

**Creating Awareness  
and Building Capacity**

**2012-2017**

# A Roadmap for Advancing Green Chemistry in Washington State



*“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.”*

Paul Anastas & John Warner  
from *Green Chemistry: Theory and Practice*

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# A Roadmap for Advancing Green Chemistry in Washington State

Recommendations for Creating Green Chemistry  
Awareness and Capacity in Washington State

Updated May 2013

A collaborative report by

Washington State Department of Ecology  
Washington State Department of Commerce



**Department of Commerce**  
Innovation is in our nature.

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## Foreword

Green chemistry is the design of chemical products and processes that reduces or eliminates the use and generation of hazardous substances. Green chemistry seeks to advance implementation of 12 guiding principles (see Appendix A). These principles help drive innovations in chemistry and will boost environmental and competitive economic advantages in Washington State. **A Roadmap for Advancing Green Chemistry in Washington State (Roadmap)** is a multi-year strategy to increase the awareness and capacity to establish a green chemistry program in Washington State and the Pacific Northwest.

**In May 2011, the Washington State Green Chemistry Roundtable** hosted a two-day regional partnership meeting. This open forum allowed participants to discuss and share information and experiences to advance green chemistry and green nanotechnology in Washington State. In addition to the Roundtable, Washington State University (WSU) researched the status of green chemistry in Washington State. The Roadmap is an outcome of those efforts. It records and synthesizes many of the suggestions made by leaders from government, chemical users, small business, academia, and the public.

The Roundtable is an ongoing project of the Washington State Departments of Ecology (Ecology) and Commerce (Commerce) with partnership support provided by WSU, The Boeing Company, the Green Chemistry and Commerce Council (GC3), the Pacific Northwest Pollution Prevention Resource Center (PPRC), the American Chemical Society (ACS) Green Chemistry Institute, University of Washington, the Bullitt Foundation, and other leading organizations.

The Roundtable serves as a regional hub for sharing and disseminating information about green chemistry. Its ongoing mission is to accelerate innovation in chemistry for a sustainable future, facilitate knowledge transfer, and increase green chemistry education. The Roundtable is open to all organizations interested in advancing green chemistry efforts in Washington State and throughout the Pacific Northwest region. Roundtable members helped shape the Roadmap and their input into this process has been invaluable.

Ultimately, moving green chemistry forward requires broad support in the implementation of the Roadmap. Ecology, Commerce, and WSU appreciate the participants of the Roundtable for their continued involvement and commitment to green chemistry.

In 2012, Ecology published the draft Roadmap to solicit input and recommendations from stakeholders. As a result, the Roadmap has been updated as of May 2013 to incorporate the comments received as our commitment to keep the Roadmap current. We appreciate the input received from a broad spectrum of stakeholders and anticipate the Roadmap will continue to evolve in the coming years.

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# Introduction

In 2011, the Washington State Department of Ecology (Ecology) initiated the development of a green chemistry “roadmap” project in partnership with industry, small business, educators, government, other states, and nongovernmental organizations (NGOs). To assist in this effort, Ecology worked in partnership with Washington State University (WSU) to conduct research into the current status of green chemistry efforts in Washington that culminated in a Green Chemistry Roundtable, which attracted over 150 attendees in May 2011.

The results from the WSU research and Green Chemistry Roundtable are the basis for the Washington State Green Chemistry Roadmap (Roadmap). The Roadmap recommends actions Washington State should undertake over the next three biennia to support the state’s needs for advancing and sustaining green chemistry in Washington.

- Phase One (2011-2013) – Creating Awareness and Capacity
- Phase Two (2013-2015) – Building the Green Chemistry Program
- Phase Three (2015-2017) – Sustaining the Program

Washington State is currently focused on creating awareness and capacity for green chemistry to better position the state to influence the anticipated growth in this sector. Green chemistry covers a broad area of activities. The field of green chemistry emerged from the early 1990’s pollution prevention movement and is based on 12 principles that guide the design and use of chemicals and processes (see Appendix A).

Green chemistry has the potential to increase a business’ competitive edge and solve contamination and technical problems posed by chemicals of concern used in products today. It also helps position Washington State to create green jobs in academia and manufacturing. Green chemistry science and product innovation will be a major opportunity for job creation in the future.

Strengthened coordination and capacity building is needed to integrate green chemistry into Washington’s efforts to transition to a greener and more sustainable economy. Washington is known for promoting pollution prevention, energy efficiency, renewable energy, biomaterials, green building, and other emerging technologies, such as nanotechnology. The link between technical and business interests and training are key to adoption and implementation of green chemistry.

This Roadmap provides state policymakers with options and recommendations in key areas to advance green chemistry efforts, including:

- Establishing a Green Chemistry Center.
- Advancing incentives, research, and education.
- Promoting product and process innovation.
- Securing a sound economy.
- Developing policy options.

As Washington State develops a green chemistry program, the scope of the program:

- Builds on more than 20 years of existing state pollution prevention and toxics reduction program expertise.
- Provides for green chemistry research, development, demonstration, education, and technology transfer.
- Supports policies and programs designed to reduce exposures to and hazards of chemicals of concern.
- Emphasizes hazard reduction at the chemical and process design stages.
- Reduces the release of hazardous substances and considers the lifecycle effects of exposures to human and ecosystem health.
- Considers all stages of the lifecycle of a chemical.
- Creates opportunities for economic development and education.
- Provides appropriate regulatory authorities to address chemicals of concern.
- Supports regional and state collaboration.

At least five states have established green chemistry programs through legislation or executive order, including California, Connecticut, Michigan, Minnesota and Oregon. These initiatives establish state green chemistry programs and centers, provide tax credits, and invest in workforce training and jobs.

This Roadmap will be updated periodically as program needs evolve in this rapidly expanding field.

## **Creating Awareness & Capacity for Green Chemistry (FY2011-2013)**

The establishment of green chemistry research and development programs will create new markets for products and services. Green chemistry