The 1987 United Nations report, *Our Common Future* (also known as the Brundtland Report), defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." This definition leads to the consideration of three major aspects of sustainable development: environment, economy, and community.

The establishment in the 1990s of sustainable development as a goal for society has led to the appearance of several concepts for environmental management, with the objective of developing strategies that exceed existing environmental regulations (Table 1). These concepts aim to achieve sustainability by introducing environmental considerations in human activities in general, with green chemistry being the specific response of the chemical industry in this context.

Table 1. Definition of Related Concepts to Green Chemistry for Environmental Management

Concept	Definition
Eco-efficiency	The delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the Earth's estimated carrying capacity (WBCSD 1993).
Industrial ecology	An integrated systems-perspective examination of industry and environment, which conceptualizes the industrial system as a producer of both products and wastes, and examines the relationship between producers, consumers, other entities and the natural world (Sagar and Frosch 1997).
Cleaner Production	The continuous use of an integrated and preventive environmental strategy, applied to processes, products and services to increase the eco-efficiency and reduce risks to the population and the environment (Rigola 1998).
Ecodesign	Designing products to minimize their direct and indirect environmental impacts at every possible opportunity - (Lewis et al. 2001).
Green Engineering	The design, commercialization, and use of processes and products, which are feasible and economical while minimizing pollution at the source and risk to human health and the environment (Kirchhoff 2003).
Life-cycle Thinking	Addressing environmental issues and opportunities from a system or holistic perspective. This way of thinking involves evaluating a product or service with the goal of reducing potential .

Concerns about environmental stewardship are gaining broader traction through emphasis on sustainability and "green chemistry" principles. Occupational safety and health is slowly becoming viewed as a component of environmental sustainability, and its integration with sustainability and green chemistry practices is essential to the effective realization of all of these endeavors.

In the ecological area "sustainability" calls for policies and strategies that meet societies' present needs without compromising the ability of future generations to meet their own needs. Green chemistry is a suite of 12 enabling principles intended to lead to chemical products and processes that are more efficient, use less toxic materials, and produce less waste in the environment.

Green Chemistry and Sustainability

'Green chemistry' and 'sustainable chemistry' are closely interrelated since the vision of green chemistry is holistically aligned with environmental sustainability. Green chemistry can advance environmental sustainability by informing the design of molecules, manufacturing processes, and products in ways that conserve resources, use less energy, eliminate pollution, and protect human health (Figure 5).

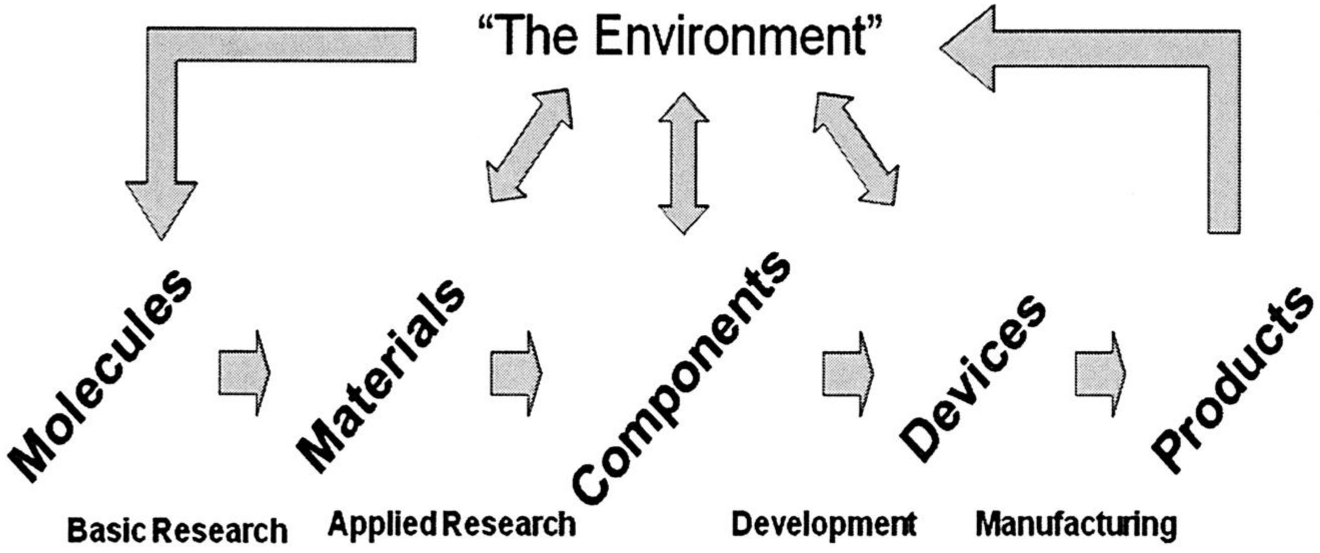

Figure 5: *Product Development Schematic*

This approach has been expressed under initiatives identified as "green." With its direct linkages to other major science disciplines, such as the life sciences, materials science, chemical engineering and environmental science, and its indirect linkages to economics and ethics, together with its principal aim to provide benefits to society, green chemistry is rapidly changing the negative public image of chemistry, which has prevailed for decades.

At the 2002 Green Chemistry and Engineering Conference, developed through a cooperative project of the American Chemical Society's (ACS) Green Chemistry Institute and the ACS Education Division with support from the U.S. Environmental Protection Agency's Office of Pollution Prevention and Toxics, presentations showed how green chemistry can address global challenges, such as reducing the use of toxic chemicals, mitigating the risk of climate change, limiting water and resource depletion, and meeting growing demands for energy and food.

To better understand how green chemistry fits into the bigger picture of product development, it is beneficial to reflect on the product development process. Figure 3 shows the different stages of product development, and that each stage has an environmental impact. Integrating sustainable chemistry concepts into each design stage results in a more sustainable design. Green chemistry principles, such as 'atom economy', 'waste reduction', 'toxic versus benign', 'energy efficiency', 'renewable feed-stocks', 'quality control' and 'safety management' are sustainable strategies traditionally not highly considered in product development.

With this understanding of how green chemistry drives consideration of environmental and human health criteria throughout the product development phases, we can now consider how the science of green chemistry relates to the bigger picture of sustainability. Green chemistry is a framework that has driven numerous improvements over the past decade resulting in a variety of products and processes with a reduced environmental footprint.

Holistic Approach "Cradle-to-Cradle"

The design of commercial products under the "Cradle-to-Cradle" approach is a modern and innovative concept to make products through a continuous use and recycling (or regenerative circle) of biological and technological materials, thus avoiding waste and using renewable materials.

The "Cradle-to-Cradle" design (it appears also under other names, such as C2C, or cradle 2 cradle, or is referred to as regenerative design) is a new philosophy of how to produce green products with minimal pollution and waste. It is a biomimetic approach to the design of systems. Its basic idea is to model human industry after nature's processes in which materials are viewed as nutrients circulating in healthy, safe metabolisms (Figure 4).

In an almost idealistic way, the innovators of cradle-to-cradle want industry to protect and enrich ecosystems and nature's biological metabolism while maintaining safe, productive technical metabolism for the high-quality use and circulation of organic and synthetic materials. It is a holistic economic, industrial, and social framework that seeks to create systems that are not just efficient but essentially waste free. The cradle-to-cradle model is not limited only to industrial design and manufacturing, but can be applied to many different aspects of human civilization (urban environments, buildings, economics, and social systems).

Certain materials, including metals, fibers, and dyes, may be reused without causing a negative impact on the environment. According to McDonough and Braungart[4] they are called "technical nutrients," and they maintain their integrity even after being used in several products. Similarly, some organic or "biological nutrients" may be used and then returned to the earth to decompose. In either case, the materials are regenerative.

The Cradle-to-Cradle Certified program is a multi-attribute eco-label that assesses a product's safety to humans and the environment and design for future life cycles. The program provides guidelines to help businesses implement the cradle-to-cradle framework, which focuses on using safe materials that can be disassembled and recycled as technical nutrients or composted as biological nutrients. Materials taken from the biosphere are returned to the biosphere: for example, plant oils are converted to biodegradable surfactants.

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[4] *McDonough, W. and Braungart, M. 2002. Cradle to Cradle. North Point Press.*

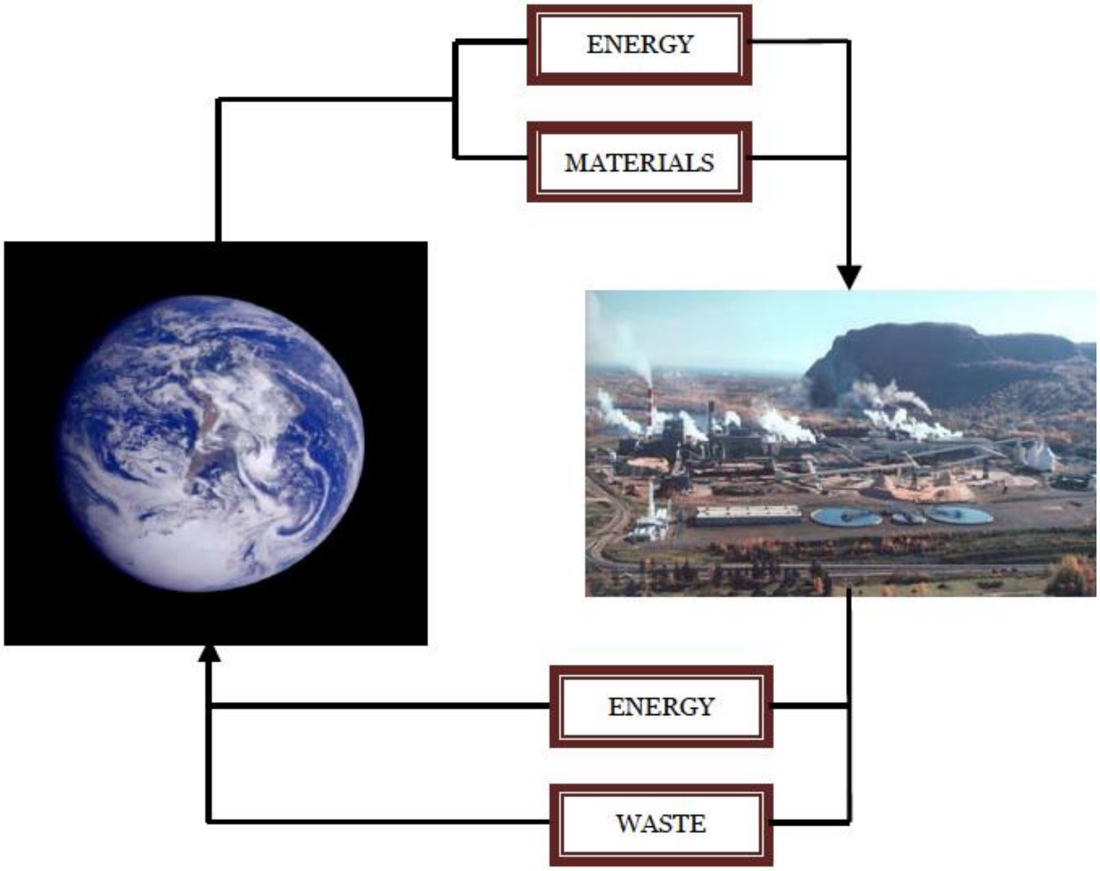

Figure 6: *Achieving Material Sustainability in Natural Cycles*

Is All Green Chemistry P2?

Green chemistry and design is the product design/formulation step at the top of the pollution prevention (P2) hierarchy. Green chemistry is a term that describes the incorporation of P2 principles into scientific and engineering methodology used to design and synthesize chemicals. It is concerned with minimizing or eliminating the potential adverse impacts on health and the environment posed by the production or processing of industrial and consumer chemical products. The goal of green chemistry is to integrate the traditional industrial concerns of feedstock costs, optimization of yield, and energy burden with P2 theory and practice.

Modifications in the design, synthesis, transportation, and use of chemicals result in safer production and use conditions, as well as reduced environmental and health impacts. The most effective modifications occur early in the design process and result in the greatest P2 value for the overall chemical life cycle, and provide the most effective protection for public health and the environment. Green chemistry is a highly effective approach to P2 because it applies innovative scientific solutions to real-world environmental situations.

How does “green chemistry” differ from traditional efforts to reduce pollution?

While “pollution prevention” programs focus on reducing pollutants at the source, many of them do not focus enough on the design issues that are the core of “green chemistry.” Green chemistry reduces pollution at its source by minimizing or eliminating the hazards of chemical feedstock’s, reagents, solvents, and products.

Paul Anastas, then of EPA, and John C. Warner developed the Principles of Green Chemistry (Figure 7), which help explain what the definition means in practice. The principles cover such concepts as:

- Designing processes to maximize the amount of raw material that ends up in the product.
- Using safe, environmentally-benign substances, including solvents, whenever possible.
- Designing energy-efficient processes.
- Using the best form of waste disposal: not creating it in the first place.

Figure 7: *Principles of Green Chemistry*

When implementing green chemistry, those designing consumer products and determining manufacturing processes consider the public health and environmental effects of products at the design phase. Green chemistry practitioners design new products and processes that reduce or eliminate the use or generation of hazardous substances when:

- Companies manufacture the products.
- Consumers use the products.
- The products (and their packaging) are disposed.

The economic benefit of green chemistry results from designing products and processes to reduce or eliminate the need to manage and control waste at the end of the lifecycle. EPA defines green chemistry as the use of chemistry for source reduction (Figure 8).

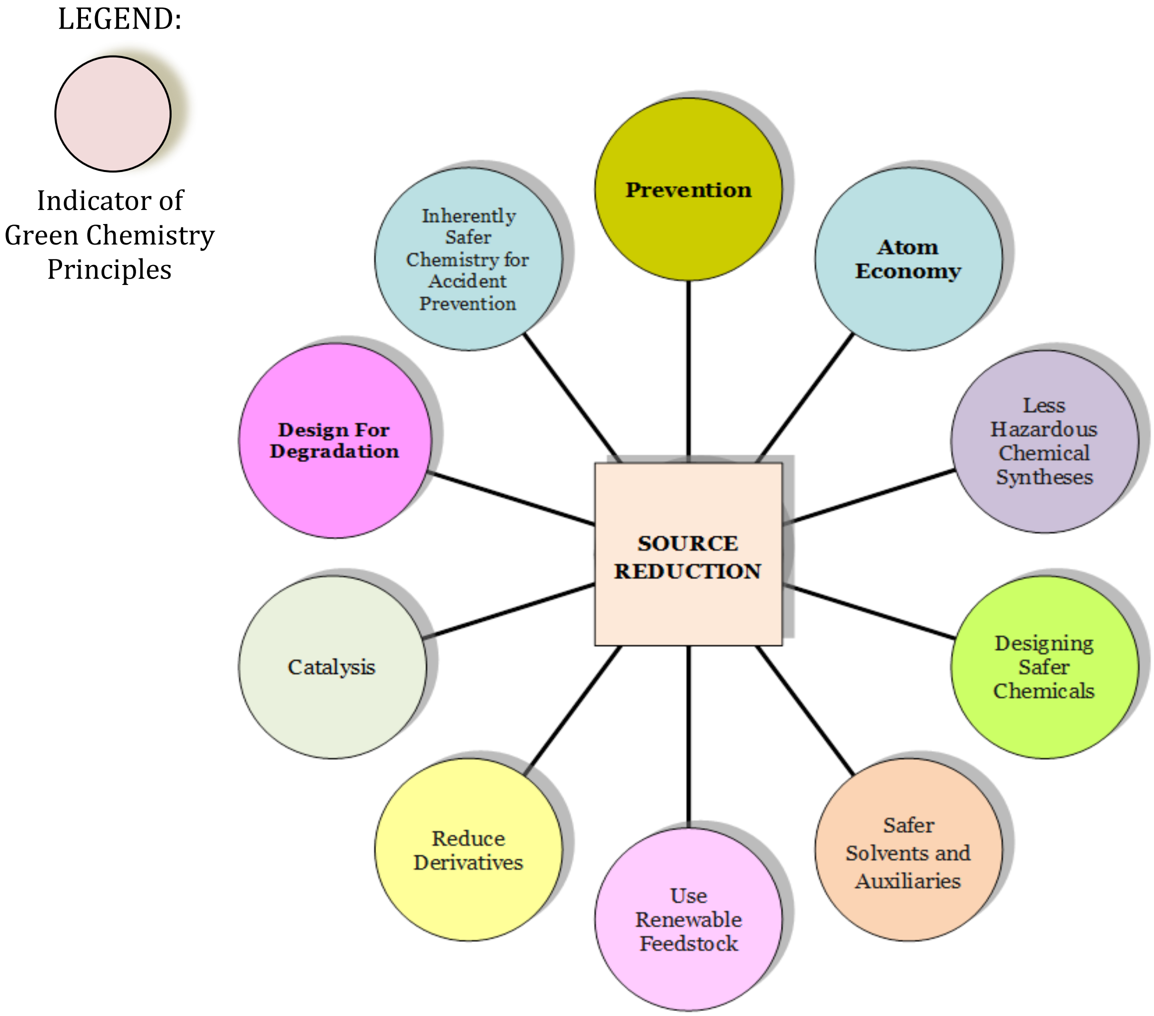

Figure 8: *Green Chemistry and Source Reduction*

"One day, we'll be able to clean up a tanker's chemical spill with water and a broom. It might take decades to get there, but that is what green chemistry will achieve."

- Dr. John Warner, Warner Babcock Institute for Green Chemistry

Chapter 3

Green Chemistry and Life-Cycle Thinking

Chemistry has improved our quality of life and made thousands of products possible. Unfortunately, this achievement has come at a price: our collective human health and the global environment are threatened. Our bodies are contaminated with a large number of synthetic industrial chemicals, many of which are known to be toxic and carcinogenic while others remain untested for their health effects. They come to us from unlabeled products, chemically-contaminated food, air, water, and dust. Developing fetuses are exposed directly to chemicals in the womb. Many chemicals work their way up the food chain and circulate round the globe: pesticides used in the tropics are commonly found in the Arctic; flame retardants used in furniture and electronics are now commonly found in marine mammals.[5] [6]

There is a need for the chemical industry to become more transparent and diligent in testing and disclosing information about their product impacts on the ecosystem. Regulators need to be more proactive in promoting safer chemicals. Although these industry attitudes and the regulatory systems are slowly changing, as demonstrated by the recent passing of the European Union’s new chemicals policy, REACH, the consequence of this delayed action has been the devastating effects of certain chemicals on human health and the environment. The focus must be on overhauling the way chemicals are designed from the outset. This is what green chemistry sets out to do: create better, safer chemicals while selecting the safest, most efficient ways to synthesize them and to reduce wastes.

Chemicals are typically created with the expectation that any chemical hazard can somehow be controlled or managed by establishing “safe” concentrations and exposure limits. Green chemistry aims to eliminate hazards at the design stage. The practice of eliminating hazards from the beginning of the chemical design process is the most effective means of protecting our ecosystem throughout the life cycle of the product. Two U.S. chemists, Dr. Paul Anastas and Dr. John Warner outlined Twelve Principles of Green Chemistry to demonstrate how chemical production could respect human health and the environment while also being efficient and profitable.

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[5] Muir, D.C.G et al. 2006. Brominated Flame Retardants in Polar Bears (*Ursus maritimus*) from Alaska, the Canadian Arctic, East Greenland and Svalbard. Environ. Sci. Technol., 40(2):449-455.

[6] Pearce, F. 1995. Tropical Toxins Ruin Arctic Catch. NewScientist, #1987.

The green chemistry concept applies innovative scientific solutions to solve environmental issues posed in the laboratory and in manufacturing. These principles can be grouped into two overarching themes: "Reducing Risk" and "Minimizing the Environmental Footprint."

Reducing Risk

Green Chemistry is dedicated to providing alternative products designed with the health and safety of the employees, customers, and the public in mind.

- **Use Safer Chemicals –** Use performance chemicals that have the lowest levels of toxicity.
- **Design Less Hazardous Synthesis Methods –** Where feasible, make use of synthetic or biosynthetic methods that pose little or no toxicity to human health and the environment.
- **Use Safer Solvents and Reaction Conditions –** Search for the most up-to-date information on green solvents that will optimize your process and provide a safer working environment.
- **Prevent accidents –** Select substances that minimize the potential for explosions, fires, and chemical releases into the environment.

Minimizing the Environmental Footprint

The Principles of Green Chemistry focus on reducing the volumes of chemicals used and preventing pollution.

- **Waste Minimization and Prevention** – Develop chemical synthesis techniques, which reduce or prevent waste. It is better to *prevent* waste than clean it up after it's created.
- **Use Catalysts Instead of Stoichiometric Quantities** – Catalytic reactions inherently use smaller quantities of chemicals to carry out a specified transformation.
- **Reduce the Use of Chemical Derivatives –** The use of protecting groups or other forms of temporary modification of a functionality adds to the total waste incurred in a synthetic route.
- **Synthetic Efficiency (Atom Economy)** – An efficient chemical process ensures the maximum amount of starting materials is used in the final product so that less is wasted.
- **Taking Advantage of Chemicals Designed for Degradation –** Reduce the effect on the environment by using chemicals that are designed to be biodegradable.
- **Establishment of In-process Controls for Pollution Prevention** – To avoid the formation of hazardous substances, adopt real-time analysis and in-process monitoring during synthesis.
- **Use Renewable Feedstocks –** Use raw materials or renewable feedstocks (waste from other processes or products derived from agricultural streams) whenever technically or economically feasible.

- **Encourage Energy Efficiency**– The realization of the economical and environmental impact of energy use in a chemical process, promotes the development of alternative means to reduce the impact.

The principles of green chemistry provide a framework for scientists and engineers to use when designing new materials, products, processes, and systems. The principles focus on sustainable design criteria and have proven to be the source of innovative solutions to a wide range of problems. Green chemistry and green engineering embrace this power of design. If we use it wisely, we can make significant contributions in the drive toward sustainability for the simultaneous benefit of the environment, economy, and society.

As much as the science of green chemistry requires an interdisciplinary effort between many fields in science, the Twelve Principles of Green Chemistry are a universal sustainable approach to any science. Basic concepts behind the principles include: pollution prevention, economy, less hazard, safe design, energy efficiency, renewable feedstocks, design for degradation, accident prevention, etc. are applicable to the production and manufacture of any "consumable" or product, not just chemicals.

A traditional concept in process chemistry has been the optimization of the time-space yield.[7] From our modern perspective, this limited viewpoint must be enlarged, as for example toxic wastes can destroy natural resources and especially the means of livelihood for future generations. In addition, the chemical industry relies almost entirely on non-renewable petroleum as the primary building block to create chemicals.

This type of chemical production is typically very energy intensive, inefficient, and toxic, resulting in significant energy use, and generation of hazardous waste. Raw materials from agricultural waste or biomass and non-food-related bio-products, which are significantly less hazardous, are potential alternatives. The key question to address is: what alternatives can be developed and used, and will they be available to future generations?
"Sustainability" is a concept that is used to distinguish methods and processes that can ensure the long-term productivity of the environment, so that subsequent generations of humans can live on this planet. Sustainability has environmental, economic, and social dimensions.

Green chemistry is one of the most important areas of current research. Green chemistry serves not only to protect our resources, it can also make an economic contribution given the proper choice of methods. The minimization of wastes, the use of recyclable heterogeneous catalysts, and for example the use of oxygen as an oxidant or of hydrogen as a reductant, all offer enormous potential savings compared with conventional chemistry. Traditional methodology that employs stoichiometric reagents (e.g., chromium-based oxidants) is taught in great detail at universities, whereas oxygen is more likely to be perceived as a source of impurities. A paradigm shift would

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[7] Minimizing the time and amount (space) of "reactants" and maximizing the output (yield).

seem to be quite difficult, since it would mean replacing traditional methods that have already been in use for decades.

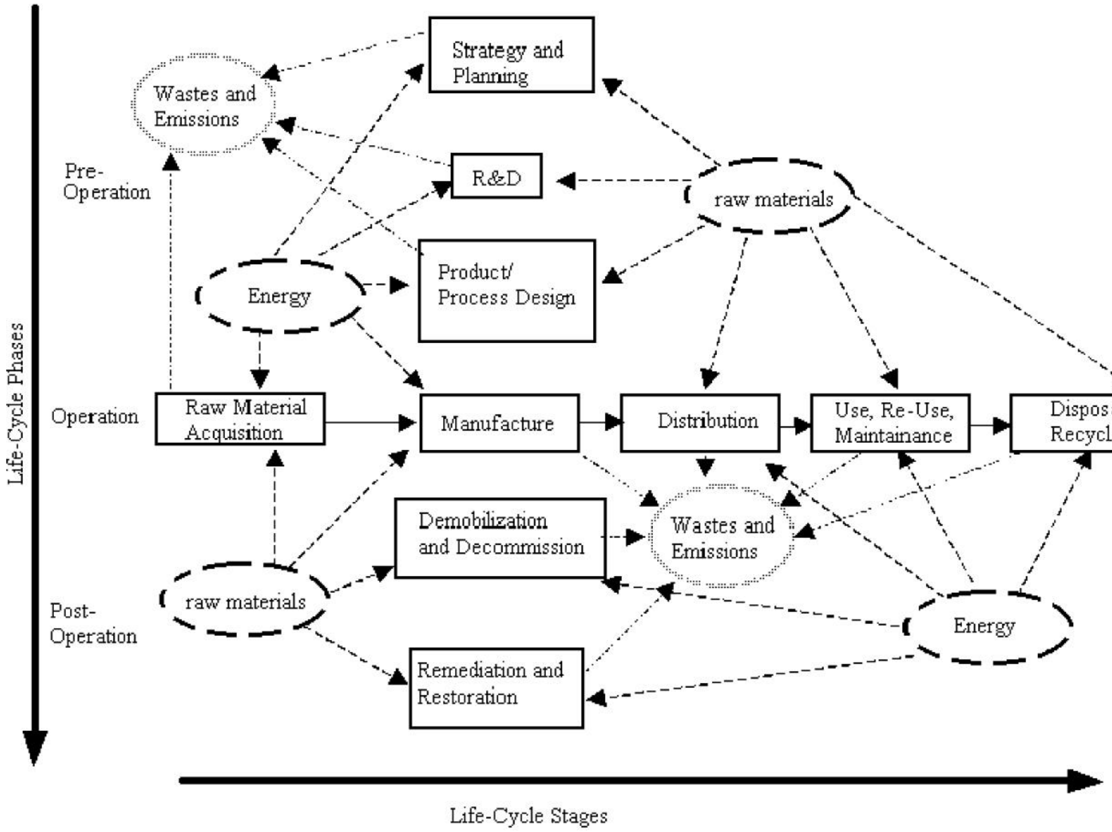

Figure 9: *Product Life-cycle Stages*

Product life cycles include raw material extraction, material processing, use and disposal steps, and are illustrated along the horizontal axis. Process life cycles include planning, research, design, operation, and decommissioning steps and are shown along the vertical axis. In both product and process life cycles, energy and materials are used at each stage of the life cycle and emissions and wastes are created.[8]

The Benefits of Green Chemistry

- Economical
- Energy efficient
- Lower production costs
- Lower compliance costs
- Less waste(or fewer wastes)
- Fewer accidents
- Safer products
- Healthier workplaces and communities
- Protects human health and the environment
- Competitive Advantage

Using green chemistry techniques would result in safer workplaces for industry workers, greatly reduced risks to fence line communities and safer products for consumers. Also, because green

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[8] Rosselot, K. and Allen, D.T. 2002. Life Cycle Concepts, *Product Stewardship and Green Engineering*. Green Engineering: Environmentally Conscious Design of Chemical Processes. (Allen, D.T and Shonnard, D.R., eds) Prentice-Hall, Inc. N.J.

chemistry processes are more efficient, companies would consume fewer raw materials and less energy and save money on waste disposal.

The more understood a chemical structure's effect on toxicity is, the more options are available to design a safer chemical. Chemists now have access to many sources of information to determine the potential toxicity of the molecules they design and the ingredients they choose. Green chemists are trained to integrate this information into the design of molecules to avoid or reduce toxic properties. For example, they might design a molecule large enough that it is unable to penetrate deep into the lungs, where toxic effects can occur. Alternatively, they might modify the properties of a molecule to prevent its absorption by the skin or ensure it safely breaks down in the environment.

Introduction to Life Cycle of the Product

Products, services, and processes all have a life cycle. For products, the life cycle begins when raw materials are extracted or harvested. Raw materials then go through a number of manufacturing steps until the product is delivered to a customer. The product is used, then disposed of or recycled. These product life cycle stages are illustrated in Figure 9, along the horizontal axis. As shown in the figure, energy is consumed and wastes and emissions are generated in all of these life cycle stages.

Processes also have a life cycle. The life cycle begins with planning, research, and development. The products and processes are then designed and constructed. A process will have an active lifetime, and then will be decommissioned and, if necessary, remediation and restoration may occur. Figure 9, along its vertical axis, illustrates the main elements of this process life cycle. Again, energy consumption, wastes, and emissions are associated with each step in the life cycle.

The environmental effects of a product - the environmental load throughout the product life cycle - are primarily determined at the planning and design stages. Environmental awareness and environmental initiatives in these stages are thus critical for the creation of eco products. Planning and design activities are governed by the three basic policies: energy-saving design, resource saving, and elimination of harmful substances (Figure 10).

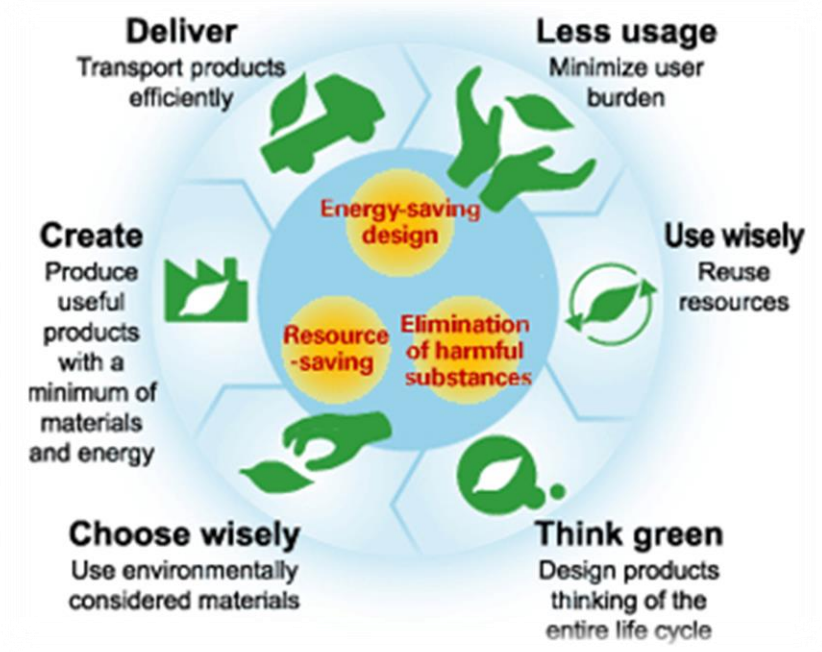

Figure 10: *Three Basic Policies of Product Design*

For many years, reducing the environmental impacts of products focused solely on production processes, treatment of waste, and effluent streams. While this remains important, in order to successfully address environmental sustainability issues, we must also consider the design, manufacture, and use of a product across its entire life cycle: from raw material extraction and conversion; to manufacture and distribution; through use, re-use, and recycling; to ultimate disposal. The use of a holistic life cycle perspective helps manufacturers and policy makers identify possible improvements across the industrial system and through all the product's life cycle stages. It also applies to improving industrial processes and activities.

The key to thinking about products and processes using a life cycle perspective is to avoid shifting the burden. This means minimizing impacts at one stage of the life cycle, or in one geographic region, or in a particular impact category, while avoiding unrecognized increased impacts elsewhere. Taking a life cycle perspective requires a policy developer, environmental manager, or product designer to look beyond their own system, knowledge, or in-house operations.

Environmental Issue or Problem

Applying a life cycle perspective can help identify opportunities and lead to sustainable solutions that help improve environmental performance, societal image, and economic benefits. Businesses do not always consider their supply chains or the 'use' and 'end-of-life' processes associated with their products.

The approach to applying a life cycle perspective to arrive at a broader perspective is called Life-cycle Assessment (LCA). LCA methods have been standardized as part of the International Organization for Standardization (ISO) environmental management standards in ISO 14040:2006 and 14044:2006. Life-cycle studies range from highly detailed and quantitative assessments that characterize, and sometimes assess the environmental impacts of energy and raw material use, wastes, and emissions over all life stages, to assessments that qualitatively identify and prioritize the types of impacts that might occur over a life cycle. LCA is intended to be a quantitative approach. However, to form a complete picture of the product system and the environmental impacts that are involved, qualitative aspects can, and should be taken into account when quantitative data are not obtainable.

LCA is a way to analyze the inputs and outputs of materials and energy, and the environmental impacts that are directly attributable to a product, process, or service. The goal is to enable decision makers to make the most environmentally benign choices. Analyzing the full life cycle forces decision makers to look holistically at consumption and production.

Basic LCA guidance is available in EPA's LCA101 document entitled, "*Life Cycle Assessment: Principles and Practice*," which provides an introductory overview of LCA and describes the major components: goal and scope definition, life-cycle inventory, life-cycle impact assessment, and interpretation.

Life-cycle assessment is a useful decision-support tool in the chemical industry. However, in contrast to other fields such as energy, many chemical-specific environmental issues are not adequately represented in LCA. It is the goal of green chemistry to improve the modeling of such chemical-related issues within LCA and provide an adequate tool for the identification of environmental improvement potentials in the chemical industry.

Example: Region 9 Green Remediation

EPA Region 9 is applying the life cycle concept to estimate the environmental footprint of a corrective action cleanup in a pilot study at Romic in East Palo Alto, California. Investigative research of chemical life cycles, i.e., the impacts of the production and use of chemical products and their precursor and successor compounds as well as impacts from the release of chemical products into the environment, is a necessary step. To this end, case studies were developed on the life cycle of chemical products, process-integrated production measures, and end-of-pipe technologies in collaboration with industry.

Life-cycle Inventories

Life-cycle inventories account for material use, energy use, wastes, emissions, and co-products over all stages of a product's life cycle. Life-cycle Inventory (LCI) analysis involves creating an inventory of flows from and to nature for a product system. Inventory flows include inputs of water, energy, and raw materials, and releases to air, land, and water. To develop the inventory, a flow model of the technical system is constructed using data on inputs and outputs.

The flow model is typically illustrated with a flow chart that includes the activities that are going to be assessed in the relevant supply chain and gives a clear picture of the technical system boundaries. The input and output data needed for the construction of the model are collected for all activities within the system boundary, including from the supply chain (referred to as inputs from the techno-sphere) (Figure 11).

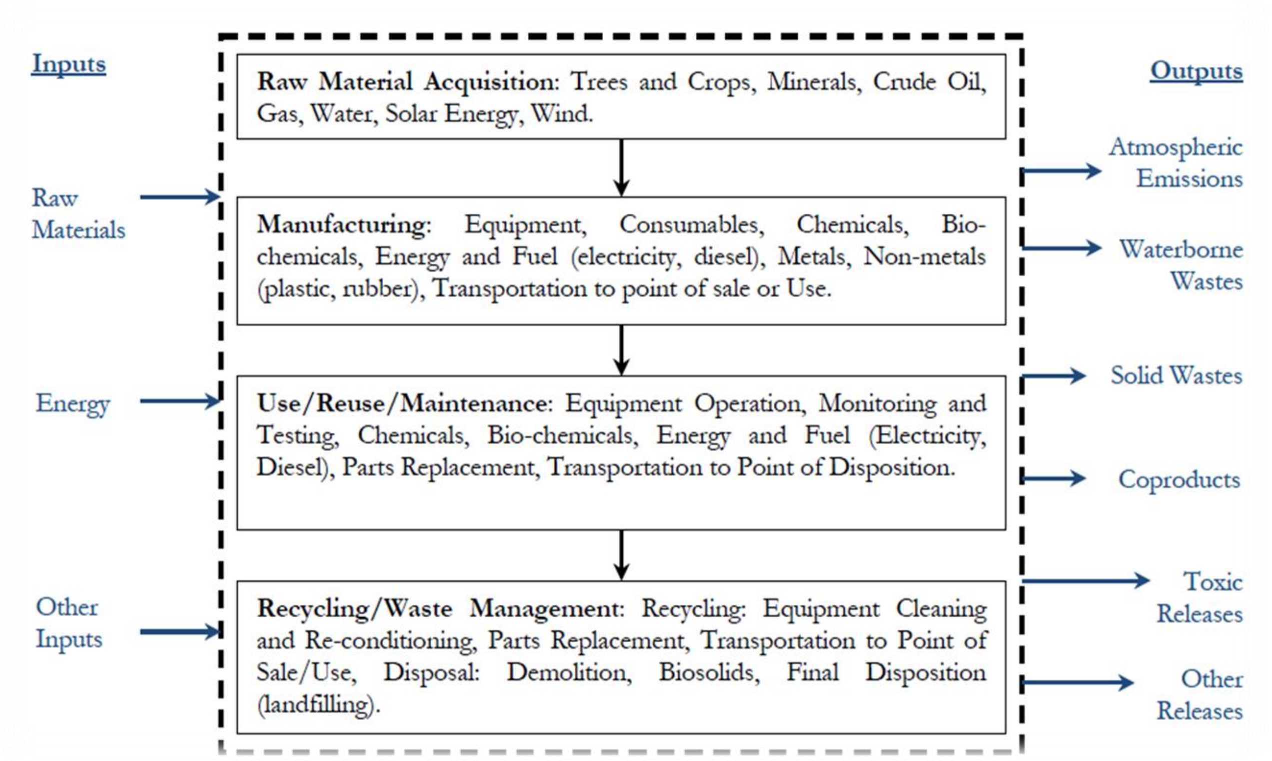

***Figure 11:** Adapted from the U.S. EPA's report #EPA/600/R-06/060*

Process Design and Optimization

The development and lifecycle of a chemical process consists of different stages: chemical research, process design, process implementation, plant operation, process monitoring, process retrofitting, and re-design. During each stage, questions arise and decisions are made that influence the layout and operation of the process. For the assessment of these decisions technical, economic, safety and environmental aspects should be considered. Energy and material flows in sustainable chemical process design framework including cradle-to-gate environmental impacts, gate-to-gate process efficiency, downstream material recovery, and waste treatment options (Figure 12).

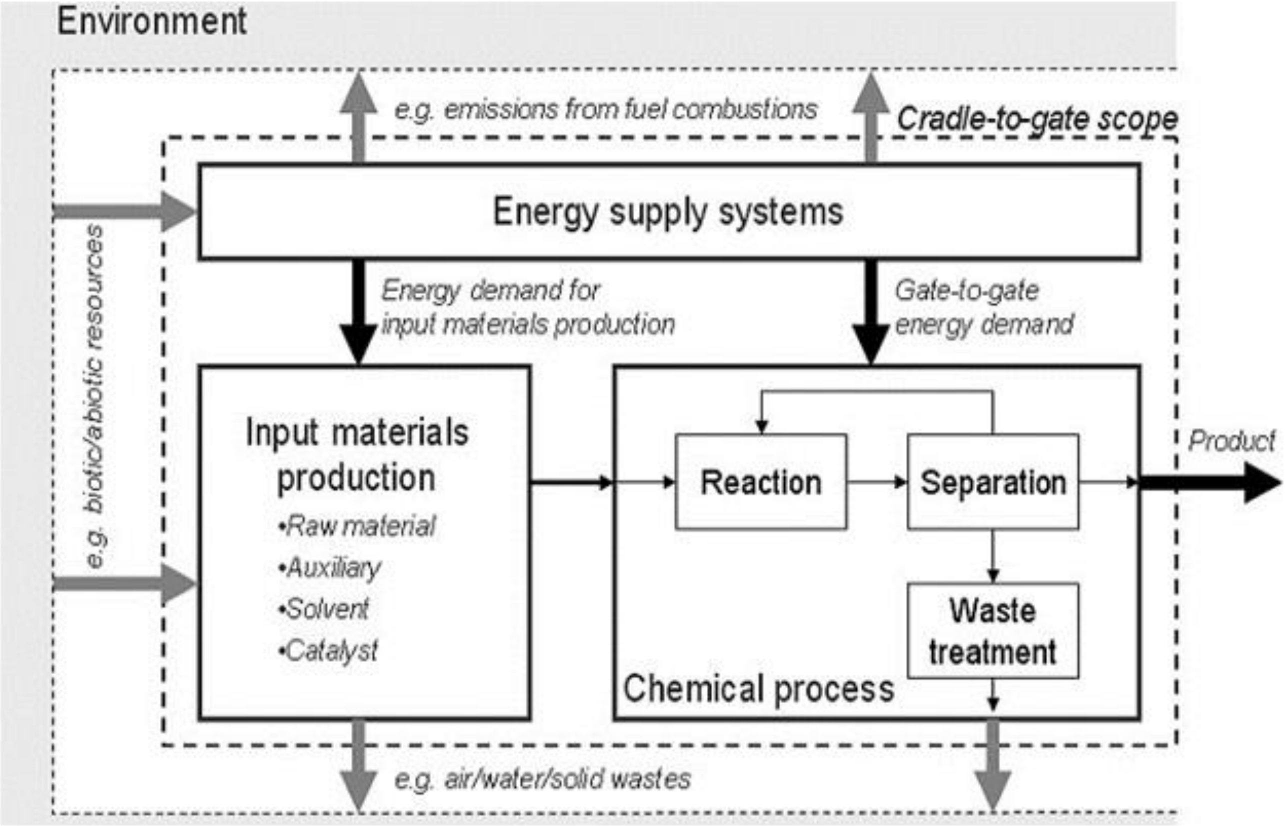

Figure 12: *Energy and Material Flows in a Chemical Process*

To approach optimum decision-making, it is necessary to develop:

- Process models on the basis of the available information in each decision stage.
- Indicators to capture the process "footprint" in all the aforementioned aspects.
- Optimization algorithms to "tune" the parameters or decision variables of the process models towards the desired optimum.
- Decision support tools (e.g., Sensitivity/Uncertainty analysis, Pareto methods), which assess the robustness of the achieved solution in a multi-objective way.

It is also necessary to use:

- Available databases for physical properties of the substances involved in the process. These properties should capture a wide range of effects relevant not only to the process setup (e.g., kinetic data, separation related critical properties) but also to the proposed indicators for the multi-objective assessment of the process (raw materials prices and cradle-to-gate environmental footprint, as well as environmental, health, and safety hazards).
- Elaborate commercial software tools for process simulation and flow sheeting.
- Suitable programming environments.

Naturally, the ensemble of tasks associated with the goals mentioned above is not far from being characterized as infinite. Focus is mainly on the following subset of tasks:

- **Operation of batch processes**, particularly in multiproduct/multipurpose batch plants, modeling of the most typical unit operations (e.g., reactors, distillation and absorption columns, crystallizers, filters, etc.) and optimum production scheduling with respect to productivity, flexibility, and environmental impact.
- **Retrofitting of batch processes**, focusing especially on indicator-based heuristic actions and their quantification with respect to financial and environmental targets.
- **Development of deterministic and empirical (or short-cut) process models**, including advanced industrial-data fitting procedures. Common software for this purpose includes ASPEN Plus, gPROMS, and Matlab, among others.
- **Energy flow analysis in batch plants**, estimation of avoidable and unavoidable losses, and systematic definition of the energy-saving potential.
- **Integrated chemical batch plant design** with the extension of the typical process system boundaries to take into account energy conversion and waste management operations that serve the production processes. For the latter we use pragmatic tools, either developed in-house (waste management) or accessible through our cooperation with other institutes.
- **Green batch process chemistry** promotion through the development of robust indicators for multi-criteria process assessment in early-phase process design. The end-goal is to create a pool of financial and environmental indicators based on the least possible process information, which identify the critical design issues in a multi-dimensional decision space, while maintaining the maximum possible qualitative and quantitative validity with respect to later-stage detailed design results.
- **Stochastic optimization algorithms** for design variables specification and empirical model development through data fitting. These algorithms are linked with weighting and Pareto-based techniques to support multi-criteria decision making.
- **Up-to-date databases** for environmental, health, and safety hazards as well as life-cycle inventories.
- **Development of computer-aided tools** suitable both for design related decision making and plant performance monitoring, focusing on environmental (e.g., energy efficiency related) issues.

Different tools are used to answer different questions, with all tools having their advantages and drawbacks. The choice of tool or group of complementary tools will depend from case-to-case on several factors (Table 2):

Table 2: Factors Affecting the Choice of Tools for Process Optimization

1	Object under assessment	Chemical product, technology, process, plant, or company.
2	Level of effort	Preliminary screening, detailed evaluation, monitoring, number of tools to be used.
3	Site dependency	Need to account for global, regional, or local impacts.
4	Environmental issue of interest	Toxicity to humans and/or ecosystems, energy, waste management, or environmental impacts in general.
5	Data availability	From laboratory, pilot plant, or full scale.

Effective product and process stewardship requires designs that optimize performance throughout the entire life cycle. One goal of this chapter is to introduce available tools for assessing the environmental performance of products and processes throughout their life cycle. The primary focus will be on product life cycles, but similar concepts and tools could be applied to process life cycles. The remainder of this chapter presents quantitative tools used in product life-cycle assessments (LCAs), qualitative tools, and describes a number of applications for these tools.

Product Stewardship

The Chemical Manufacturers' Association (American Chemistry Council) *Product Stewardship Code* (Code) was developed for Management Practices to make health, safety, and environmental protection an integral part of designing, manufacturing, marketing, distributing, using, recycling, and disposing of our products (Figure 13). The Code provides guidance as well as a means to measure continuous improvement in the practice of product stewardship.

***Figure 13**: Product Stewardship*
All stages of product life management, from development through the end of the product life cycle.

The scope of the Code covers all stages of a product's life. Successful implementation is a shared responsibility. Everyone involved with the product has responsibilities to address society's interest in a healthy environment and in products that can be used safely. All employers are responsible for providing a safe workplace, and all who use and handle products must follow safe and environmentally sound practices.

Life-cycle Assessment

Life-cycle assessment (LCA) is the most complete and detailed form of a life-cycle study. A life-cycle assessment consists of four major steps.

Step 1: Determine the scope and boundaries of the assessment. The reasons for conducting the LCA are identified; the product, process, or service to be studied is defined; a functional unit for that product is chosen; and choices regarding system boundaries, including temporal and spatial boundaries, are made. The *system boundaries* are simply the limits placed on data collection for the study.

Step 2: Inventory the outputs that occur, such as products, byproducts, wastes and emissions, and the inputs, such as raw materials and energy that are used during the life cycle. This step, shown conceptually in Figure 3, is called a *life-cycle inventory*, and is often the most time-consuming and data-intensive portion of a life-cycle assessment.

Step 3: Assess the environmental impacts of the inputs and outputs compiled in the inventory. The output from a life-cycle inventory is an extensive compilation of specific materials used and emitted. Converting these inventory elements into an assessment of environmental performance requires that the emissions and material use be transformed into estimates of environmental impacts. This step is called a *life-cycle impact assessment*. A life-cycle inventory is a set of data, material, and energy flow calculations that quantifies the inputs and outputs of a product life cycle.

Step 4: Interpret the results of the impact assessment, suggesting improvements whenever possible. When life-cycle assessments are conducted to compare products, for example, this step might consist of recommending the most environmentally-desirable product. Alternatively, if a single product were analyzed, specific design modifications that could improve environmental performance might be suggested. This step is called an *improvement analysis* or an *interpretation step*. Life-cycle inventories do not by themselves characterize the environmental performance of a product, process, or service. This is because overall quantities of wastes and emissions, and raw material and energy requirements must be considered in conjunction with their potency of effect on the environment.

The process of producing life-cycle impact assessments is generally divided into three major steps.[9] They are:

1. **Classification**, where inputs and outputs determined during the inventory process are classified into environmental impact categories; for example, methane, carbon dioxide and CFCs would be classified as global warming gases.
2. **Characterization**, where the potency of effect of the inputs and outputs on their environmental impact categories is determined; for example, the relative greenhouse warming potentials of methane, carbon dioxide, and CFCs would be identified in this step.
3. **Valuation**, where the relative importance of each environmental impact category is assessed, so that a single index indicating environmental performance can be calculated.

As a first step in life-cycle impact assessment, inputs and outputs that were the subject of the inventory are classified into environmental impact categories.

Examples of environmental impact categories:

- Global warming
- Stratospheric ozone depletion
- Photochemical smog formation
- Human carcinogenicity
- Atmospheric acidification
- Aquatic toxicity
- Terrestrial toxicity
- Habitat destruction
- Depletion of nonrenewable resources
- Eutrophication

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[9] Fava, J and Consoli, F. 1996. Application of Life-Cycle Assessment to Business Performance, Environmental Life Cycle Assessment, M.A. Curran, ed. McGraw Hill, New York.

The second step of impact assessment, characterization, generally consists of assigning relative weights or potencies to different types of emissions, energy use, and material use. These potencies reflect the degree to which the inventory elements contribute to environmental impacts. Once these *potency factors* are established, the inventory values for inputs and outputs are combined with the potency factors to arrive at *impact scores*.

Impact categories frequently considered in life-cycle assessments, range from local to global in their spatial extent and operate over time scales ranging from hours to decades. These spatial and temporal characteristics are listed in Table 3, below.

Table 3. Impact categories[10]

Impact Categories	Spatial scale	Temporal scale
Global warming	Global	decades/centuries
Stratospheric ozone depletion	Global	Decades
Photochemical smog formation	regional/local	hours/days
Human carcinogenicity	Local	hours (acute) – decades (chronic)
Atmospheric acidification	continental/regional	Years
Aquatic toxicity	Regional	Years
Terrestrial	Local	hours (acute) – decades (chronic)
Habitat destruction	regional/local	years/decades
Depletion of nonrenewable resources	Global	decades/centuries
Eutrophication	regional/local	Years

The final step in life-cycle impact assessment, valuation, consists of weighting the results of the characterization step (Table 4) so that the environmental impact categories of highest importance receive more attention than the impact categories of least concern. Valuation schemes based on the "footprint" of the inputs and outputs have been suggested. In these schemes, characterization would be conducted so that the air, water, land, and other resources required to absorb the inputs and outputs are quantified.

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[10] Rosselot, K. and Allen, D.T. 2002.

Table 4. Strategies for valuing life-cycle impacts[11]

Life-cycle impact assessment approach	Description
Critical volumes	Emissions are weighted based on legal limits and are aggregated within each environmental medium (air, water, soil).
Environmental Priority System (Steen and Ryding, 1992)	Characterization and valuation steps combined using a single weighting factor for each inventory element. Valuation based on willingness-to-pay surveys.
Ecological scarcities	Characterization and valuation steps combined using a single weighting factor for each inventory element. Valuation based on flows of emissions and resources relative to the ability of the environment to assimilate the flows or the extent of resources available.
Distance to target method	Valuation based on target values for emission flows set in the Dutch national environmental plan.

Green chemistry reduces risks all along the life cycle of chemical production and use (Table 5). A transformation to green chemistry techniques would result in safer workplaces for industry workers, greatly reduced risks to fence line communities and safer products for consumers. Additionally, as green chemistry processes are more efficient, companies would consume fewer raw materials and less energy and save money on waste disposal.

Table 5. The Benefits of Green Chemistry[12]

Raw Materials	Chemical Synthesis	End Products	End of Life Management
Eliminate Potential Risks	Eliminate Potential Risks	Eliminate Potential Risks	Eliminate Potential Risks
To workers	To workers	To workers	To workers
To suppliers	-	-	-
To shippers	-	To shippers	-
-	-	To shippers	-
To communities near manufacturing site	To communities near manufacturing site	To communities near manufacturing site	To communities near manufacturing site
-		To consumers	
To local environment	To local environment	To local environment	To local environment
-	-	-	To waste sites and communities near them
To global environment	To global environment	To global environment	To global environment

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[11] Christiansen, K. ed. 1997. *Simplifying LCA: Just a Cut?* Final Report from the SETAC-Europe LCA Screening and Streamlining Working Group. SETAC. Brussels.

[12] The factsheet was produced by: Clean Production Action Co., etc. August 2009

Conclusions

Green chemists take a life-cycle approach to reduce the potential risks throughout the production process. They work to ensure that a product will pose minimal threats to human health or the environment during production, use, and at the end of its useful life when it will be recycled, or disposed of. A green chemistry approach is one of “continual improvement, discovery, and innovation,” that will bring us ever closer to processes and products that are safe within natural ecosystems. Ultimately, a product should degrade safely as a biological nutrient or it should be recycled safely.

Life-cycle studies are a uniquely useful tool for assessing the impact of human activities. These impacts can only be fully understood by assessing them over a life cycle, from raw material acquisition to manufacture, use, and final disposal. Life-cycle techniques have been adopted in industry and the public sector to serve a variety of purposes, including product comparison, strategic planning, environmental labeling, and product design and improvement.

Life-cycle assessments have four steps. The first is **scoping**, where boundaries are determined and strategies for data collection are chosen. The second step is an **inventory of the inputs and outputs** of each life-cycle stage. Next is an **impact assessment**, where the effects of the inputs and outputs are evaluated. The final step is an **improvement analysis**. Even for simple products, comprehensive life-cycle studies require a great deal of time and effort. Also, irrespective of how much care is taken in preparing a study, the results obtained have uncertainty.

However, life-cycle studies remain useful. Environmental concerns that are identified early in product or process development can be most effectively and economically resolved and life-cycle studies can also be used as tools to aid in decision-making.

Consumers and business purchasing departments can promote green chemistry by demanding safer, non-toxic products from manufacturers. This will help give a competitive advantage to those companies who screen the chemicals used in their products and demand safer substitutes from their suppliers. Such demand will also help increase the number of green chemistry courses in universities, training the next generation of chemists to consider life-cycle impacts of the chemicals they design.

To what degree the chemical industry is actually adopting green chemistry principles is unknown because some of the most innovative examples are proprietary. Researchers at Yale are identifying the barriers within the chemical industry that prevent or slow the adoption of green chemistry. Green chemistry awards help publicize the feasibility of green chemistry but much more needs to be done.

Governments have a major role in adopting policies that promote green chemistry innovation and implementation in the commercial sector. At the same time, the chemical industry has a duty to integrate the principles of green chemistry into their manufacturing processes. Product manufacturers and retailers have a responsibility to demand chemicals from their suppliers that have been tested and shown to be inherently safe. Green economic innovation for the twenty-first century will require green chemistry.

Supporting green chemistry education ultimately gives chemical companies a competitive advantage by providing a quicker time to market by:
- Reducing regulatory compliance for hazardous materials.
- Reducing worker injury by minimizing exposure to toxic chemicals, processes, and waste.
- Increasing efficiency and productivity of new employees who are better prepared after graduating from academic programs.

The University of California Berkeley, University of Minnesota, and Northeastern University are among twelve colleges and universities that have signed the Green Chemistry Commitment, a consortium that designs and develops innovative, efficient, and environmentally sound chemical products and processes. The Green Chemistry Commitment is organized by *Beyond Benign*, a non-profit foundation created and led by green chemistry scientist Dr. John Warner. As an academic and industrial field, green chemistry encourages chemists and scientists to develop safer, non-toxic, renewable chemistry and materials.

"The goal of green chemistry is for the term to disappear and it simply becomes how we practice chemistry," says Dr. John Warner, co-founder and president of Warner Babcock Institute for Green Chemistry, president of Beyond Benign, and a founder in the field of green chemistry as co-author of the seminal 1998 book *Green Chemistry: Theory and Practice*. "One day, we'll be able to clean up a tanker's chemical spill with water and a broom. It might take decades to get there, but that is what green chemistry will achieve."

Paul Anastas and John C. Warner co-authored the groundbreaking book, Green Chemistry: Theory and Practice in 1998. The 12 Principles of Green Chemistry *declared a philosophy that motivated academic and industrial scientists at the time and continues to guide the green chemistry movement.*

Chapter 4

The Principles of Green Engineering

Green engineering is an approach to engineering design that includes concepts of sustainability in all stages of product development and considers the entire life cycle of the product. Systems and unit processes are designed to eliminate or reduce the need for the use of hazardous substances while minimizing energy usage and the generation of unwanted by-products.[13] Designs based on green engineering principles move beyond baseline engineering quality, safety, and cost considerations to include environmental and social factors. Green engineering embraces the concept that decisions to protect human health and the environment can have the greatest impact and cost effectiveness when applied early to the design and development phase of a process or product. An estimated 70% of the life-cycle cost of products is determined at the design stage.[14]

Green engineering is defined by 12 principles that were originally developed to help drive sustainable practices within the chemical processing industry, which is ultimately the provider of the products and materials we use every day.[15] Green engineering concepts are now integral to any sustainable process or system design. The 12 Principles of Green Engineering[16] are:

1. **Inherent rather than circumstantial**: Ensure designs are as efficient and non-hazardous as possible.
2. **Prevention instead of treatment**: Preventing the production of waste is better than cleaning or treating the waste.
3. **Design for separation**: Separation and purification processes should consume minimal amounts of energy and material.
4. **Maximise efficiency**: Any process should be designed to its maximum efficiency in terms of mass, energy, space, and time.

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[13] Anastas, P. et al., 2007. Green Engineering: Introduction. *In* Green Engineering. (Anastas, P. et al., editors). p. 1-5. American Chemical Society. Washington, DC.

[14] Edwards, S. 2009. The Lowell Center Framework for Sustainable Products. The Lowell Center for Sustainable Products. University of Massachusetts, Lowell.

[15] Anastas, P. et al. 2003. Design Through the 12 Principles of Green Engineering. Environ. Sci. Technol. (37)5:94A-101A.

[16] *Ibid.*

5. **Output-pulled versus input-pushed**: To minimize the energy and material consumption of a process, continually remove ('pull') outputs from the system, rather than adding more input stresses ('push').
6. **Conserve complexity**: More complex products should be designed for longer reuse times than less complex products, as they are harder to recycle and dispose of.
7. **Durability rather than immortality**: Products should be designed to last for their required lifetimes only, in order to avoid environmental problems.
8. **Meet need, minimise excess**: Over-production to meet targets is not only wasteful but also costly and should be avoided.
9. **Minimise material diversity:** The fewer materials a product contains, the easier that product is to recycle and reuse.
10. **Integrate material and energy flows:** Strive to utilize waste energy and material flows to improve the efficiency of another part of the production process.
11. **Design for commercial 'afterlife':** The materials or components of a process, product or system should be reusable or unchanged in value once their initial intended function is over.
12. **Renewable rather than depleting:** Use renewable sources of energy, materials or reagents where possible in a given process or system.

Green Engineering and Green Chemistry

Both green chemistry and green engineering are design philosophies that incorporate material and energy efficiencies, toxicity effects, and product degradation and environmental impacts.[17] Green chemistry is primarily focused on the chemistry of processes and products, whereas green engineering is a more holistic approach to designing products, processes, and systems, and is not limited to the chemistry. These two green philosophies outline goals for achieving more sustainable processes, products, and systems that are more efficient, safer, and cleaner, and generate less waste.[18] However, both of these green tools can also be considered frameworks for collaboration within all stages of product development to accomplish the goals of sustainable design.

Green chemistry and green engineering principles share common themes, several principles are repetitive, and the concept of waste prevention is a foundation in both frameworks (Table 6). Consequently, green chemistry and green engineering should not be thought of as being independent concepts, but inter-related principles.

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[17] Mulvihill, M.J. et al. 2011. Green Chemistry and Green Engineering: A Framework for Sustainable Technology Development. Annu. Rev. Environ. Resour. 36:271-93.

[18] Jimenez-Gonzales, C. and Constable, D.J.C. 2011. Green Chemistry and Engineering in the Context of Sustainability. *In* Green Chemistry and Engineering. p.3-16. John Wiley & Sons, Inc. Hoboken, NJ.

Table 6: Green Engineering and Green Chemistry Principles

Principle	Green Engineering	Green Chemistry
1	Inherent rather than circumstantial	Prevention
2	Prevention instead of treatment	Atom economy
3	Design for separation	Less hazardous chemical use
4	Maximize efficiency	Design for safer chemicals
5	Output-pulled vs. input-pushed	Safer solvents and auxiliaries
6	Conserve complexity	Design for energy efficiency
7	Durability rather than immortality	Use renewable feedstock
8	Meet need, minimize excess	Reduce use of derivatives
9	Minimize material diversity	Catalytic reagents rather than stoichiometric reagents
10	Integrate material & energy flows	Design for degradation
11	Design for commercial afterlife	Use real-time analysis for pollution prevention
12	Renewable rather than depleting	Use safer chemistry to prevent accidents

The connections between the two green approaches can be seen in Table 7, where similar green engineering and chemistry principles are grouped within central themes, which underlie the green principles.

Table 7: Common Themes in Green Chemistry and Green Engineering Principles[19]

Principles	Chemistry & Technology Innovation	Mass and Energy Efficiency	Toxicity and Persistence	Renewability of Feedstocks
Green Chemistry	2,4,5,8,9-12	1,2,5,6,8,9	3,4,10	7,10
Green Engineering	3,11	2-5,10	1,7	12

Because of the close connection between green chemistry and engineering, the two terms are often not differentiated, and frequently the term green chemistry infers the inclusion of green engineering.

Table 7 can be transformed into a scenario for designing nanomaterials. Table 8 shows the association of green chemistry and green engineering principles and how they can be applied to address key impacts during the design of greener nanomaterials. The fact that both green principles can be applied at each stage emphasizes the need for collaboration between green chemists and green engineers, to fully develop the most efficient processes that minimize the detrimental impacts on human health and the environment.

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[19] Jimenez-Gonzales, C. and Constable, D.J.C. 2011.

The development of cellulose nano-crystals is an example of the benefits of capitalizing on the intersection of green engineering and green chemistry. Recently, cellulose nano-crystals, which are bio-based and are a renewable feedstock, have been suggested as being the basis of a new class of biomaterials.[20] These nano-crystals can be obtained from different organic materials such as woody products, plants and algae. They have a wide range of potential functions, from being replacements for carbon nanotubes as structural reinforcement to a new type of biodegradable polymer.

Table 8: Designing Greener Nanomaterials[21]

Design Objective	Practicing Green Nanoscience	Green Eng (GE)/Green Chem (GC) Principles
Safer nanomaterials	Avoid incorporation of toxic elements; determine biological impacts of nanomaterials	1 (GE) 4,12 (GC)
Reduce environmental impacts	Use biobased/renewable feedstocks; determine degradation & fate; design material to degrade into harmless products	1,7 (GE) 7,10 (GC)
Reduce waste	Eliminate solvent-intensive purifications; develop new purification methods; use bottom-up approach to enhance material efficiency	2,4,6,8,9,11 (GE) 1,5,8 (GC)
Process safety	Develop replacements for toxic/pyrophoric reagents; use more benign reagents/auxiliaries; use water/biobased solvents	1 (GE) 3,5,7,12 (GC)
Material efficiency	Optimize incorporation of raw materials in product and processes; use real-time monitoring to maximize process efficiency	1,3,5,8,10 (GE) 2,5,11 (GC)
Energy efficiency	Run reactions under ambient conditions; utilize noncovalent/self-assembly methods; use real-time monitoring to optimize reaction chemistry	1,4,5,10,12 (GE) 6,9,11 (GC)

Appendix B lists green engineering resources that more fully explain the philosophy of these principles, describe the integration into manufacturing processes, and contextualize the concept within a sustainability framework.

Pollution Prevention and Green Engineering

Pollution prevention (P2) is the foundation on which green chemistry and engineering was built. The basis of P2 is the reduction or elimination of pollutants before their generation (i.e., before recycling, treatment or disposal) through more efficient use of raw materials and processes, with the objective of reducing hazards to public health and the environment. When the Pollution Prevention Act of 1990 formalized this concept, defined as source reduction, it was a radically

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[20] Venere, E. 2013. Cellulose Nanocrystals Possible "Green" Wonder Material. Purdue News. Purdue University.

[21] Adapted from: Mulvihill, M.J. et al. 2011. Green Chemistry and Green Engineering: A Framework for Sustainable Technology Development. Annu. Rev. Environ. Resour. 36:271-93.

different approach from previous pollution reduction efforts, which traditionally focused on reducing pollution through “end-of-pipe” techniques (i.e., pollution control devices). The U.S. EPA developed a solid waste management hierarchy (Figure 14), which identifies source reduction as a most preferred strategy for managing waste (i.e., waste generation reduction/elimination).

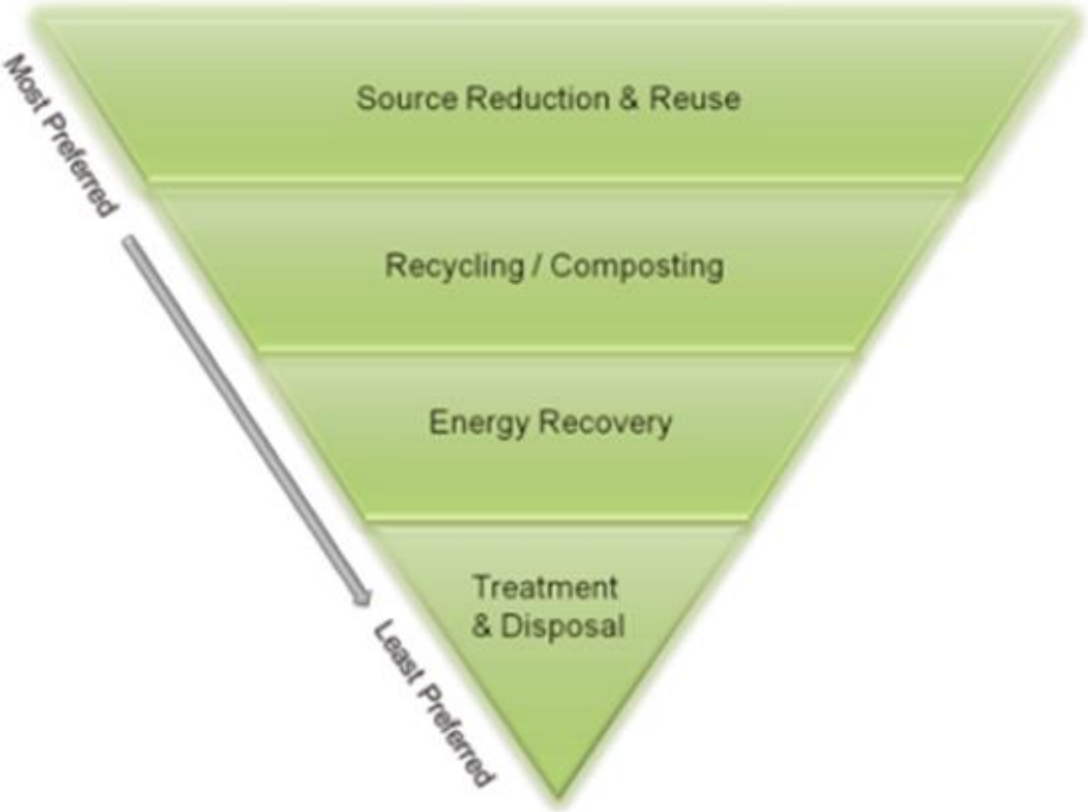

Figure 14: *EPA Solid Waste Management Hierarchy*

Source reduction concepts are directly incorporated into many green engineering and chemistry principles. Table 9 indicates the principles that directly invoke the pollution prevention concept.

Table 9: Green Engineering and Chemistry Principles Related to Pollution Prevention

Green Engineering	Green Chemistry
#1: Ensure designs are as efficient and non-hazardous as possible	#1: Preventing the production of waste is better than cleaning or treating the waste
#2: Preventing the production of waste is better than cleaning or treating the waste	#2: Maximize incorporation of raw materials in to product
#4: Any process should be designed to its maximum efficiency in terms of mass, energy, space, and time	#3: Use less hazardous chemicals
	#4: Design safer chemicals
	#5 Use safer solvents and auxiliaries

Integrating P2 strategies/green principles into product design and development will have major effects on cost savings and ecosystem impacts, as an average of 94% of the resources that go into manufacturing a product is discarded as waste.[22]

An example of the need for implementing source reduction strategies at the product design stage is the current practice of recycling products that contain "chemicals of concern" (COC) – those chemicals that have been deemed to be very toxic, but are still in "circulation." Polybrominated diphenyl ethers (PBDEs) are flame retardants and considered COCs.[23] PBDEs are used in furniture foam as a flame-retardant, and foam carpet pads are commonly produced from recycled furniture foam. Although recycling is a promoted waste strategy, and products are usually considered "green(er)" if they are recycled or contain recycled components, this well-intentioned solid waste strategy can expose workers and consumers, (e.g., children crawling on carpeted floors[24]) to potential hazards.

Green engineering has its roots not only in pollution prevention, but also in Lean Manufacturing. Lean thinking, the American version of the *Toyota Production System* (an integrated socio-technical system developed by Toyota from 1948-1975), focuses on efficiency in manufacturing, in both the processes and workforce, which results in waste reduction.

Traditionally, manufacturing industries focus on quality, cost, and productivity. Lean companies have less scrap, less downtime, less inventory, cleaner factories, and a more productive workforce,[25] while maintaining high product quality, low cost, and rapid product demand response. Although Lean thinking is usually not considered a primary strategy for reducing environmental impacts, it allows companies to produce products more efficiently and to consume fewer natural resources. The following characteristics of Lean businesses[26] indicate that Lean thinking reduces detrimental impacts on the environment, and potentially public health, and incorporates source reduction strategies:

- Lean companies have very low scrap rates due to a focus on eliminating the causes of defects at the source. Consequently, scrap generation is reduced. Less scrap means reduced consumption of raw materials, and less waste potentially going to landfills.
- Lean companies develop more efficient processes, which results in fewer waste discharges and lower energy usage.
- Lean companies maintain their equipment. Proper operations and maintenance translates into longer lifetime and less power consumption.

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[22] Hawker, N. 2013. The Business Case for Green and Sustainable Chemistry. Echochem. http://web.ecochemex.com/business-case-for-green-chemistry

[23] Stockholm Convention on Persistent Organic Pollutants. 2001.

[24] DiGangi, J. et al. 2011. A Survey of PBDEs in Recycled Carpet Padding.IPEN

[25] Tracy, R. 2009. Lean is Green: No Marketing Spin Needed. Effect Magazine. http://www.larsonallen.com/EFFECT/Lean_IS_Green_No_Marketing_Spin_Needed.aspx

[26] Adapted from Tracy, 2009.

- Lean companies have a reduced carbon footprint. A smaller inventory and a smaller, efficient workforce means smaller buildings, and less energy used for maintenance and activities.

Consequently, the "Lean and Green" business model was developed from Lean Manufacturing. The terminology "lean and green" is derived from the notion that a more efficient business model can lead to a reduced environmental footprint. A "lean and green" business model simultaneously enables "green" business practices and cost reductions. The green component of this operating model includes green chemistry and engineering principles.

Applying Green Engineering Principles

Producing sustainable products means minimizing environmental and social costs throughout the product life cycle. Sustainable product manufacturers aim to maximize environmental and social benefits to communities, while remaining economically viable.[27] The principles of green engineering can be applied throughout the life cycle of a product.

The following are examples[28] of green engineering principles being applied in manufacturing processes:

1. Argonne National Laboratory created a novel process to synthesize organic solvents from sugars, which replaced many more hazardous solvents, such as methylene chloride. The process requires a very low energy input, has a high efficiency, and eliminates large volumes of salt waste, while also reducing pollution and emissions.
2. Apple Inc. greatly reduced the number of parts needed for the frames of their range of laptops to just one; a 'unibody' piece of aluminum that considerably reduced the product's weight and allowed for easy recycling.
3. The Dow Chemical Company developed a system for producing polystyrene foam sheets using CO2 as a replacement for traditional blowing agents (which are often toxic and/or ozone depleting substances). All of the CO2 used comes from existing commercial processes as a waste by-product, or from natural sources.

Paul Anastas defined four stages of design development (design scales)[29] where "greening" efforts could be integrated. These design scales are (1) molecular, (2) process, (3) product, and (4) system, and green engineering principles can be incorporated into each. Using Principle 2 (Waste Prevention) as an example, Table 10 shows the applicability of Principle 2 (as well as other principles) to each of the four design scales.

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[27] Edwards, S. 2009. The Lowell Center Framework for Sustainable Products. The Lowell Center for Sustainable Products. University of Massachusetts, Lowell.

[28] Anastas, P. et al. 2003. Design Through the 12 Principles of Green Engineering. Environ. Sci. Technol. (37)5:94A-101A.

[29] *Ibid.*

Table 10: Green Engineering Principles Applied to Design Scales in Waste Prevention[30]

Design scale	Current practice	Application of principle	Green Engineering Principle
Molecular	Protecting groups; substitution reactions	Atom economy	1,2,4
Process	Dry cleaning with perchloroethylene	Dry cleaning with supercritical CO_2	1,2,12
Product	Virgin paper	Paper with recycled content	2,12
System	Fossil energy	Fusion energy	2,12

Efficiency, customer demand, and regulatory compliance are driving companies to embrace green engineering and other sustainable strategies to enhance their competiveness domestically and internationally.[31]

1. Improving efficiency reduces costs, especially in the current business climate of unstable material and energy costs. For example, recycling aluminum cans saves 95% of the energy used to make cans from virgin ore and produces 97% less water pollution.
2. Companies are facing greater demands from a variety of customers along the supply chain. For example, in 2007, Wal-Mart announced that it would only sell concentrated liquid laundry detergent in an effort to reduce water use and packaging. Because Wal-Mart wields such power in the retail sector, detergent producers had to comply with the new policy.
3. There is an increasing number of both domestic (federal, state, and local) and international environmental regulations that make compliance more complicated. The European Union's REACH regulation requires industry to provide chemical safety information on approximately 30,000 substances.

Achieving Profitable Outcomes with Green Engineering

The objectives of green engineering are to optimize efficiency in processes and systems and reduce waste generation, while minimizing the detrimental impacts of these on the environment and public health. Increased efficiency will lower costs, as processes and systems often use more time, space, energy, and material than are necessary; waste requires the expenditure of capital, energy, and resources with no realized benefit.[32] The decrease in the use of hazardous chemicals will reduce regulatory and compliance costs, and the burden of liability and manufacturing security. [33] [34]

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[30] Adapted from Anastas, P. et al. 2003

[31] The Business Case for Sustainable Manufacturing (PowerPoint presentation). U.S. Dept. of Commerce. International Trade Association, Manufacturing & Services. 2011.

[32] Anastas, P. et al. 2003.

[33] The Environment: Public Attitudes and Individual Behavior — A Twenty-Year Evolution. 2011. C.S. Johnson.

[34] Jimenez-Gonzalez et al. 2011.

Integrating green engineering principles into a company's manufacturing processes may accrue other profitable benefits.

- Financing may become easier: for example, companies that are more sustainable may be seen as more responsible, better managed, and less risky, and thus, may have an easier time obtaining financing.[35]
- Market share for products and customer loyalty may also increase as consumers are becoming more knowledgeable about environmental issues and problems.[36] According to a recent survey in the U.S., 42 percent of the respondents said they would be more likely to make purchases from companies with good environmental reputations.
- Employee hiring and retention may improve: for example, 81 percent of Americans said they would "prefer to work for a company that has a good reputation for environmental responsibility."[37]

Companies are becoming more aware of the benefits of sustainable business practices and are incorporating green engineering as part of their sustainability strategy to enhance growth and competitiveness.

This case study[38] describes a green engineering approach to improving an existing process:

Perchloroethylene is a toxic solvent that is commonly used in the dry-cleaning industry. A water-based process, wet cleaning, has been identified as a promising alternative with equivalent performance, but reduced hazards. Ace Cleaners is a small business (four full time equivalents) in Massachusetts that decided to install wet-cleaning equipment to replace its perchloroethylene cleaning operations. The business realized a savings of over $1800 per year, which included a 15% reduction in electricity use. Other benefits included elimination of risks of clean up costs, and reduced potential environmental damage and public health liability. Employees were also more satisfied because of improved air quality in the workplace, and many customers were happy because of the switch to an environmentally friendly process.

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[35] The Business Case for Sustainable Manufacturing (PowerPoint presentation). U.S. Dept. of Commerce. International Trade Association, Manufacturing & Services. 2011.

[36] The Environment: Public Attitudes and Individual Behavior — A Twenty-Year Evolution. 2011. C.S. Johnson

[37] The Business Case for Sustainable Manufacturing (PowerPoint presentation). 2011.

[38] Eliminating the Use of Toxic Chemicals in Dry Cleaning: A Feasibility and Cost Comparison of Perchloroethylene Dry Cleaning to Professional Wet Cleaning. 2011. Toxics Use Reduction Institute. University of Massachusetts, Lowell.

Supporting Resources

Designing sustainable products means ensuring the product is healthy for consumers, the processes are safe for workers, and the product life cycle is environmentally sound, economically viable, and socially responsible.[39] To achieve sustainable designs, in which green chemistry and engineering principles are integral, software tools have been developed for assisting businesses in decision making with respect to resource use, chemical safety, comparative benchmark performance, waste generation, ecosystem impacts, and costs during all stages of a life cycle.

Inherent in any sustainable product design is the safety of the chemicals contained in the product and in the manufacturing of the product. Methodologies and tools have been developed for assessing the detrimental impacts of hazardous chemicals and determining safer alternatives and are more associated with green chemistry (versus engineering), and these are reviewed in Chapter 6.

Software tools more focused on the (green) engineering aspects of sustainable product design have also been developed, and some of these tools were originally intended for conventional P2 assessments. However, many of these tools are also appropriate for transitioning to safer chemicals. Appendix B lists many commonly used tools and references to websites that contain reviews of different types of software. Additional examples of businesses successfully integrating green chemistry and engineering concepts into their operations can also be found in Appendix B.

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[39] Edwards, S. 2009. The Lowell Center Framework for Sustainable Products. The Lowell Center for Sustainable Products. University of Massachusetts, Lowell.

Chapter 5

Green Chemistry Mindset

Understanding green chemistry from different vantage points can be a powerful tool for practitioners in the business assistance line of work. With a systems oriented perspective, a practitioner can then translate these ideas into action from any point in business operations or the supply chain.

However, why would a business want to take action? Why would a business analyze or replace existing products, from cleaning products and office chairs to production materials and packaging, when they already perform the task? To do so, a business must disrupt processes, change procedures and purchasing guidelines, as well as assess and evaluate the impact of the new chemical's use throughout their operations. These activities, at first glance, would seem to counter our current collective goals of increased economic growth, stable employment, and increased efficiency in manufacturing and production. Implementing these changes implies risk.

However, similar concerns were found in the beginning of energy efficiency efforts in homes and businesses. In order to increase efficiency, positive outcomes often require upfront costs and are not immediately quantifiable. For example, Wal-Mart experimented in their "Eco-store" in Lawrence, Kansas by installing a novel daylight, energy efficient full spectrum lighting system in one half of the store and leaf fluorescent lighting in the other half. Not only did they save electricity and reduce operating costs, but an unexpected outcome occurred. There was a significant increase in sales for the cash registers on the daylight side.[40]

In another example, VeriFone built a 76,000 square foot (sq. ft.) new distribution headquarters with day lighting, a new air filtration system, and non-toxic materials, and achieved a low $39 sq. ft. budget. It brought a predicted 65-75% energy reduction and an unanticipated 45% decrease in absenteeism.[41]

Production of new molecules, materials, and products that are more environmentally benign, more economically viable, and that will rival or outperform existing materials, is clearly

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1Natural Capitalism, Creating the Next Industrial Revolution. Paul Hawken Amory Lovins, L Hunter Lovins. p. 89. Little, Brown and Company. 1999

41 Natural Capitalism p. 89; Browing, 1997, 1997a

underway. Now is the time to help businesses see how upfront costs associated with the transition to these new materials can translate into business benefits.

Across the globe, the chemical industry has emerged a key driver of economic growth in this decade. The industry already:

- Generates over $760 billion in sales in the United States.
- Is one of our top exporting sectors at almost $200 billion annually.
- Accounts for over 8% of all U.S. exports.
- Invests $50 billion per year in U.S. research and development (R&D).

These are vital contributions to our future prosperity. Export demand will be a key driver for U.S. businesses in the coming decade, as households and the government remain constrained by debt burdens. R&D spending in investments that boost productivity is a critical contributor to economic growth.[42]

There is a unique opportunity in the U.S. to benefit from the increased use of "green," renewable, or bio-based chemical technology. U.S. companies produce and develop innovative high-performance materials from renewable resources for safer products that often use less energy during manufacturing. These companies are currently on the global stage and partnering effectively with incumbent chemical producers to provide both alternatives and new materials worldwide. Development of state-of-the-art technology in the U.S. is foundational to emerging, energy-efficient plastics and materials value chain, unique to the twenty-first century.

The demand for "greener" products is growing rapidly. In 2011, McKinsey conducted a survey of 500 executives who had influence in the selection and use of plastics in six major industries: consumer goods, packaging, automotive, medical devices, electronics, and construction; the survey also included 1000 U.S. and European consumers.[43] Key findings demonstrated important indicators of the rise in green chemical development and use: 80% of executives surveyed saw green chemicals and materials as an important trend, while 90% of consumers agreed. In a similar survey in 2007,[44] only one in three consumers said they would consider purchasing green products. This increased to four out of five consumers in a short five years.

The report also found that the majority of consumers surveyed would pay a green premium of 5% or more, with a sizable group willing to entertain a price increase of 20-30%. The widespread readiness to pay a premium for green materials without regard to geography or industry will afford a significant opportunity for the entire supply chain in the chemicals industry to profit.

Even if this 'trend' continues to grow, why should businesses replace harmful chemicals in the

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42 Pike Research, 2011

[43] McKinsey on Chemicals, Spring 2012

[44] Bonini et al. *Helping Green Products Grow*. October 2008. McKinseyQuarterly.com

workplace if there is any risk that it might exert additional pressure on their operations? Why change supply chain priorities and begin to use green materials in product manufacturing when there is a ready market place for the incumbent product? In other words, why not leave well enough alone?

The most compelling reason is simply stated: the status quo of chemical and materials production and use in the U.S. today is not 'well enough.' In fact, it is frightfully uncertain. Michael J. Wright, Director of the United Steelworkers Health, Safety & Environment Department, described the U.S. health and safety policy foundation before the U.S. House Subcommittee on Commerce, Trade, and Consumer Protection on Feb. 25, 2009, in Washington, DC:[45]

> *"…the mission which affected me the most, and which haunts me to this day, was as a member of an international team which traveled to Bhopal, India to investigate the December 1984 methyl isocyanate release from a Union Carbide plant that took several thousand lives … and continues to claim victims even a quarter century later from the injuries suffered that night and perhaps from the chronic toxicity of the chemicals released. In my sleep I still see the faces of the parents whose children died, of the children left without parents; I can still hear the constant coughing of the victims who survived, but with most of their lungs burned away.*
>
> *Two members of our team were from the United States. And one thing we quickly realized was that, had the Bhopal plant existed in the United States, none of the underlying causes of the accident – the lack of any risk assessment of the potential for harm under the conditions of use, the storage of large amounts of highly toxic chemicals, the inoperability or undersizing of safety systems – none of it would have violated any existing EPA or OSHA or any other regulation. That includes the Toxic Substances Control Act, although TSCA was then in force. … the Toxic Substances Control Act wouldn't have controlled the causes, much less prevented, the worst toxic substance accident in human history.*
>
> *… much has changed since then. We have the OSHA Process Safety Standard, the EPA Risk Management Program, the Toxic Release Inventory, the Chemical Safety Board, and in the private sector, industry's Responsible Care Program and a whole variety of citizen groups and labor organizations organizing for better chemical safety. But the basic chemical safety law in this country, TSCA – the cornerstone on which everything else rests – remains unchanged."*

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[45] Michael Wright served as a member of the federal National Advisory Committee on Occupational Safety and Health; the Program Advisory Committee of the International Program on Chemical Safety, which is a collaborative effort of several United Nations agencies; and on the industry side, the Public Advisory Panel for the Responsible Care Program of the American Chemistry Council. He was the leader and chief negotiator for the Workers Group in the tripartite negotiations that led to the International Convention on Safety in the Use of Chemicals at Work, which is binding international law on those countries, which have ratified it. Most recently, he was a member of the Steering Committee and several subcommittees of the international group, which wrote the Globally Harmonized System of Classification and Labeling of Chemicals.

Whether at the forefront of the news or not, the green chemistry mindset is driven by this uncertainty regarding the safety and impact of the chemicals used both in the home and the workplace. For example, a bi-partisan poll by the American Sustainable Business Council revealed that 74% of U.S. voters nationwide believed there is a serious threat posed to their health due to exposure to toxic chemicals in day-to-day life.[46] Additionally, 93% of small business owners agreed or strongly agreed that companies using chemicals of concern to human health should disclose their presence to customers and the public. In the same poll of 511 geographically stratified small business owners, 91% believed that chemical manufacturers, that is, chemical companies, should be held responsible for ensuring that their chemicals are safe prior to entering the marketplace, as the Lautenberg draft legislation provided.[47]

In addition, a poll result appeared which may surprise some. It makes clear an unrecognized distinction between safety regulation and "job killing," or "burdensome" regulation in the ongoing debate. Safety regulation is an expectation and the embodiment of the very purpose of federal government. 73% of small business owners supported government regulation to ensure that the products companies buy and sell are non-toxic, yet, the cornerstone legislation, the Toxic Substances Control Act remains unchanged. The green chemistry mindset is a significant course correction to address what can only be interpreted as a deep skepticism among consumers, and a nearly unanimous distaste for increased direct product liability among business owners.

Companies that embrace the green chemistry mindset can see the big picture and understand the risks and rewards of change. The need for change is driven by various forces: economic, social, personal, and consumer preferences. Whatever the reason, the rewards are intrinsically bound to the principles of green chemistry, which will catalyze this fundamental change in our supply chain, manufacturing practices, and business operations.

P2 practitioners strive to identify the multitude of hazards, risks, and inefficiencies in current production processes all along the supply chain. Short and long term negative outcomes are understood at the outset and are compelled to drive more environmentally-preferable solutions. The detrimental impacts of chemical use on the environment including the risks to groundwater supply, poorly managed wastes, ongoing industry non-disclosure, and inadequate regulations are well understood.

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[46] http://asbcouncil.org/node/846

[47] Senator Lautenberg (D-N.J.) introduced the Safe Chemicals Act of 2013 (S. 696) to amend the Toxic Substances Control Act to ensure that risks from chemicals are adequately understood and managed. The objectives of the bill were to increase chemical safety, improve consumer access to information on chemical hazards in products, and protect vulnerable populations, such as low-income communities, children, and pregnant woman. The bill would require that chemical companies show their products are safe before they are included in consumer goods.

Once these sometimes jarring impacts are acknowledged, adopters of the green chemistry mindset often grow even more committed because it's apparent that:

1. The reduction of hazardous chemicals and materials reduces business regulatory risks and legal liability.
2. The use of green chemistry increases health and safety in the workplace.
3. An alignment occurs with previous sustainability efforts, such as an increase in energy efficiency or a reduction in impacts throughout the product's life cycle, for example because of a transition to the use of renewable materials that use less water, energy, and hazardous chemicals in their feedstocks.
4. Green chemistry contributes to a reduction in dependence on oil through increased energy efficiency in materials production and development of new materials early in the supply chain.
5. Green chemistry often produces lighter packaging and products—further decreasing shipping costs and increasing waste management efficiencies.
6. Green chemistry often results in materials that are biodegradable or compostable, which can make localized on-site waste management technologies, such as anaerobic digesters, a viable option.

All of these changes increase the bottom line for businesses. While it is true that the introduction of chemical safety regulation, on par with global standards, may create a few hurdles for some in the short term (higher insurance rates for producers of styrene, a known carcinogen,[48] for example), these costs signify a market correction not a market loss.

Lack of regulatory support for chemical safety in the U.S. continues to decrease consumer confidence, destabilize investments, stifle innovation for safer products, increase legal liability throughout the supply chain, diminish corporate good will, and send U.S. manufacturing and jobs to our competition where risks are known and the rules of business are made plain.

As can be seen in the auto, food, and pharmaceutical industries, government-led safety standards are foundational to a healthy marketplace. Adequate safety regulation and government reporting provides critical information for businesses, consumers, and investors alike. A business can better anticipate and transition away from problem areas, as well as invest in the development of safer products. Consumers can make more informed choices and, therefore, more directly drive market forces for successful new application development based on targeted demographics. Investors can analyze material risks in the industry more accurately, ensuring truer industry characterization for smarter investment.

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[48] U.S. Department of Health and Human Services Secretary Kathleen Sebelius released the *12th Report on Carcinogens* on June 10, 2011 See: http://1.usa.gov/Mh1DqG

Where the chemical industry at large often argues that products—everything from cosmetics to building materials to baby toys—are safe because there is little to no exposure to their toxic chemical ingredients, they fail to address the mounting concerns of bio-accumulative exposure or to make their scientific findings transparent to the public. Implementation of green chemistry norms would promote:

- Restoration of public trust in U.S. manufacturing and imports.
- Creation of an industry best practice for health and safety that meets global market expectations.
- Ability for long term business planning and stimulation of investment.
- Prevention of the investment of critical R&D dollars in innovations that fail to meet global market expectations for health and safety.
- Reduction of direct product liability for business owners, customers, and partners throughout the supply chain.
- Improved transparency of information and creation of an accurately educated customer base.
- Increased competition through safety regulations that increase the value proposition of products, and spurs competition for demand of safer solutions.
- Increased bottom line by ensuring safety in the workplace, which reduces health care costs and improves productivity, and lowers risks and liabilities in all areas.
- Reduction of business risk by elimination of offending technology that creates skepticism in the market, discourages investment across the sector, increases legal liability throughout the supply chain, diminishes company good will and decreases workplace health and safety, which, in turn, decreases productivity and profitability.

The outcomes mentioned above are not merely aspirational goals, but changes that will be necessary to ensure long-term sustainable, social, and economic prosperity. Awakening to the opportunity of green chemistry provides the foundation upon which change is built. Once the green chemistry mindset takes hold, a new perspective on business opportunities and operations emerges.

- We have the ability to observe formulation of products on a chemical molecular level, and think constantly of how to produce new molecules that are more environmentally benign, more economically viable, and that will rival or outperform existing materials.
- We note the extraction of material and disposal of chemicals that make-up the product. We ensure that new synthetic chemicals and materials are designed “in environmentally friendly ways” to be recycled or reconstituted and take into consideration the end-of-life and disposal of the product.

- We begin controlling chemical hazards at the source to promote pollution prevention, minimization of waste, and the conservation of energy and other critical resources at every stage of the life cycle of products.
- We ask, “Is there a safer alternative?”
- We ask if waste can be reused or disposed of easily, or if the material can be optimized to produce less waste.
- We employ an ongoing practice of reducing the input of materials and energy, look at new products to consider materials from a perspective of “atom and energy efficiency, hazard reduction, and holistic design,” and thus “select more sustainable projects.”
- We rethink ingredients during the design phase to design and develop products that can be manufactured, transported, used, disposed of, or recycled safely.

Through these inquiries the supply chain rapidly changes and impact is achieved. Fundamental improvements can be made during the design and development phases that reduce impacts throughout the entire value chain. With a green chemistry mindset, businesses, governments, and institutions can rapidly catalyze a positive impact on the planet, profit, and people.

Avoid "the perfect uselessness of knowing the answer to the wrong question"

- The Left Hand of Darkness Ursula K. LeGuin, 1969

Chapter 6

Overview of Tools

The list of tools to help companies begin the process of transitioning to safer chemicals in their products and processes is growing rapidly, and it can sometimes be challenging to know which among the many available options will prove the most useful. In this section, the objective is to provide a way to review some well-known and proven tools in a more coherent manner by organizing them into different categories. We will also provide guidance on how to determine which tools are most appropriate for the end result desired.

Tools vary in several ways, the most important being that different tools are used to accomplish different ends. A *hazard assessment* is not the same as an *alternatives assessment*, although a hazard assessment is often a part of an alternatives assessment. An alternative assessment is not the same as a *lifecycle analysis (LCA)*, and a resource analysis is another different approach. Equally important, especially for those with a limited background in chemistry who are looking for ways to use tools which integrate the principles of green chemistry into P2 and engineering applications, some tools require less technical knowledge of toxicology and chemistry than others, and are more applicable for technical assistance providers seeking to introduce companies to the concepts of green chemistry.

Another way in which tools can be categorized is by their applicability to the user given where they are positioned in the supply chain. Companies who produce consumer products such as toys and apparel, for example, may be looking for something very different than chemical manufacturers, formulators, and the pharmaceutical industry. Chemical manufacturers, for example, may be more interested in initially approaching hazard elimination and reduction from a process perspective, and are more familiar with traditional engineering approaches to P2. Chapter 4 explains the twelve principles of green chemistry and green engineering, and discusses how the concepts of hazard reduction and elimination can also be used to drive assessments and improvements in process efficiency and sustainability.

Another important difference among tools used for transitioning to safer chemicals is that some tools are open-access, that is, there is no fee for using them and they are easily accessible, usually online. Most tools require that the users know what chemicals are being used. The size of the company and their position in the supply chain may determine how much information they have about the products they are using and the processes involved. In some cases, companies may find it helpful or necessary to engage consultants for assistance in using these tools.

Other tools are proprietary, and require contractual services with the company that created the tool; typically in this case, it is the contractor who should have the expertise required in areas such as toxicology, chemistry, and/or chemical engineering. A key factor in looking at the tools and deciding on a contractor is determining the degree of transparency required. Often there is a trade-off between the degrees of involvement the consultant requires from the client versus the transparency of the process to the client.

Finally, there is another class of tools, which offer a label that identifies a product that has been determined to meet certain environmental standards. These usually require what is called "third party certification," that is, independent verification that the product meets the criteria for making the claim the labeling represents. Once again, the position of the business in the supply chain and, therefore, their customer expectations will usually drive the decision to pursue this type of certification.

A resource that is particularly helpful in understanding how to navigate the decision-making process, the different criteria, and matching the needs of the user to tool capabilities is a publication called *A Compendium of Methods and Tools for Chemical Hazard Assessment* that was written by The Lowell Center for Sustainable Production. The information about understanding the differences between the available tools and the criteria for choosing the tools that are best suited to the client's needs can be easily applied and are extremely useful across the board.

The following sections give a brief overview of the different types of tools available to help businesses:

- Identify the most toxic chemicals in their products, processes, and supply chain.
- Identify and assess potential alternatives and substitutions.
- Reassess their products and/or processes from a lifecycle perspective.
- Spur innovation.

The process may, in some cases, be challenging, but the rewards can be significant:

- Greater efficiency leading to reduced costs and higher profits.
- Improved market competitiveness.
- Greater facility in meeting or exceeding existing regulations.
- New incentives for innovation, and, of course.
- A healthier and more sustainable environment.

Resources for Hazard Assessment & Alternatives Assessment

Two of the more well-known categories of tools using the principles of green chemistry are *hazard assessment* and *alternatives assessment*. A *hazard assessment* evaluates the health and environmental hazards of chemicals in use, as well as potential alternatives under consideration for substitution.

An *alternatives assessment* (AA) more fully evaluates the impacts of chemical hazards by including other assessment components, such as risk/exposure evaluation and social impact analysis. However, no standard presently exists that defines the components of an *alternatives assessment*, although there is consensus that a chemical hazard assessment is the foundation of any AA.

Various tools employ different frameworks for analysis, and it is important to choose the framework that will give the best information to suit the client's needs. The use of *alternatives assessments* in particular, is growing. An AA helps companies seeking to replace problematic chemicals determine what alternatives exist and assures that any substitute selected is not worse than what it is replacing. This is sometimes known as "regrettable substitution" (which is, unfortunately, more common than one would expect).

The Interstate Chemicals Clearinghouse has developed an extensive document, the *Alternatives Assessment Guide* that is divided into modules to assist users as they determine what approach is most appropriate and then leads them through the assessment process in that module. The Toxics Use Reduction Institute (TURI) in Lowell, Massachusetts has also developed alternative assessment methodologies and case studies that are available online, as well as an *Alternatives Assessment Framework* in collaboration with Clean Production Action. BizNGO Network has published several guidance documents: *Guide to Safer Chemicals, Chemical Alternatives Assessment Protocol* and *The Commons Principles for Alternatives Assessments*. These are just a few examples of the many guidance publications emerging onto the landscape.

Many tools are available for performing a chemical hazard assessment. The U.S. EPA, for example, has a tool called TEST for estimating toxicity, and has developed tools to assist in the replacement of industrial solvents (PARIS III) and facilitate waste reduction (WAR). Other well-respected tools in this category include GreenScreen™ for Safer Chemicals, GreenWERCS®, and the Quick Chemical Assessment Tool, more commonly known as QCAT. In addition, organizations such as the Green Chemistry and Commerce Council (GC3), the state of California, and others have put together databases, which include tools across a spectrum of needs.

The plethora of available tools makes navigating them challenging. There is also no standard definition for what comprises an effective alternatives assessment and/or accepted understanding of what differentiates it from other evaluation tools. Companies will often need assistance in matching their needs to the tools available.

Life-cycle Assessment

A life-cycle analysis (LCA) is a procedure for evaluating environmental impacts through all stages of a product's life, and most of the tools available for LCA are proprietary. However, the U.S. EPA has an excellent webpage that covers many aspects of LCA and gives a good definition and grounding in what LCA is about. The California Department of Toxic Substance Control published a document, *Hazard Assessment Tools and Methods*, which includes an extensive review of LCA tools. Other resources include the Cradle to Cradle concept, and its not-for-profit institute, the Cradle to Cradle Products Innovation Institute.

Tool Selectors

Essenscia, the Belgian Federation for Chemistry and Life Sciences Industries, has developed an online tool selector for searching for appropriate sustainability tools, called SUSCHEM compass. The site contains an inventory of tools that "measure the ecological and/or economic impact of products and/or processes and that are useful in the chemical value chain" - "eco-efficiency measurement methods." However, this toolkit also contains some tools that would assist with a *hazard assessment*, including life cycle, economic, and other ecological evaluation tools that would be useful in conducting an *alternatives assessment.*

The Organization for Economic Cooperation and Development (OECD) is in the process of developing a web-based selection tool that focuses on *chemical hazard assessment* methods, but will also contain tools that are applicable to *alternatives assessments*. At the time of this writing, a release date of 2014 is expected.

Summary

Table 11 compares attributes of tools previously mentioned. Additional resources for safer chemical substitutions can be found in Appendix B.

Table 11: Assessment Tool Summary

Tool	Objective	Life Cycle Stage	Proprietary	Expertise Level
Cradle-to-Cradle	Product certification	Product	Yes	N/A
GreenScreen	Chemical hazard assessment	Design	No	Training needed
GreenWERCs	Chemical hazard assessment	Design/Product	No/Fee-based	Medium
QCAT	Simplified hazard assessment	Design	No	Medium
Paris III	Solvent assessment	Design	No	Medium
TEST	Toxicity evaluation	Design	No	High
WAR	Waste generation impacts	Design/Process	No	Medium

Four tool attributes are compared: tool objective, life cycle stage that the tool is most appropriate for, if the tool is proprietary or open source and the highest level of expertise needed to use tool and interpret results. Life cycle stages include: extraction/synthesis, design, process, product and disposal/reuse. Expertise level is defined broadly: low is someone with little technical knowledge, for example only able to use a tool to find "greener" consumer products; high is someone with advanced knowledge of chemistry, toxicology, etc.; medium falls between low and high.

Conclusion

Transitioning to safer chemicals often produces significant rewards for businesses, such as creating safer and healthier work environments and improved market competitiveness, among others. Different approaches and tools are available for evaluating safer alternatives, although selecting the appropriate methodology and tools may be challenging, especially due to the many capabilities and attributes of tools. However, guidance publications and toolkits are available to assist businesses with better decision making in selecting the most appropriate approach and tools for their needs.

Wal-Mart, Target, Staples, Procter & Gamble, Hewlett Packard, Ford, S.C. Johnson, Herman Miller, Nike, Patagonia, Johnson & Johnson, Steelcase, Timberland and many more companies are now actively pushing or pulling product change up supply chains.

Chapter 7

Building the Business Case for Green Chemistry

A. Introduction

A 2013 Ernst & Young/GreenBiz[49] study showed that responding companies with over $1 billion in annual revenue see sustainability as a core business consideration and are approaching sustainability strategically as a revenue driver. Where corporate sustainability programs used to be in areas such as marketing or regulatory compliance that are outside the corporate suites, 65% of respondents report their Chief Financial Officer now getting involved in sustainability efforts. This change in priority was also supported by study responses that indicate that the top corporate sustainability drivers now relate to maintaining or increasing revenue:

- Energy costs (93%)
- Changes in customer demand (87%)
- Brand risks (87%)
- Increased stakeholder expectations (86%)
- Competitive threats (81%)
- New revenue opportunities (80%)

Considerations like these were far more prevalent than basic compliance with government regulations (~40%) as a sustainability driver.

The Ernst & Young/GreenBiz report also finds increasing inquiries from investors and stakeholders in many sustainability-related areas, including producer responsibility for recycling of products and packaging (42%), toxic chemicals in products (39%), and sustainable sourcing and procurement (34%). This is where investment in green chemistry and product design comes in. An oft-cited study by Pike Research[50] states that green chemistry is a global market opportunity, which will grow from about $2.8 billion in 2011 to $98.5 billion in 2020. To compete

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[49] Ernst & Young Global Limited (2013). Six Growing Trends in Corporate Sustainability. Retrieved from http://www.ey.com/Publication/vwLUAssets/Six_growing_trends_in_corporate_sustainability_2013/$FILE/Six_growing_trends_in_corporate_sustainability_2013.pdf

[50] Pike Research LLC (2011). Green Chemistry – Biobased Chemicals, Renewable Feedstocks, Green Polymers, Less Toxic Alternative Chemical Formulation and Foundations of a Sustainable Chemical Industry. Retrieved from http://www.pikeresearch.com/research/green-chemistry

for this opportunity, companies will need to prepare products and services for domestic and global markets in which consumer expectations for product safety and transparency are rising, foreign governments are applying more stringent safety performance standards to products, and state governments are seeking greater transparency on content.

Wal-Mart, Target, Staples, Procter & Gamble, Hewlett Packard, Ford, S.C. Johnson, Herman Miller, Nike, Patagonia, Johnson & Johnson, Steelcase, Timberland and many, many more companies are now actively pushing or pulling product change up supply chains. They use restricted substance or priority chemical lists, supplier questionnaires and audits, established third-party standards, prioritized products types, public announcements, and other tools to signal their expectation of change and to drive and document progress.

On the government procurement side, “environmentally preferable purchasing” is being picked up and adopted by local, state, and federal governments across the U.S., and in various forms, around the world. Government purchasing may be directed by executive or legislative policy restricting specific chemicals or product applications, or through long-term purchase or service contracts, amended to require greener or safer chemistries in office supplies, cleaning chemicals, maintenance products and services, military supplies, fuels or equipment, or any of the myriad other purchases that governments make.

Grassroots changes are the foundation of the business case, driving both private commerce and government. A small but growing percentage of consumers and the manufacturers/retailers who supply them have decided to interpret scientific uncertainty over priority chemicals as a reason to take a proactive and preventive approach. Review of the results of several consumer surveys shows anywhere from 10 to 25 percent reporting themselves as strongly motivated to buy greener products indicated, for instance, by their willingness to pay a premium price. The proportion of respondents indicating softer support for green products (e.g., interest, selection preference independent of price) can top 80 percent. While green chemistry and products are not yet dominant market forces, there is little doubt that the market for green products is significant, especially if price-competitive.

Many businesses have forged ahead in using green chemistry techniques to develop safer products for that growing group of consumers seeking such products and in many cases, willing to pay a premium price for them. While green chemistry is not yet a mainstream consideration across the economy, manufacturing and retail sectors that develop products for internal consumption, direct skin contact (personal care products), building supplies, and home and workplace maintenance are particularly engaged and actively developing products, which can be marketed as safer to use.

B. Being Aware of Barriers to Implementation

Different barriers to implementation of green chemistry initiatives can arise depending on whether a company is starting up, is developing a new product, needs information from suppliers to baseline existing product (components), needs supplier, in-house, or other provider research and development resources, and so on. Small and mid-sized companies getting pressured by high-volume purchasers downstream to improve products tend to lack the resources to conduct necessary R&D and are therefore at risk for losing customers, contracts, and revenues.

Even to get started on product change, these companies or even much larger ones are often stymied by lack of purchasing leverage or the resources necessary to persist and get full baseline information on product content from suppliers. The supply chain problem is worsened when some companies in the chain are located overseas in barely-regulated developing economies. American buyers might expect a high level of awareness of product chemical issues in regulated markets such as Japan, Europe, and Australia, but elsewhere, both awareness and oversight are lagging. It is projected that by 2020, more than half of the world's chemical production will take place in developing countries[51]. In addition to market differences, distance and language are additional barriers to gaining full product content information on supplied components or parts.

Tools to gain information from suppliers include:

- Surveys
- Certifications
- First- or third-party audits of supplier facilities
- Partnership and pooled resources with buyers or suppliers who share suppliers
- Supplier disclosure databases
- Testing programs for incoming products

Think about risk to brand and future liability when considering how to design and resource a due diligence program.

Large companies who use one or more of the tools to monitor upstream suppliers will still encounter a minority who will decide that the cost and disclosure risk of complying with buyer oversight measures is too high. Or, if they gain apparent compliance, is it genuine or permanent? Another situation is an indefinitely prolonged discussion and negotiation with a remote supplier to gain an adequate level of documentation of product constituents.

When product redesign is closer to home, including within the company's fenceline, lack of time, expertise, information, or consulting support can throw up many technical barriers to implementing a chemical substitution. In general, there are four steps to replacing problematic chemicals; each step adding complexity and time:

1. Hazard screen of a single chemical.

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[51] Massey, R and M. Jacobs (2013). Chapter 1: Trends and Indicators. In United Nations Environment Programme, *Global Chemical Outlook – Towards Sound Management of Chemicals*: pp. 1-66.

2. Comparison of one or more possible alternatives to an incumbent chemical used for a defined function in a specific product type.
3. Successful replacement of a validated replacement in a specific company's production process and supply chain.
4. Transfer of one company's specific replacement to another company's product, process, and supply chain (or continual reinvention of this step when information is not available due to confidentiality and competition concerns.

Most leading governmental authorities agree on the negative effects of chemicals, which are commonly high priority for replacement, and hazard/exposure data is readily available. The difficulty comes in getting a clear safety scoring on a less-well known and authoritatively-tested alternative since it is costly and time-consuming to analyze for both the toxicity and feasibility of the alternative. In addition, an alternative that is known and feasible in one company's application may not be for a similar function in a different application, or for the exact same application and function but in a different company's manufacturing process.

Researching entirely new molecules to serve the same function as an incumbent can be quite difficult, given complex reaction pathways. They can be simulated, bench-tested, and safety tested (long-term safety testing of new chemicals can be quite costly), but then must be mapped into existing or new processes and equipment, with capital, piloting, and scheduling needing support from divisions and managers. Depending on the product type or application in the U.S., compliance with federal regulation or standard must be verified with the Food and Drug Administration, Department of Agriculture (pesticides or anti-microbials), Environmental Protection Agency (Pre-Manufacture Notice or Significant New Use Rule for chemicals not regulated by other agencies; volatile organic chemicals, toxic or characteristic hazardous wastes, hazardous air pollutants, and so on), Consumer Product Safety Commission, Department of Defense (branches), or others. Compliance with other air, water, waste, or consumer regulations at the state and even local levels must be considered and pre-approved as necessary. If the new chemical or product is destined for markets outside the U.S., any applicable requirements (similar to the U.S.) in play must also be met.

If some possible replacements are not feasible and an alternatives assessment shows some safety improvement but not across-the-board (including possible gaps in authoritative data), then the company has to decide whether the benefits of eliminating the priority chemical are greater than the known or unknown risks of using the replacement. In many cases, companies have chosen to eliminate a priority chemical with human toxicity, or developmental or endocrine-disrupting effect in favor of one with environmental toxicity or moderate persistence, which is expected to be detoxified during wastewater treatment or broken down by ultraviolet light or microorganisms within a few days in receiving waters or sediment. In all cases making the decision regarding chemical substitution requires that a risk management plan be developed that considers any new or different consumer exposure, manufacturing release, post-consumer recycling worker exposure, or different pathways to the environment.

All of these steps and processes to replace chemicals may add cost to the product, at least temporarily, which may violate supplier or buyer policies against price rises, or worse, lead to lost business. An additional complicating factor can arise if one company division or department is assigned to lead product improvement, but other divisions, which develop, produce, or market the products in question, have practices or directives that are in opposition to the product improvement mission.

C. Accounting for All Costs

Most business enterprises will understand the value of justifying the investment in green chemistry using a business case that is focused on direct impacts, such as raw material and equipment costs or development costs, and their subsequent payback in terms of revenue. Green chemistry's emphasis on material conservation, pollution prevention, and more efficient synthesis suggests that these projects can often be easily justified in these terms. However, as an advocate for green chemistry, the goal of the pollution prevention practitioner is to enable the business to look at these opportunities through a broader lens. The case for green chemistry can be strengthened by including costs that often remain hidden in the cost benefit analysis. Typical organizations absorb expenses, such as the cost of waste management and control, regulatory fees, the cost of energy and water use during manufacture, and changes in labor costs in corporate overhead that is rarely linked to an individual project.

Even more elusive than these hidden costs are those related to long-term or external impacts. Sustainable organizations must account for items such as future regulatory costs and liabilities, the scarcity of natural resources, and the human health and environmental impacts of the products they produce both within and outside of their workplace. The International Federation of Accountants guidance document on Environmental Management Accounting (EMA)[52] describes these items as "less tangible costs." The following examples of costs in this category include:

- "Liability (such as legal judgments related to natural resource damage).
- Future regulation (such as likely future costs of stricter regulation of greenhouse gas emissions).
- Productivity (such as worker absenteeism due to pollution-related illness).
- Image and stakeholder relations (such as, barriers to financing for projects with negative environmental components.
- Externalities (external effects on society, such as the loss of property values due to proximity to high-polluting factories)."

Text in the EMA guidance document provides two interesting case studies that demonstrate the impact of including the hidden or difficult-to-quantify estimated burdens in the full business case.

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[52] International Federation of Accountants (2005). Internal Guidance Document – Environmental Management Accounting. New York.

Case Study 1: EMA for Investment in Process Efficiency – U.S.

A fine paper mill in the U.S. commissioned a study of its rather complex water recycling and reuse system to identify changes that would reduce peak wastewater flows, contaminant levels in wastewater, and total freshwater intake for the mill as a whole. The final study recommended that the mill consider installation of new equipment for capturing more wastewater in process, separating lost raw materials from the water and recycling both materials and water for reuse in the facility.

The feasibility study included an estimate for the up-front capital costs necessary to purchase and install the new equipment. Annual operating costs were also estimated for:

- Purchase costs of raw materials lost in the wastewater.
- Purchase costs of energy for operating the new equipment.
- Purchase costs of operating materials for the new equipment.
- Personnel costs to operate the new equipment.
- Wastewater treatment fees to the local utility.

Unfortunately, this initial investment appraisal estimated the internal rate of return (IRR)[53] on the project to be only 1% over five years. However, a second and more thorough look at the project produced very different results. The original financial analysis did not include a number of environment-related costs that were relevant and significant:

- Purchase costs of freshwater treatment chemicals.
- Purchase costs of fuel for generating process steam to heat freshwater.
- Purchase costs of electricity for pumping both freshwater and wastewater.

When these costs were included in the analysis, the five-year IRR jumped from 1% to 37% because the annual monetary savings from the project were actually three times higher than originally expected. The environmental benefits of the project included significant reductions in materials, freshwater, and energy use, as well as the generation of wastewater.

Source: A. L. White, M. Becker and D. E. Savage, "Environmentally Smart Accounting: Using total Cost Assessment to Advance Pollution Prevention," Pollution Prevention Review (Summer 1993). Extracted from: International Federation of Accountants Guidance Document - Environmental Management Accounting (2005)

Case Study 2: EMA and Less Tangible Liability Costs – U.S.

A major manufacturing firm in the US was concerned about the potential cleanup and liability costs associated with potential fires or chemical spills involving its hundreds of transformers currently using polychlorobiphenyls (PCBs) as a transformer fluid. PCBs released to the environment are highly persistent (resistant to degradation), able to accumulate in the food chain, and are connected with a variety of animal and human health problems. According to US regulations at the time, the

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[53] Internal Rate of Return is the interest rate that makes the net present value of all cash flows equal zero. It is measure of the yield of an investment, so the higher the better.

company could continue to use its PCB transformers until the end of their useful life (which could be as much as 40 years), but then it would have to replace them with transformers using other fluids.

The company decided to investigate the technical and cost implications of phasing out the PCB transformers ahead of schedule. Various costs associated with such a phase-out were estimated: the cost for removal and safe disposal of the PCB-contaminated transformers; the purchase costs of new transformer equipment; and purchase costs of new alternative fluids vs. the current PCB fluids. Some of these data were available from the company's accounting and information systems, while other data were collected from equipment vendors and chemical suppliers. The company also wished to further assess the less tangible costs of greatest concern, including potential cleanup and liability costs. To that end, the possible ramifications of acute events, such as PCB transformer fires or spills, were mapped. It was determined that the most significant potential costs associated with such events would be those related to PCB cleanup, litigation insurance, and business shutdown. Approximate cost estimates and event probabilities were developed using publicly available historical data and internal company estimates. These costs and probabilities were combined to generate a total cost per transformer per year of lifetime. This unit cost was applied to the company's many transformers over their various remaining useful lifetimes to generate a series of annual total cost estimates for the period of years that the company would have PCB transformers under business as usual.

In the opinion of the company's managers, the less tangible costs turned out to be quite significant. The accelerated phase-out project was initially rejected when only the costs from the accounting records and vendors were presented. When the less tangible cost estimates were presented, however, even considering all the uncertainties in these estimates, upper management decided to approve the project, and the company proceeded to phase out its PCB transformers in favor of less hazardous options.

Source: White, Dierks and Savage, Environmental Accounting Principles for the Sustainable Enterprise, 1995. Extracted from: International Federation of Accountants Guidance Document - Environmental Management Accounting (2005)

Of course, producing an exhaustive assessment of estimated cost savings would require more knowledge and time than the typical practitioner tasked with building the business case for a project can afford. Some simple guidance from the Northeast Waste Management Officials' Association (NEWMOA) and the Massachusetts Office of Technical Assistance (OTA) is presented below that can be used to quickly arrive at a comprehensive assessment.

NEWMOA/OTA[54]procedure for accounting for cost savings for pollution prevention (P2) projects:

- Draft a process flow diagram of the existing process that will be altered by the project. The flow diagram should include both the primary production process and any secondary or auxiliary processes that will be impacted.
- Use the process flow diagram to identify all cost generators. Cost generators include labor activities, materials, equipment, and other items that have an associated operating expense. Table 12 provides a list of potential operating costs that should be considered.
- Repeat steps 1 and 2 for the new process. Table 12 provides a list of initial start-up costs that should be considered for any new equipment, material, or other process change.
- Calculate the differences between the current and proposed process costs. Start with the initial costs related to the purchase and installation of the new equipment. Next, calculate the differences in the operating cost, subtracting the 'new cost' from the 'old cost' to determine the difference as either a cost incurred by the project or a savings gained.

Table 12: Potential Operating Costs[55]

Materials	**Regulatory Compliance**
Direct product materials	*Monitoring*
Catalysts and solvents	*Manifesting*
Wasted raw materials	*Reporting*
Transport	*Notification*
Storage	*Recordkeeping*
	Training (right-to-know, safety, etc.)
Waste Management (Materials & Labor)	*Training materials*
Pre-treatment	*Inspections*
On-site handling	*Protective equipment*
Storage	*Labeling*
Hauling	*Penalties/fines*
Insurance	*Lab fees*
Disposal	*Insurance*
	R&D to comply with regulations
Utilities	*Handling (raw materials and waste)*
Electricity	Closure and post-closure care
Steam	
Cooling and process water	**Revenues**
Refrigeration	Sale of product
Fuel (gas or oil)	*Marketable by-product*
Plant air and inert gas	Manufacturing through-put change

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[54] Northeast Waste Management Officials Association and the Massachusetts Office of Technical Assistance. 1998. Improving Your Competitive Position: Strategic and Financial Assessment of Pollution Prevention Projects. Training Manual 3rd Ed. NEWMOA and MA OTA, Boston, Massachusetts.

[55] Extracted from: Northeast Waste Management Officials Association and the Massachusetts Office of Technical Assistance. 1998. Improving Your Competitive Position: Strategic and Financial Assessment of Pollution Prevention Projects. Training Manual 3rd Ed. NEWMOA and MA OTA, Boston, Massachusetts.

Sewerage	*Change in sales from:*
	increased market share
Direct Labor	*improved corporate image*
Operating labor and supervision	
Manufacturing clerical labor	**Future Liability**
Inspection (QA & QC)	*Fines and penalties*
Worker productivity changes	*Personal injury*
Indirect Labor	
Maintenance (materials & labor)	
Miscellaneous (housekeeping)	
Medical surveillance	

Table 13: Potential Initial Costs[56]

Purchased Equipment	**Materials**
Equipment	Piping
Sales tax	Electrical
Price for initial spare parts	instruments
Process equipment	Structural
Monitoring equipment	insulation
Preparedness/protective equipment	Building construction materials
Safety equipment	Painting materials
Storage & materials handling equipment	Ducting materials
Laboratory/analytical equipment	
Freight, insurance	
Utility Connections and New Systems	**Site Preparation**
Electricity	Demolition, clearing etc.
Steam	Disposal of old equipment, rubbish
Cooling & process water	Walkways, roads, and fencing
refrigeration	Grading, landscaping
Fuel (gas or oil)	
Plant air	**Engineering/Contractor (in-house & ext)**
Inert gas	Planning
General plumbing	Engineering
Sewerage	Procurement
	Consultants
Installation	Design
Vendor	Drafting
Contractor	Accounting
In-house staff	Supervision
Construction/installation	
Labor & supervision	**Contingency**
Taxes & insurance	

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[56] Extracted from: Northeast Waste Management Officials Association and the Massachusetts Office of Technical Assistance. 1998. Improving Your Competitive Position: Strategic and Financial Assessment of Pollution Prevention Projects. Training Manual 3rd Ed. NEWMOA and MA OTA, Boston, Massachusetts.

Equipment rental	**Permitting – Fees & In-House Staff**
Start-up & Training	**Initial Charge for Catalysts and Chemicals**
Vendor/contractor	
In-house	**Working capital** (funds for raw materials, inventory, materials/supplies)
Trials/manufacturing variances	**Salvage value** of replaced equipment

D. Articulating Value to the Brand

As described in the previous section, green chemistry projects should be evaluated based on anticipated cost savings relative to the initial investment. It is also important to consider that these projects may have an impact on the company at the level of both the product and the company itself. At the product level they facilitate access to untapped or restricted markets. At the corporate level, they build positive brand loyalty and awareness.

Articulating the impact of a project on the strength of the brand to stakeholders within the company requires a clear understanding of the outward messages of the company. Companies that report environmental performance indicators, for example, metrics related to energy efficiency, water use, carbon emissions, the use of hazardous chemicals, or safety incidents, may have a unique driver for committing to a green chemistry initiative.

International Flavors and Fragrances, Inc. (IFF) views green chemistry as the framework for its research and development approach. In support of one of the four pillars of its sustainability strategy, IFF committed to adopting the twelve principles of green chemistry and to training all of the company's chemists on the principles by the end of 2013.

As an example of their commitment, "IFF is working with Evolva, a Swiss biosynthesis technology firm, to produce natural vanillin through a cost-effective and sustainable route. IFF's vanillin will be developed from a renewable, botanically derived feedstock processed through yeast-based fermentation."
(IFF Sustainability Report 2012)

Among their many stakeholders, most companies will tell you that the customer is king. The perceived ability of environmental messages to target customers will be of interest to internal decision-makers. Because of the pressure of competitive pricing and the importance of market share to most businesses, competitive positioning is an extremely important element of business case development for the green chemistry project – particularly if it results in a final product that is less toxic or has improved performance. In all business sectors, consumer and commercial, customer expectations are constantly evolving, but one point remains constant -- only differentiated products can demand a premium price in the market.

As customers in all segments become more aware of the impacts of global issues such as population growth, resource depletion, climate change and the human health impacts of products, the development of "greener" technologies and products will become even more salient. When evaluating green chemistry projects, as well as any other product-related project, decision-makers should have a sense of industry trends, the product attributes of key competitors, and the needs and influencers of their target customers. Advocates for green chemistry must be able to communicate how potential projects support existing market strategies based on this body of knowledge and to translate changes in hazard, energy efficiency, waste minimization, and the use of renewable inputs into new messages that help the company provide value to their key customers.

A positive brand image is sustained by customer loyalty that develops over time as a result of a company's commitment to innovation, quality, integrity and transparency. The linkage between brand credibility and financial performance is often made[57,58]. Sustainable companies understand that transparency bolsters the brand and is a critical tool for risk management. In a market where green washing is so prevalent, implementing the principles of green chemistry can have a trickle-up effect on the broader company image, in addition to avoiding all of the burdens previously described as less tangible costs or liabilities in the previous section.

E. Audience-Specific Strategies for Communicating the Business Case

Once project savings have been estimated and impacts on corporate branding and reputation are understood, this information needs to be translated into relevant key messages for company decision-makers. In all cases, the most relevant decision-making criterion is the payback period, which is calculated as shown below.

Payback Period = Cost of Project / Annual Cost Savings

The payback period is how long it will take the company to recover the investment that they are making in the project. Given the pace of the business today, most companies can only justify investing in projects that have a payback period of less than two years.

Moving beyond this two year threshold requires that the investment be of strategic importance. As noted previously in the chapter, there are other audience-specific measures that may have singular importance to the company. Below are some examples of specific project attributes or measures that can positively influence decision-making.

- **Production/Plant Manager: Productivity**

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[57] Roberts, P. and G. Dowling (2002). Corporate Reputation and Sustained Superior Financial Performance. *American Strategic Management Journal*, *23*: 1077-1093.

[58] Reputation Institute (2012). Corporate Reputation the Main Driver for Business Value. Retrieved from http://www.reputationinstitute.com/thought-leadership/white-papers

In a manufacturing environment, the key imperative is to produce the volume of product needed at minimum cost. A business case that demonstrates a positive impact on productivity will be a powerful selling point for the plant/production manager. An investment in green chemistry can have direct impacts on productivity. For example, reducing the steps in a chemical synthesis can result in savings in labor, defect rate/scrap material production, and production rate.

- **Future or Current Product Marketing Manager : Market Share**
  For those in the organization specifically focused on capturing market share, tying the project to a value-add for the customer is critically important. As discussed in Section D, gaining the support of the product marketing manager for a green initiative requires articulating a value proposition that is simple, easily connected to the brand, and will impact competitive position. For example, a project focused on the use of a safer solvent can be sold if it eliminates a known customer concern about handling or odor and will help the company become more relevant to a new or previous audience.

- **Commercialization Manager: Manufacturability**
  A product commercialization team works as a bridge between the two audiences discussed above: marketing and manufacturing. At this interface, it is of strategic importance that the product can quickly move from prototype to the manufacturing floor. Many of the principles of green chemistry—reduction of hazardous synthesis steps, design for safety, the use of safer solvents, etc.—are all enablers of this transition that make it easier to scale-up and reduce regulatory and other barriers.

This chapter has provided considerable information on accounting for cost savings, identifying higher level benefits for the company and then using this inventory to deliver solid key messages that are audience-specific. The remainder of the chapter presents case studies from the field. These case studies are designed to clearly delineate the financial model and/or other business drivers that lead to the project, as well as showcase practical examples of the application of the principles of green chemistry.

F. Case Study – Ecolab – Hard Surface Cleaners

www.pca.state.mn.us/index.php/topics/preventing-waste-and-pollution/p2-pollution-prevention/reducing-toxicity/green-chemistry-and-design/green-chemistry-and-design-demonstration-project.html#ecolab

Ecolab, Inc., based in St. Paul, Minnesota, serves businesses in the food service, food processing, hospitality, healthcare, industrial, and oil and gas markets. The company's institutional business unit, which carried out this project, offers products and product/equipment/service support programs to restaurants, hotels, long-term care facilities, schools, commercial buildings, and military facilities. For the most part, Ecolab no longer uses priority chemicals in their products, so instead of regulation, their drivers are market-based: customer demand for renewable and bio-based raw materials to increase cycling of existing atmospheric carbon and avoid adding fossilized carbon.

The purpose of this Ecolab improvement project was to develop a new line of hard surface cleaners to replace Ecolab incumbents provided to institutional customers, and to compete with similar products from other companies. The line included:

- Glass cleaner
- All-purpose cleaner
- Neutral bath cleaner
- Alkaline bath cleaner was originally intended, but acidic options were found to be more feasible so Ecolab switched to an acid bath cleaner, intended for EPA registration as a disinfectant
- Acid bath cleaner (not intended for EPA registration)
- More sustainable or renewable materials for its product packaging, and reduced packaging intensity overall

Since Ecolab had no chemicals of environmental or human health concern (such as triclosan or nonylphenol ethoxylates) in their hard surface cleaner line, activity in this project was primarily finding bio-based, renewable sources for chemicals already in use (citric acid, sodium citrate, alkylpolyglucoside, sodium lauryl sulfate, cocamidopropylbetaine, d-limonene, sodium laureth sulfate, and glycerine). Sources of non-petroleum raw material from which these chemicals can be derived include corn oil, soy oil, palm kernel oil, coconut oil, vegetable oil, sugar, and minerals. Once the chemicals and sourcing was identified, Ecolab determined if supply and price would be reliable and low enough to justify full product development and launch. From there, the basic steps for developing each product type were prototype development, bench (performance) testing, field testing, regulatory review, internal reporting and preparation of launch plans.

Results

Cleaning performance: Soil removal tests showed all new products performing equal to or better than Ecolab incumbents, and where compared, better than other companies' products.

Product renewable material content: Overall renewable percentage increased from 20% to 84%, which equates to a 502,000 pound reduction in non-renewable chemicals. All product types now measure from 65% to 85% renewable, from a mix of different plant sources and suppliers.

Bio-based material content: Ecolab's calculations show the overall average bio-based material percentage moving from 22% to 83%. All product types except the registered acidic bath cleaner are now between 60% and 85% bio-based, exceeding corresponding U.S.D.A. Bio-Preferred minimums by an average of 22%.

Packaging renewable material content: Plant-based resins are limited in availability; polylactic acid resin is compatible with some of the products but much less cost-effective than petroleum-based sources and susceptible to heat during transport or storage. Therefore, there were no changes to packaging design within the project.

Packaging sustainability: Through increased functionality and concentration, the overall product-to-package ratio has more than doubled, equivalent to 49,900 pounds less packaging for the same amount of cleaning capacity (at current sales volume).

Acute human oral and aquatic toxicity: All formulas in the new line exceed (are safer than) the Green Seal 37 standard. (The Green Seal Standard for Industrial and Institutional Cleaners, GS-37, establishes requirements for industrial and institutional general-purpose, restroom, glass, carpet cleaners, and biologically-active cleaning products. The standard includes product performance requirements and environmental and health considerations for vulnerable populations.)

Biodegradation of chemistry: All of the new product types meet the Green Seal 37 standard for being readily biodegradable. The glass, all-purpose, and registered acidic cleaners are now biodegradable.

Volatile organic compound (VOC) content: For all product types and based on current sales, the VOC reduction calculated for product sold prior to dilution was 295,000 pounds. This reduction was achieved by using less monoethanolamine, n-propoxypropanol, isopropyl alcohol, and ethylene glycol monobutyl ether. All product types are now under 1% VOC.

Safety Data Sheet (SDS), Globally Harmonized System (GHS)-aligned comparison: The SDS for the registered acidic bath cleaner will not be ready until EPA-defined toxicity testing is complete. The all-purpose cleaner will require use of safety glasses. Any formula that still requires glasses is being reconsidered as Ecolab implements Safety Data Sheets aligned with the U.N. Globally Harmonized System of Classification and Labeling of Chemicals and the resulting U.S. rules. The three other products will have less-restrictive SDS wording and not require personal protective equipment for using the solution after dilution.

Chemical life-cycle analysis: Ecolab continues to research how suppliers are extracting chemicals from plant sources; since many are also food sources, they are looking for alternative biomaterial feedstocks.

G. Case Study – NYSPPI - Wet Cleaning Program

The New York State Pollution Prevention Institute (NYSPPI) implemented the Wet Cleaning Program to assist the garment cleaning industry in reducing their use of perchloroethylene, a toxic dry cleaning solution. The case study can be found in Appendix C.

The full support of management is essential in planning, structuring, and implementing green chemistry efforts within a business framework.

Chapter 8

Implementation of the Green Chemistry Change

Sell Change: Sustainability as a Business Model

In a global economy, sustainability has become an essential part of business strategy. Leading organizations worldwide understand that sustainability can lower costs, open new markets, and drive efficiency and innovation throughout an organization. A cornerstone of sustainability is pollution prevention (P2). By implementing P2 and green chemistry strategies, businesses can integrate sustainability into day-to-day operations to promote long-term cost savings, increase efficiency, and improve environmental performance. A green chemistry strategy should establish and maintain a systematic management plan to continually identify and reduce the environmental impacts from an organization's use of toxic materials. A P2 management plan should include a green chemistry strategy and continually identify and reduce the environmental harm (impacts) from the organization's activities, products, and services.

Successful implementation of P2 and green chemistry initiatives is often a direct result of an organization's ability to identify and assimilate relative information, recognize the relationship of environmental performance to the business model, and focus existing systems and resources towards the specific goal of reducing toxic materials use. Green chemistry achievements will rely largely on an organization's ability to transparently incorporate environmental improvements into products and services without losing performance or increasing cost. The full support of management is essential in planning, structuring, and implementing green chemistry efforts within a business framework. An organization that is committed to achieving green chemistry in their day-to-day operations will integrate strategies and tools that include eliminating or reducing pollution at its source through transitioning to safer chemicals.

In the post 9-11 era, P2 plans and programs had an extraordinary opportunity to make a unique contribution to homeland security, which provides a new driver for P2 and green chemistry implementation. This new arena of environmental security is the time to design and implement a more preventive, risk reduction approach based on P2 and green chemistry that protects human health, the environment, and the community. Substituting less toxic materials in production, making environmentally preferable purchases, and modifying processes, will help organizations have less hazardous materials and waste on site and reduce their risk and vulnerability. This preventive approach will gain in popularity as organizations realize that simply responding to incidents as they happen may not be the best approach for protecting human health, the environment, and the community.

Financial Sustainability

Proactive management and financial stability within an organization will typically parallel the evolution of an organization's environmental management and commitment to sustainability. As business and industry increasingly embrace the concept of a global economy, sustainability has become a key component in achieving a competitive advantage. Typically, a proactive company will be better positioned to respond more effectively to implementing toxics use reduction opportunities and achieving sustainable practices. P2 activities usually save an organization money in the long term. Many P2 projects have good returns on investment and short payback periods. Even if an organization is not subject to complicated regulations, P2 can still result in cost savings by reducing health risks through the introduction of new safer materials, reducing energy and water usage, and increasing materials productivity. Organizations may also save money in solid waste disposal costs and improved operating efficiency. Unfortunately, too few P2 teams (a company's internal group) and professionals communicate the economic benefits of P2 progress to management.

Reducing wastes and improving efficiency are goals of both P2 and continual improvement. Many organizations use continual improvement to constantly improve certain work processes. Sometimes small process improvements involving material substitutions and changes in operating procedures can result in increased product yield and better quality. Reducing the use of toxic materials in the workplace should be a major component of P2. Reducing or eliminating toxic substance use, improves safety of the work environment and reduces the need to use personal protective equipment. It also reduces the likelihood of leaks, spills, and harmful releases that can expose workers, visitors, and contractors. These steps will produce cost savings through material loss prevention and may result in reduced insurance rates as medical claims and disability absences? decrease. Improved worker safety often means better labor relations too.

Unfortunately, there have been cases where P2 activities have inadvertently decreased worker safety (e.g., substituting the flammable solvent isobutyl alcohol for the halogenated solvent 1,1,1-trichloroethane, which is non-flammable but a worker health issue). It is important that P2 and green chemistry do not trade off environmental improvement with workplace health and safety.

Meet Regulatory Requirements and Achieve Sustainability

Green chemistry efforts should improve compliance with environmental laws, enable organizations to achieve performance beyond compliance with legal requirements, and reduce environmental impacts from both regulated and unregulated activities. Although regulatory compliance remains an important driver of environmental performance and of the adoption of advanced practices such as raw material substitution, business factors such as cost savings and improved business performance are just as important. It is increasingly important for organizations to understand that it is more cost effective to prevent environmental damage by adopting a guiding principle of cleaner production and green chemistry than to attempt to control or mitigate it later.

Undertaking P2 and green chemistry projects can reduce regulatory exposure and, in some cases, eliminate the need for permits, manifesting, monitoring, and reporting. Keeping up with regulatory requirements and submitting the required reports can be an expensive and time-consuming process that, if eliminated, saves money. The organization should try to achieve and remain in compliance by using P2 and green chemistry instead of classical environmental engineering and regulatory compliance techniques.

An organization's ability to achieve improved environmental performance often directly relates to whether its management is reactive or proactive. A *reactive organization* is typically driven only by regulatory compliance or by trying to correct problems that could have been prevented through proactive planning. A *proactive organization* is driven by strategic planning and long-term commitments to improving its operations and processes, especially when transitioning to alternative safer chemicals. There are many new product-focused drivers for P2 including regulations, certifications, and green product procurement programs. Green markets are driving new opportunities to achieve P2 particularly for raw material substitution and green chemistry. Organizations need to gear up to provide the “green” skills and knowledge to assist the workforce in transitioning to the use of greener chemicals and products.

How a business operates, either in a reactive or proactive manner, is an indicator of organizational capability. The more proactive a company is, the better positioned it will be to respond effectively to implementing green chemistry opportunities and achieving sustainable practices. The evolution of an organization’s success in P2 has been a process of finding new ways of moving from creating P2 awareness to promoting action at all levels of the organization. Strategic planning and effective management systems are key elements of a proactive organization and moving to implementation of P2 and green chemistry action plans. Some organizations have been able to change their regulatory compliance status (e.g., move from a large quantity generator of hazardous waste to a small quantity generator) through green chemistry and the use of less toxic materials. P2 reduces the generation of wastes (discharges, emissions, spills, and leaks) at the source, results in less toxic waste, and assures improved environmental protection. P2 and green chemistry can help reduce long-term liability by reducing the amount and toxicity of the wastes generated.

Develop a Systems Approach to Implement Green Chemistry Change

Sustainability is the overriding environmental goal for green chemistry programs and the systems approach is the framework for meeting toxics use reduction challenges. Organizations that resist change make implementation of P2 and green chemistry opportunities a challenge and can create a P2 implementation gap. By adopting a systematic approach, such as the *Energy Star Seven-Step Management Process*, organizations that struggle to overcome built-in barriers and lack basic knowledge about safer chemical strategies can begin to plan and implement a successful program.

The commitment to continual improvement is the first and most critical step to overcoming the P2 implementation gap. Achieving P2 and safer chemical implementation success through the seven-step process requires top level support communicated by a green chemistry policy, a cross-functional team representing the administrative and process knowledge of the organization and an appointed leader to ensure continuity of focus, communications and effort.

The *Energy Star Seven-Step Management Process*

Step 1: Commitment to Continual Improvement

Implement a Green Chemistry Policy

Involvement of top management in defining a green chemistry policy, reviewing the current plan for toxics use reduction, and maintaining green chemistry awareness is critical to the success of this process. It is management's responsibility to develop a shared vision and direction for the organization's Green Chemical Policy and to commit to its implementation. The Green Chemical Policy should promote and encourage:

- Product reformulation.
- Development and use of less or non-hazardous products, constituents, processes, and methods.
- Collection of products and materials that contain hazardous components for reuse, recycling, or hazardous waste management.

In developing a Green Chemistry Policy, management should define its scope and ensure consistency with the organization's vision, core values, beliefs, and other goals. Management may use the new Green Chemistry Policy to expand the organization's environmental perspective. The policy should be used as the guiding principle for setting and reviewing the organization's environmental objectives and targets for using safer chemicals. Once management reaches agreement on the policy, it should be documented, kept up to date and used by all employees.

Establish a Cross-functional Team

In the traditional P2 paradigm, P2 projects are usually investigated and implemented by a champion from the organization's environmental department. The new paradigm calls for long-term organizational change and an integrated systems approach for green chemistry that involves employees from a variety of the organization's departments. The primary role of an interdepartmental P2 Team is to facilitate a change in organizational behavior through awareness and knowledge that empowers the organization (process owners) to improve its environmental performance. The P2 Team needs to set the stage for a green chemistry program paradigm shift – a change in the organization's basic beliefs in order to achieve a major toxics use reduction breakthrough.

The P2 Team needs to develop a coherent and coordinated approach to environmental management and green chemistry planning and programs that the organization can support. They need resources and the full support of management to successfully respond to the green chemistry opportunities identified by a P2 Team assessment. An engaged P2 Team effort, supported by management and viewed as a critical contributor to business strategy, will ensure the ability of an organization to identify and achieve P2 and safer chemistry outcomes. The P2 Team is challenged to demonstrate to the organization the many benefits of incorporating a Green Chemistry Policy into business practices. Their role is one of promoting, cheerleading, and informing the organization how incorporating a Green Chemistry Policy makes good business sense.

The P2 Team is authorized to take direct action, make decisions, and initiate changes that improve compliance with the Green Chemistry Policy and achieves the organization's objectives and targets for use of safer materials in its processes and products. When the employees' roles have been formally structured to support the team approach, members can rely on one another for cross-training, problem solving, administrative duties, and mutual support. The P2 Team's role as a facilitator and primary resource for information, coupled with the organization's knowledge of processes and operations, results in greater buy-in, ownership, and increased acceptance of green chemistry alternatives by the employees.

Team Lead to Champion Green Chemical Change

Top management should appoint a team leader to ensure the organization accomplishes its goals when establishing a green chemistry program. The team leader monitors and evaluates the green chemistry management system and reports to top management on its effectiveness. The team leader works with the P2 Team to generate new ideas and modify the green chemistry plan when necessary for improvement. The team leader should create an environment and select a forum in which creative ideas for toxic use reduction can be heard and tried. The team leader also ensures a special effort is made to assist in cost and operational justification, to document barriers to be addressed, and ensure a commitment to adoption of the green chemistry action plan.

Step 2: Assess Performance and Opportunities

The P2 assessment is a systematic, periodic survey of the organization's operations designed to identify toxics use reduction opportunities, as well as areas of potential waste reduction and conservation. The green chemistry assessment provides insight and understanding of the organization's ability to identify potential raw material substitutions leading to the development of an action plan. Active employee and management involvement is a key component of a successful green chemistry assessment effort that is specifically tailored to an organization's operations. A cross-functional team-based P2 assessment that evaluates performance, systems, and equipment will leverage the intellectual capital of an organization and allow recognizable improvement opportunities for green chemistry from many perspectives. Identifying environmental performance improvement and safer chemistry opportunities begins with understanding current and past waste generation and toxic materials use. Identification of health and environmental concerns associated with the toxic raw materials used by an organization is important in assessing the environmental aspects associated with that toxic materials use.

Conversations with staff at the operational level can lead to “ah-ha” moments that can solve problems and find creative solutions. Assessing environmental performance based on analyzing collected data and establishing baselines to measure progress while using the knowledge base of the organization will create new ways of seeing the business opportunities that a transition to safer chemicals can provide and the reduction of risks associated with use of toxic raw materials. Substituting less toxic raw materials may be difficult in certain situations, but it can be an efficient part of P2 operational control to reduce multimedia wastes. The P2 Team must build confidence by verifying the effectiveness of green chemistry alternative materials and practices that solve the organization’s real-world problems. The P2 Team must effectively and efficiently deploy technical resources that integrate with the organization’s culture and result in internal standardization of green chemistry improvements.

The green chemistry assessment report is structured to provide relevant information for both decision-makers and the P2 Team that will implement and track performance. The green chemistry recommendations developed by the P2 assessment serve as a checklist for the follow-up cycle that continues until the P2 Team has determined a course of action or disposition for all recommendations. Some recommendations may require additional planning and investigation by the P2 Team with the intent to implement. The P2 Team’s role in the assessment phase is to overcome perceived barriers and demonstrate how the opportunities will improve environmental performance and competitiveness.

Knowledge management is a tool that allows the organization to create, capture, analyze, and act on information gathered through its assessment activities. Products of knowledge management include reports, case studies, staff experiences, cataloging, databases, and publications. Capturing and managing the knowledge of lessons learned through successful experiences are key factors in continual improvement. Making knowledge management a distinct process related to the P2 assessment enables the P2 Team to take a systematic approach to improving and sharing intelligence gained from the green chemistry experience. Determining specific green chemistry opportunities requires a baseline understanding of organizational behaviors that support achieving toxics use reduction outcomes that are measurable and meaningful to the organization’s bottom-line. An organization’s behaviors are vital to a proactive approach toward achieving outcomes that will strengthen the organizational capabilities of successfully implementing identified green chemistry opportunities.

Step 3: Set Goals

Setting aggressive but realistic goals for improving environmental performance and the use of safer chemicals will drive activities that succeed. P2 practices and techniques succeed best when promoted as the number one strategy for improving environmental performance and meeting attainable and measurable green chemistry goals. This step provides a common view of improvement throughout the organization while capturing the commitment to P2 and reducing toxic materials use. Performance goals help monitor the success of the green chemistry management program by identifying specific areas of progress and setbacks. Effective green chemistry goals will also determine the scope of the program and estimate the potential for improvement.

The green chemistry program facilitates the achievement of plan goals by establishing and maintaining specific objectives and targets to improve the risks associated with hazardous materials use. The objectives and targets are the most important tools for articulating the green chemistry planning goals. Although an organization has discretion with regard to its objectives and targets, they must be consistent with the organization's Green Chemistry Policy, which contains a commitment to toxics use reduction that helps reinforce source reduction goals and compliance with regulatory requirements. Also, green chemistry objectives and targets may be different for various levels of the organization and these should be documented.

Step 4: Create an Action Plan

To implement the identified green chemistry opportunities, a written action plan should be prepared and submitted to management for review and approval. An action plan serves as a blueprint to guide improved environmental performance through transition to safer chemicals. It provides focus for the team by indicating the scope and scale of goals, targets, roles, resources, and a timeline. During the development of the action plan, risks should be analyzed, including the risk of investing or not investing in safer chemicals. To promote success, the action plan should be accepted by all areas of the facility that it addresses.

The action plan is designed to set up action items, assign responsibilities at all levels of the organization for plan execution, set specific timelines, and determine the resources needed to achieve the green chemistry objectives and targets. With the goals established, the subset of activities defined, and the accountabilities in place, each person with specific responsibilities must now develop the information and data needed for implementation. One person or several people on the P2 Team are assigned the accountability for meeting the green chemistry goals and objectives in the planned time frame for each task in the action plan and for maintaining the current level of performance on each of these action items. As progress is made, it should be recorded against the green chemistry action items created and the team should watch for slippage on implementing the substitution of safer materials. An organization's failure to take action on green chemistry recommendations depends on a variety of factors that include a lack of expertise and manpower, a lack of understanding of how green chemistry relates to the business model, a lack of financial resources needed for implementation of safer chemical alternatives, or simply lost interest relative to other business drivers.

While the initial focus of the P2 Team was on information transfer, the action plan helps the team and the company as a whole move from creating P2 and green chemistry awareness to promoting action. The long-term change paradigm begins with integrating green chemistry with existing organizational programs, using existing channels of communication, and preparing for, and initiating the new safer materials opportunities. Overall, the shift is from modifying existing P2 activities to modifying the contexts and framework for manufacturing design, production, shipping, and afterlife of products and services.

Step 5: Implement the Action Plan

Critical elements to successfully implement the green chemistry action plan include creating a communication plan, raising awareness, building capacity, and motivating staff. Communicating the green chemistry action plan is critical and will require an overarching message about mission, policies, and progress. While the communication plan serves to raise awareness about safer materials use and environmental sustainability, employees, customers, and the community should also be educated on how they can contribute to improved environmental performance. Identifying training needs can also contribute to successfully implementing P2 and green chemistry opportunities. Ongoing feedback on green chemistry successes can help motivate employees to continue to improve.

Step 6: Evaluate Progress

Measuring performance of the green chemistry program is vital to understanding where the organization has succeeded in terms of environmental performance-based accomplishments and where modifications are needed to achieve successful toxics use reduction in the future. Critical elements to implement the green chemistry action plan include tracking and monitoring progress on environmental performance and conformance with green chemistry objectives and targets. Determining what to monitor and measure as well as what information to record is critical. The objectives and especially the targets of the green chemistry program should be quantifiable and measurable so that progress toward achieving them can be tracked. Key operational characteristics and parameters associated with the use of toxic materials should be tracked and can also serve as measures. To ensure good measurement of green chemistry efforts, answer these questions:

- Who is responsible for tracking, analyzing, compiling, and reporting data?
- What is the frequency of measurement for data?
- How will data be analyzed/compiled?
- How will data be reported?

Periodic evaluation of the action plan will keep the P2 Team and the organization informed about progress made on established green chemistry and environmental performance improvement goals. Reviewing the green chemistry action plan will further identify any efficiency measures that should be modified or added.

Step 7: Recognize Achievements

Once the momentum of achieving P2 and green chemistry outcomes has been established, it is important to keep it going. The commitment to continual improvement needs to be maintained over time for the seven-step process to be successful. A committed leader to drive the process and a motivated P2 Team to carry it out provides the best opportunity for a long-term green chemistry program that achieves results. Recognizing achievements will help maintain the momentum of the green chemistry and environmental improvement initiatives. The most successful programs include both internal and external recognition. Internal recognition of the P2 Team connects their efforts directly to the success of the business and provides motivation for other employees.

External recognition of green chemistry successes, such as press releases and community outreach, provide positive public relations opportunities for the organization, which can lead to improved brand loyalty and acknowledgement as an environmentally responsible organization. A company that has a positive environmental reputation has a competitive advantage. Alternative measures, such as national and Governor's P2 awards and environmental leadership programs, also serve as drivers for organizations to implement a green chemistry program and begin moving up the maturity scale toward sustainability.

Implementation of the Green Chemistry Change

A P2 management system fosters innovative strategies and creates a framework for improving environmental performance by encouraging all employees of the organization to look for ways to reduce environmental impacts by first using P2 techniques. Organizations must have both the ability and the desire to systematically implement green chemistry opportunities that support the transition to safer materials resulting in greening their business operations, processes, and products. An organization can turn the considerable potential for sustainable development concepts into reality and success through its P2 and green chemistry efforts to reduce generation of all wastes, use of toxic chemicals, improve resource conservation and management, and expand environmental security. The job of informing and involving interested stakeholders in green chemistry requires constant attention and change. Change management is the focus of many P2 plans and of many new initiatives, such as green chemistry, U.S. EPA's Design for the Environment (DfE), and environmental security. There are still many challenges ahead for organizations in defining sustainable development within the context of P2 and green chemistry.

Chapter 9

Recognitions, Awards, and Sustaining Success

Sustaining Success

Previous chapters have described how businesses are integrating sustainability practices into their programs. Business sustainability refers to business models and managerial decisions grounded in financial, environmental, and social concerns, and how they interconnect. Companies are recognizing that sustainability leads to innovations, efficiencies, and improved resilience amid turbulent markets and competition for natural resources — as well as enhanced reputation.[59] Also, companies that invest heavily in sustainability have a higher return on assets than firms that invest modestly.[60] Consequently, sustainability is seen as strengthening a company's ability to compete.

Initiating a sustainable business practice is only the first step, as success only occurs with long-term maintenance of such programs. Long-term thinking is integral to the models for sustainable companies, as compared to companies that focus on short-term profits and make decisions based solely on the bottom line.[61]

Due to rapidly changing markets, conversations about sustainable business practices have shifted. Instead of focusing on regulatory compliance, aligning cost-saving measures with reputational benefits, and more recently, creating value by aligning sustainability with innovation, businesses now focus on risk management and mitigation.[62] This reflects the realization that environmental, societal, and market shifts will increasingly agitate everything from commodity prices to natural resource shortages, to disease epidemics — all of which can affect business continuity, the right to operate, and reputation. The following examples describe how green chemistry and engineering principles can sustain a robust business practice.

Example 1

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[59] Makower, J. State of Green Business 2014: Sustainable Business Trends. GreenBiz Group/Trucost Plc.

[60] Rowe, A. and Bansai, T. 2013. Ten Steps to Sustainable Business in 2013. Ivey Business Journal. http://iveybusinessjournal.com/topics/social-responsibility/ten-ways-to-help-companies-become-sustainable-in-2013#.U3w1OsfgXr0

[61] *Ibid*

[62] Six Growing Trends in Corporate Sustainability. 2013. An EY survey in cooperation with GreenBiz Group.

In a 2012 survey[63] 51% of the respondents indicated that they expected their company's core business to be affected by natural resource shortages. Not surprisingly, in the same survey, a large proportion of the respondents (43%) indicated that "cradle-to-cradle" product development[64] was being considered or currently being employed as a component of the company's sustainability strategy.

"Cradle-to-cradle" product design is an example of green chemistry and engineering principles being integrated into product development. This will not only minimize detrimental impacts over the life cycle of the product, but will enable a company to reduce future risk of instability in natural resource availability, which all lead to a more successful, long-term sustainable business model.

Example 2

The inclusion of green chemistry and engineering practices into company sustainability programs will 1) lessen the rising pressures on the business community due to increasing concerns about the safety of consumer products and company core activities that may be harmful to the environment and society, and 2) will create resiliency needed for accommodation.

Demands for disclosure on environmental and social impacts from customers and investors have been on the rise. Businesses need to address concerns about toxic chemicals in their products, not only due to increasingly more restrictive legislation, but also to maintain their identity as "sustainable" or "green". This movement was labeled as one of the ten "top sustainable business trends of 2014".[65]

In a 2012 survey[66] 50% of the companies reported that they were receiving an increase in the number of sustainability-related inquiries from investors and shareholders over the past 12 months. This underscores growing interest, particularly by institutional investors, many of which now view corporate sustainability issues as material to shareholder value. The growth of queries also mirrors the growth of shareholder proposals on social and environmental issues, which now account for 40% of all shareholder proposals. Support for those proposals is growing, too: the average proposal received 21% of investors' votes in 2011, up from 10% in 2005, reflecting a relatively high level of interest and support.

Using green chemistry and engineering principles in manufacturing processes would lead to reduced or elimination of hazardous substances, increased use of renewable and "re-usable" materials, and minimized waste generation. Consequently, detrimental impacts to the environmental and social network would lessen and relieve some of the

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[63] Six Growing Trends in Corporate Sustainability. 2013.

[64] The design philosophy of minimizing detrimental impacts throughout the life cycle of a product.

[65] Makower, J. State of Green Business 2014: Sustainable Business Trends.

[66] Six Growing Trends in Corporate Sustainability. 2013.

aforementioned pressures, and concomitantly create a more robust sustainable business practice.

The examples above examined a few of the pressures that businesses will have to address to be competitive. Integrating green chemistry and engineering principles into manufacturing operations may mitigate risks, alleviate market pressures that companies will encounter, and develop a more successful sustainable business practice.

Awards and Recognitions

Awards and recognitions are used for acknowledging an accomplishment. Individuals have a desire to distinguish themselves from other individuals, and have a strong urge to be better than others.[67] These psychological factors motivate companies to implement and maintain sustainability programs, especially since these programs often benefit market position, investor demands, and ultimately profits. Uniliver has devoted a full web page[68] to proclaiming the numerous awards and recognitions that have been bestowed upon the company for their sustainability activities.

Industry is becoming more proactive in integrating green principles into their design phases. However, to encourage "green" innovation and implementation, which includes green chemistry and engineering, and to publicize these efforts for the benefit of the initiators, awards and recognitions have been established for the business community.

A number of agencies and institutions have initiated recognitions and awards to promote green chemistry and engineering innovation and implementation, and some of the more prominent ones are listed below. There is only one award specifically designated for green engineering, but it also includes "sustainability" innovation as a context: Harvey Mudd College Green Engineering award. The criteria for the other green chemistry awards and recognitions are broadly defined and embrace both green chemistry and engineering advancements. Many state agencies and organizations also have initiated "green" or sustainability awards. However, only one is listed (Champions of Toxics Use Reduction, MA), not only as an example, but because the sponsor (TURI) has been at the forefront of promoting and implementing safer chemical substitution and sustainable manufacturing practices.

Listed Awards and Recognitions

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[67] Frey, B.S. 2006. Giving and Receiving Awards. Perspectives on Psychological Science. 1(4)377-388.
[68] Uniliver. www.unilever.com/sustainable-living-2014/news-and-resources/awards-and-recognition/ (downloaded May 2014).

ACS Award for Affordable Green Chemistry

This annual award was established by the American Chemical Society (ACS) in 2007 to identify and recognize discovery of new eco-friendly chemistries with the potential to enable products or manufacturing processes that are less expensive than existing alternatives.
www.acs.org/content/acs/en/funding-and-awards/awards/national/bytopic/acs-award-for-affordable-green-chemistry.html

Champions of Toxics Use Reduction

For more than 10 years, TURI (Toxics Use Reduction Institute, University of Massachusetts - Lowell) has been recognizing community and industry organizations with the "Champions of Toxics Use Reduction" award. This award recognizes outstanding leaders who have reduced toxic chemical use in Massachusetts through innovation and outreach.
www.turi.org/About/Success_Stories/Champions_of_Toxics_Use_Reduction_Awards

Harvey Mudd College Green Engineering Award

Harvey Mudd College (Claremont, CA) established The Green Engineering Award in 2008. Criteria for this award are based on the significant contributions in the area of "green" engineering" or sustainability in one of three areas:

1. Design and production of a specific new device, system or technology that conserves energy or natural resources, reduces the production and emission of pollutants, or reduces the organization's carbon footprint significantly below current levels;
2. Adoption and implementation of new and innovative production technologies for current products that significantly improve the environment; or
3. Support for community-based initiatives to address environmental issues related to the design, production and use of electrical and electronic technologies.

The IGCW (Industrial Green Chemistry Awards – World) Innovation Awards

The IGCW Awards began in 2011 and are presented biennially in recognition of outstanding scientific contributions by organizations / individuals who have:

- Used the principles of green chemistry in their business.
- Applied clean and sustainable technology.
- Improved efficiency.
- Reduced waste.
- Produced safer chemicals.

www.industrialgreenchem.com/igcw-2013/awards.html

MVP2 Award

The National Pollution Prevention Roundtable established this annual award in 1995 to encourage and promote pollution prevention efforts in the business community. This award is designed to recognize outstanding and innovative P2 projects/programs. The awarded projects or programs are judged on the following five broad criteria: **innovation, measurable results, transferability, commitment, and optimization of available project resources.**
http://www.p2.org/mvp2-awards/

Presidential Green Chemistry Challenge Awards (PGCCA)
This award was established in 1996 by the U.S. EPA in partnership with the American Chemical Society Green Chemistry Institute® and other members of the chemical community to promote the environmental and economic benefits of developing and using novel green chemistry. This prestigious annual award recognizes chemical technologies that incorporate the principles of green chemistry into chemical design, manufacture, and use.
www2.epa.gov/green-chemistry/information-about-presidential-green-chemistry-challenge

Safer Chemistry Challenge Program (SCCP)
The National Pollution Prevention Roundtable's (NPPR) 2025 Safer Chemistry Challenge Program (SCCP) was started in 2012 and seeks to motivate, challenge, and reward safer chemistry practices in businesses to reduce the use of chemicals, especially hazardous and toxic chemicals, through source reduction and pollution prevention measures.
www.p2.org/challenge/

Chapter 10

Green Chemistry Checklist

Checklist for Signers:[69]
Green Chemistry and Safer Products Business Commitment, v 1.0

Customers are increasingly expecting companies to show leadership in developing safer products to protect health and the environment. This creates a market opportunity for innovative companies that are able to bring safer chemicals and products to market. A commitment to Green Chemistry and Engineering Principles[70] can help demonstrate that leadership. Green Chemistry is often broadly meant to include the Principles of Green Chemistry and Engineering, and includes efforts to create safer chemicals, products and processes and the tools and resources used to achieve those goals. Implementation of the principles of Green Chemistry requires 1) an understanding of how molecular and material design can impact environmental and human health, which infers knowledge of chemistry, toxicology, ecology and biogeochemistry, 2) an understanding of chemical processes, 3) consideration of natural resource usage, and 4) business acumen.

A checklist, divided into four categories, has been designed for the business community, particularly the manufacturing sector, to measure progress in creating a culture of innovation and for supporting the building blocks necessary to develop safer products. The goal is to engage in some of the activities identified in each of the four sections with increased activity over time: education, hiring practices, support and communication, and design and innovation.

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[69] The Michigan Green Chemistry Roundtable in cooperation with the Green Chemistry and Commerce Council (GC3) developed the Checklist. It is a roadmap to guide implementation of the *Policy Statement on Green Chemistry in Higher Education* authored by the Green Chemistry and Commerce Council in 2012.

[70] Green Chemistry is the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture, and application of chemical products. Green Engineering is the design, commercialization, and use of feasible and economical processes and products while minimizing or eliminating 1) generation of pollution at the source and 2) risks to human health and the environment.

Area 1: Education Reference to Policy Statement: "Value and support continuing education on green chemistry and sustainability issues among staff of signing organizations and encourage similar practices in companies in supply chains"

Activity	Possible Metrics
☐ Identify and support Green Chemistry training opportunities for relevant employees at the time of hire	# of new hire trainings; # times per year offered; # new hires taking training, % of relevant new hires completing the training
☐ Identify and support regular Green Chemistry training opportunities for all relevant employees	# of continuing education trainings offered, # of employees taking trainings
☐ Identify and support Green Chemistry training or learning opportunities for suppliers	# of continuing ed training/learning opportunities offered, # of suppliers engaged, # of supplier employees taking seminars/trainings etc.
☐ Work with sector trade associations or other groups to identify seminars and training for sector members	# of associations approached, # of trainings offered, # of sessions at conferences
☐ Recognize staff doing outstanding work in Green Chemistry and Engineering including the development of safer chemicals, products and processes	Employee award created, # of employees recognized
☐ Recognize suppliers doing outstanding work in Green Chemistry and Engineering including the development of safer chemicals, products and processes	# of suppliers recognized
☐ Include recognition for Green Chemistry innovators in company compensation considerations	# of employees recognized; Green Chemistry activity included in compensation reviews where appropriate

Area 2: Hiring Reference to Policy Statement: "Value and support through hiring practices of people [all things being equal] with demonstrated knowledge and ability in green chemistry and sustainability"

Activity	Possible Metrics
☐ Include explicit reference to desire for Green Chemistry (GC) and Engineering (GE) and Engineering academic training in all relevant job postings	# of job postings with reference to GC and GE/all relevant job postings
☐ Hire candidates with Green Chemistry and Engineering training all things being equal	# of hiring's with experience in GC and GE
☐ Incorporate Green Chemistry corporate goals and vision into relevant new hire orientation	New hire trainings include Green Chemistry corporate goals
☐ Include Green Chemistry and Engineering performance requirements in job goals including the development of safer chemicals, products and processes	# of employees with Green Chemistry and Engineering performance requirements

Area 3: Support and Communication Reference to Policy Statement: "Provide resources and support to work with academic institutions and suppliers [to advance the goals of the policy statement]"

Activity	Possible Metrics
☐ Provide co-op internship placements for students working in Green Chemistry and Engineering fields	# of GC/GE student interns; # of GC/GE placement opportunities
☐ Provide support to local academic institutions to encourage Green Chemistry and Engineering training for students	# of institutions approached with information
☐ Work with local academic institutions on innovations needed for a green economy	# of publicly announced collaborations
☐ Communicate company Green Chemistry goals to suppliers	# of meetings/seminars held with suppliers including this topic; inclusion of GC&E goals in CDP, GRI or other relevant B to B[71] communication platforms
☐ Publicly report on Green Chemistry/Green Engineering progress including the development of safer chemicals, products and processes	Report on innovations in Green Chemistry through the Toxic Release Inventory (TRI) and other public reporting; inclusion of GC&E goals in CDP, GRI or other similar reports; publishing case studies and reports on company progress toward GC/GE
☐ Provide assistance to suppliers in meeting their Green Chemistry goals	# of examples; impact of examples (money, waste reduction, etc.)
☐ Sign the *Policy Statement on Green Chemistry in Higher Education*	Sent message to GC3 with sign-on
☐ Become a Corporate Partner of the Green Chemistry Commitment (GCC)	Signed on as a Corporate Partner with the Green Chemistry Commitment; worked with the academic signers of the GCC in one or more of the six ways that partners are involved.

Area 4: Design and Innovation Reference to Policy Statement: "Commit to encourage, value and support the recommendations in the policy statement [all things being equal] in the company's innovation, product development and sourcing practices."

Activity	Possible Metrics
☐ Establish Green Chemistry products and processes as a primary goal of the organization.	Broad executive policy promoting green chemistry in place; tracking # of KPI's[72] based on Green Chemistry principles
☐ Regularly monitor progress toward Green Chemistry goals including greening product lines.	Evaluation process in place to monitor progress toward safer chemistry goals including product development; # of product lines greened

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[71] CDP: Carbon Disclosure Project (https://www.globalreporting.org); GRI: Global Reporting Initiative (https://www.cdp.net); B to B: business to business

[72] Key performance indicators

Activity	Possible Metrics
☐ Embed Green Chemistry design criteria in product design guidelines and at each stage gate of product development	Green Chemistry criteria embedded in design guidelines, tools, processes and practices and at each stage gate of development
☐ Include Green Chemistry criteria in relevant sourcing protocols/specifications/contract	Language in standard specifications/protocols/contracts requiring/rewarding greener chemical products or green chemical manufacturing
☐ Screen all new chemical ingredients for Green Chemistry attributes	Policy and process in place for screening chemicals
☐ Devote R & D dollars to Green Chemistry innovation	Dollars devoted to Green Chemistry innovation
☐ Commercialize products with Green Chemistry advantages over existing chemicals or products	# of products commercialized; value of products commercialized
☐ Commercialize inherently green chemicals or products (product designed to be green from the ground up)	# of green chemical products commercialized
☐ Commercialize products designed to be restorative or to increase resilience in ecosystems	# of restorative products commercialized

Appendix A

A Brief History of Green Chemistry

Green chemistry traces back several decades and can be linked to impactful environmental activists, such as Rachel Carson. Her 1962 publication, “Silent Spring,” helped direct the public’s awareness to pesticides and their ties to environmental pollution. President Richard Nixon’s efforts for environmental sustainability lead to the creation of the Citizen’s Advisory Committee on Environmental Quality and a Cabinet-level Environmental Quality Council in 1969. Subsequently, the Environmental Protection Agency (EPA) was formed in 1970. The EPA references its existence as the extended shadow of Rachel Carlson who is considered a leading innovator of environmental protection, a cause that has paved the way to current green chemistry practices.

Recognizing the need to shift from end-of-pipeline control to pollution prevention, by the 1980s, the EPA established the Office of Pollution Prevention and Toxics. Two decades after the implementation of the EPA, The Pollution Prevention Act (1990), (www.epa.gov/p2/pubs/p2policy/act1990.htm), was created to enforce eco-friendly strategies, and provide grants to states in the effort to reduce source waste. President Bill Clinton devised the Presidential Green Chemical Challenge Awards during his presidency to reward those practicing sustainable chemistry. By the end of the 1990s, “Twelve Principles of Green Chemistry” was published. The guidelines serve as a reference for processes and practices to lessen negative environmental impact. These principles are 1) Reducing Waste Generation, 2) Atom Economy, 3) Less Hazardous Chemical Syntheses, 4) Designing Safer Chemicals, 5) Using Safer Solvents and Auxiliaries, 6) Designing for Energy Efficiency, 7) Using Renewable Feedstocks, 8) Reducing Use of Derivatives, 9) Catalysis, 10) Designing for Degradation, 11) Real-time analysis for Pollution Prevention and 12) Inherently Safer Chemistry for Accident Prevention.

There has been a shift in the emergence of green chemistry trends. As eco-awareness spreads to the consumer market and as the hazards of certain materials and chemicals become better known, companies and manufacturers are working to revamp the way they use chemicals in their products. These practices include:

1. Reducing formaldehyde (a gas linked to various health issues including cancer) use in the production of products.
2. Eliminating/reducing synthetic dyes in manufacture.
3. Eliminating ozone-depleting CFCs (chlorofluorocarbons) in widely used products.

4. Developing technology through chemicals that reduces natural resource consumption (i.e. converting sustainable plant-based materials to low-carbon chemicals).
5. Creating a patented system to formalize and phase out raw materials for fabrication processes.
6. Developing sustainable technology used in agrichemical treatment for farming.

Background on Pollution Prevention and Green Chemistry Movement

1962	Rachel Carson, writer, biologist and environmental conservation icon, publishes the first of three installments of "Silent Spring,"—literature that is historically tied to the launch of the environmental movement. The publication helped spread public awareness of the hazards of environmental pollution and pesticides to the environment.
1969	President Richard Nixon establishes the Citizen's Advisory Committee on Environmental Quality and a Cabinet-level Environmental Quality Council. (www.presidency.ucsb.edu) Later that year, Nixon expanded his environmental efforts by appointing the White House Committee to determine whether an environmental agency should be developed.
1970	The Environmental Protection Agency (EPA) is born.
1976	The Toxic Substances Control Act (TSCA) of 1976 provides EPA with authority to require reporting, record-keeping and testing requirements, and restrictions relating to chemical substances and/or mixtures. Certain substances are generally excluded from TSCA, including, among others, food, drugs, cosmetics and pesticides.
1980s/1988	Shift from end-of-pipeline control to pollution prevention is recognized, leading to the Office of Pollution Prevention and Toxics in 1988.
1990	The Pollution Prevention Act under the George H.W. Bush Administration is passed. Recognizing the need to shift from traditional approach of controlling, treatment, and abatement, Congress passed the Pollution Prevention Act in 1990. The Act established a "national policy to prevent or reduce pollution at its source whenever feasible".

The Pollution Prevention Act focused industry, government, and public attention on reducing the amount of pollution through cost-effective changes in production, operation, and raw materials use. Opportunities for source reduction (i.e., pollution prevention) are often not realized because of existing regulations, and the industrial resources required for compliance, focus on treatment and disposal.

Source reduction is fundamentally different and more desirable than waste management or pollution control. Source reduction refers to practices that reduce hazardous substances from being released into the environment prior to recycling, treatment or disposal. The term includes equipment or technology modifications, process or procedure modifications, reformulation or redesign of products, substitution of raw materials, and improvements in housekeeping, maintenance, training, or inventory control. Pollution prevention also includes practices that increase efficiency in the use of energy, water, or other natural resources, and protect our resource base through conservation.

1993	The EPA implements the Green Chemistry Program, which serves as a precedent for the design and processing of chemicals that lessen the negative environmental impact.
1995/1996	In 1995, President Bill Clinton established the Presidential Green Chemical Challenge Awards, which served to encourage those involved with the manufacture and processes of chemicals to incorporate environmentally sustainable design and processes in their practices. The following year, the first recipient receives the award, the only award issued by the president that honors work in chemistry. Source: http://portal.acs.org/
1997	The Green Chemistry Institute is launched. Its vision is "…to advance the broader chemistry enterprise and its practitioners for the benefit of Earth and its people." Source: http://portal.acs.org/
1998	"Twelve Principles of Green Chemistry" is published by Paul Anastas (of the EPA) and John Warner
2000s	In the past decade, advances in green chemistry policy have been realized including the **California Green Chemistry Initiative**. Governor Arnold Schwarzenegger signed the bill in 2008, which serve to develop policy options for green chemistry. Source: www.dtsc.ca.gov. One year later, President Obama nominated Paul Anastas (of Yale) as head of Research and Development at the EPA.
2007	The U.S. House of Representatives passed legislation seeking to improve federal coordination, dissemination and investment in green chemistry research and development. The Green Chemistry Research and Development

Act of 2007 (H.R. 2850) aims to provide safer, more sustainable technological options to replace traditional products and processes.

In 2008, California moved beyond voluntary partnerships and voluntary information disclosure and passed two bills (AB 1879 and SB 507) and signed into law the California Green Chemistry Initiative (GCI), which provided the California Department of Toxic Substances Control (DTSC) the authority to control toxic substances in consumer products. In 2012, the DTSC submitted its draft of "Safer Consumer Products (SCP) Regulations" for public review. These proposed laws would require manufacturers of selected products sold in California to identify safer alternatives to a potential range of 3,000 chemicals known to be harmful to public health and the environment.

2013 **The California Safer Consumer Products regulations** were approved by the Office of Administrative Law (OAL) on August 28, 2013 (OAL File No. 2013-0718-03 S), and took effect on October 1, 2013. They require manufacturers or other responsible entities to seek safer alternatives to harmful chemical ingredients in widely used products, offering California the opportunity to lead the way in producing safer versions of goods already in demand around the world.

Thinking about the implications before we formulate new materials can prevent a plethora of human and environmental ills.

In the decades since the publication of Rachel Carson's environmental classic *Silent Spring*, since the incidents of pollution that caused the Cuyahoga River to catch fire in 1969 and contaminated residents of Love Canal in the 1970s, our knowledge of how synthetic chemicals—chemicals that are made in laboratories but not found in nature—make their way into the environment and how they interact with living cells has grown remarkably.

We now know that many such chemicals enter the environment, not only from smokestacks, drainpipes, leaky storage tanks and waste sites, but also as they migrate from furniture, textiles, building materials, electronics, toys, personal care products, packaging and many more manufactured goods we encounter every day. As a result, many of these chemicals are present in indoor air and dust. Many are traveling the global environment with air and ocean currents. Many are in the food web and in our bodies.

The discovery that our lives are filled with so many potential sources of exposure to chemicals with so many subtle but significant impacts has prompted the need for a pollution prevention strategy that goes well beyond putting filters and scrubbers on chimneys or treating wastewater. It has catalyzed the creation of a new approach to designing molecules that aims to prevent problems from occurring in the first place: green chemistry.

The most fundamental principle of green chemistry is that the best way to prevent harmful chemical pollution is to design materials that are inherently environmentally benign and safe for human health. Green chemistry works toward this goal by using resources efficiently, eliminating use of inherently toxic ingredients and chemical combinations, eliminating waste and hazardous by-products, and minimizing use of energy throughout a product's entire life cycle.

Since it was introduced almost 20 years ago, green chemistry has become firmly established as an approach to designing new chemical products and manufacturing processes in ways that make them less hazardous to human health and the environment.

On May 22, 2013, US Senators Frank Lautenberg (D-NJ) and David Vitter (R-LA) announced a bipartisan bill – the Chemical Safety Improvement Act (CSIA) – to modernize the federal Toxic Substances Control Act of 1976 (TSCA) that would help ensure chemicals can be used safely in the United States while maintaining the country's competitive advantage. **In April 2014,** American Chemistry Council President and CEO Cal Dooley, testified before the House Energy and Commerce Subcommittee on Environment and the Economy, and encouraged Congress to update the Toxic Substances Control Act (TSCA), the law overseeing our nation's chemical regulatory system.

Appendix B

Green Chemistry and Green Engineering Resources

I. Publications: Green Chemistry/Engineering

1. Anastas, P.T. and Warner, J.C. 1998. Green Chemistry: Theory and Practice. Oxford University Press. New York.
2. Anastas, P. and Zimmerman, J. 2003. Design Through the 12 Principles of Green Engineering. Environ. Sci. Technol. (37)5:94A-101A.
3. Jimenez-Gonzales, C. and Constable, D.J.C. 2011. Green Chemistry and Engineering. John Wiley & Sons, Inc. Hoboken, NJ.
4. Mulvihill, M.J., Beach, E.S, Zimmerman, J.B and Anastas, P.T. 2011. Green Chemistry and Green Engineering: A Framework for Sustainable Technology Development. Annu. Rev. Environ. Resour. 36:271-93.

II. Frameworks: Safer Chemical Alternatives

1. BizNGO
   a. Chemical Alternatives Assessment Protocol
   www.bizngo.org/alternatives-assessment/chemical-alternatives-assessment-protocol
   b. The Commons Principles for Alternatives Assessments
   www.bizngo.org/alternatives-assessment/commons-principles-alt-assessment
   c. Guide to Safer Chemicals
   www.bizngo.org/safer-chemicals/guide-to-safer-chemicals
2. German Federal Environmental Agency
   www.umweltbundesamt.de/en/publikationen/guide-on-sustainable-chemicals

3. Interstate Chemicals Clearinghouse: Alternatives Assessment Guide
   www.newmoa.org/prevention/ic2/IC2_AA_Guide-Version_1.pdf

4. The Lowell Center Framework for Sustainable Products (GE)

   a. www.sustainableproduction.org/downloads/LowellCenterFrameworkforSustainableProducts11-09.09.pdf

   b. www.chemicalspolicy.org/downloads/FinalAltsAssess06.pdf

5. Ontario Ministry of the Environment
   www.ontario.ca/environment-and-energy/ontario-toxics-reduction-program-reference-tool-assessing-safer-chemical
6. US EPA
   www.epa.gov/dfe/pubs/tools/ctsa/index.htm

III. Tools

Green Chemistry/Hazard Assessment

1. A Compendium of Methods and Tools for Chemical Hazard Assessment (a review & comparison of tools)
   www.sustainableproduction.org/downloads/Methods-ToolsforChemHazardAss5-2011.pdf

2. GreenScreen for Safer Chemicals
   www.greenscreenchemicals.org

3. GreenWERCS
   www.thewercs.com

4. PARIS III
   www.epa.gov/nrmrl/std/parisIII/parisIII.html

5. QCAT (Quick Chemical Assessment Tool)
   www.ecy.wa.gov/programs/hwtr/chemalternatives/QCAT.html

6. TEST (Toxicity Estimation Software Tool)
   www.epa.gov/nrmrl/std/qsar/qsar.html#TEST

7. WAR (Waste Reduction algorithm)
   www.epa.gov/nrmrl/std/war/sim_war.htm

Green Engineering/P2

1. EMFACT (Energy & Materials Flow & Cost Tracker)
   www.newmoa.org/prevention/emfact/

2. P2OASys: (Pollution Prevention Options Assessment System)
   www.turi.org/About/Library/TURI_Publications/P2OASys_Tool_to_Compare_Materials

3. US EPA
   - a. Multiple Tools www.epa.gov/opptintr/greenengineering/pubs/software.html
   - b. Sustainable Manufacturing Tools (contains links)
     www.epa.gov/sustainablemanufacturing/tools.htm
   - c. Waste Reduction Model (WARM)
     http://epa.gov/epawaste/conserve/tools/warm/index.html
   - d. P2 Cost Savings Calculator
     www.epa.gov/p2/pubs/resources/measurement.html
   - e. P2 Greenhouse Gas Calculator
     www.epa.gov/p2/pubs/resources/measurement.html

Life Cycle Analyses

1. *Hazard Assessment Tools and Methods*. Alternatives Analysis Workshop Tools, Methodologies and Frameworks. California Environmental Protection Agency, Department of Toxic Substances Control.

2. US EPA www.epa.gov/nrmrl/std/lca/lca.html

3. COMPASS® (Comparative Packaging Assessment): life-cycle approach
   https://design-compass.org/

IV. Toolkits

1. Essenscia SUSCHEMcompass
   http://www.suschemanswers.be//node/66

V. Business Case Studies

1. Clean Production Action
   www.cleanproduction.org/resources/category/case-studies

2. EPA

   a. www.epa.gov/oppt/greenengineering/pubs/case_studies.html

   b. www.epa.gov/sustainablemanufacturing/case-studies.htm

   c. www.epa.gov/lean/environment/studies/index.htm

   d. www.epa.gov/dfe/alternative_assessments.html

   e. www.epa.gov/nrmrl/std/lca/resources.html#casestudies

3. Green Engineering. 2001. Anastas, P.T, Heine, L.G. and Williamson, T.C. (editors). ACS Symposium Series 766. American Chemical Society. Washington, DC.

4. Lowell Center for Sustainable Production
   www.sustainableproduction.org/publ.alternatives.php

5. Reducing Automobile Emissions and Saving Energy
   www.climatevision.gov/sectors/steel/pdfs/green_casestudy.pdf

6. SUBSPORT
   www.subsport.eu/case-stories-database

7. Toxics Use Reduction Institute (TURI) @ University of Mass, Lowell

   a. www.turi.org/TURI_Publications/Toxics_Use_Reduction_Case_Studies

   b. www.turi.org/TURI_Publications/Case_Studies

VI. Organizations and Institutions

1. ACS Green Chemistry Institute
   www.acs.org/content/acs/en/greenchemistry.html

2. American Institute of Chemical Engineers (AIChE)
   www.aiche.org/

3. Berkeley Center for Green Chemistry
   http://bcgc.berkeley.edu

4. BizNGO
   www.bizngo.org

5. Center for Green Chemistry and Green Engineering at Yale
   www.greenchemistry.yale.edu/

6. Center for Sustainable Engineering
   www.csengin.org/csengine/

7. Clean Production Action
   www.cleanproduction.org

8. Great Lakes Green Chemistry Network
   www.glgc.org

9. Institute for Green Science, Carnegie Mellon University
   www.chem.cmu.edu/groups/Collins/index.htm

10. Interstate Chemicals Clearinghouse
    www.newmoa.org/prevention/ic2/

11. Lowell Center for Sustainable Production
    www.sustainableproduction.org

12. Michigan Green Chemistry Clearinghouse
    https://migreenchemistry.org/

13. Toxics Use Reduction Institute (TURI)
    www.turi.org/

14. University of Oregon
    http://greenchem.uoregon.edu

15. Warner Babcock Institute
    www.warnerbabcock.com

Appendix C

New York State Pollution Prevention Institute

Wet Cleaning Program

The Benefits of Professional Wet Cleaning

A Preliminary Case Study of All Fabric Cleaners, Farmingville, NY

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The goal of NYSP2I's Wet Cleaning Program is to reduce the use of toxic perchloroethylene (perc) in the NYS garment cleaning industry by promoting environmentally preferable alternatives through information dissemination, assisting cleaners in the conversion to professional wet cleaning, and holding demonstrations at established wet cleaners.

History of Cleaning at All Fabric Cleaners

All Fabric Cleaners, located at 2316 North Ocean Avenue, Farmingville, New York has operated with perchloroethylene, commonly referred to as perc, as their dry cleaning solution for the last 15 years. All Fabric's owner, Yong Choi, was interested in the promise that professional wet cleaning is not only healthier for the environment and employees but it can clean many garments better than perc. In 2011, Yong visited many successful wet cleaning shops and attended The Cleanshow to learn more about the benefits and practicality of wet cleaning. Yong was selected for NYSP2I's Wet Cleaning Conversion Program, a NYSDEC and USEPA Region 2 jointly funded initiative providing financial and technical assistance to cleaners converting their operations from perc dry cleaning to professional wet cleaning.

Conversion from Perc to Professional Wet Cleaning

All Fabric Cleaners installed their professional wet cleaning system – consisting of a washer, dryer, top tensioner, and pant tensioner – in September 2011. At the time of installation, the perc dry cleaning system was not removed from the shop, as Yong intended to gradually convert his operations over to wet cleaning. The system proved successful beyond Yong's expectations. The perc dry cleaning system was disconnected in December 2011 and removed in spring 2012.

Yong Choi, owner, proudly stands next to his wet cleaning system

Professional Wet Cleaning Success at All Fabric Cleaners

Since converting to wet cleaning, quality has increased, as shown by a 98% reduction in sendouts, redos, and claims. Efficiency has increased 36%, as the wet cleaning system is able to clean more garments in a shorter period of time than the dry cleaning machine. In addition to saving money, perc use and its associated health and environmental effects as well as hazardous waste are eliminated. All Fabric's employees are happier operating in a cleaner environment, without the smell of perc and their customers are pleased with the quality of cleaned garments.

Preliminary Metrics	Estimated Annual Savings	Estimated Annual Cost Savings
Performance	36% increase in efficiency, 98% reduction in quality defects	--
Electricity usage	43% reduction	$3,820
Natural gas usage	11% reduction	$1,030
Detergent & spotter usage	290 gallons, 99% reduction	-$1,830
Perc used for cleaning	166 gallons, 100% eliminated	$2,820
Filters & equipment maintenance	--	$3,920
Hazardous waste disposal	730 pounds, 100% eliminated	$780
Perc air pollution	950 pounds, 100% eliminated	--
NYSDEC permit	permit eliminated	$160
Total	--	$10,700

Comparing Jan, Nov, Dec 2010 operating data with 11/11-1/12 operating data. Data are extrapolated to 1 year and normalized to pounds of garments cleaned in 2010.

The New York State Pollution Prevention Institute was established in 2008 to make New York State more sustainable for workers, the public, the environment and the economy through reductions in toxic chemical use, emissions to the environment, and waste generation; and the efficient use of raw materials, energy and water.

For more info, contact
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Or visit our website at
http://www.rit.edu/affiliate/nysp2i/garment-cleaning

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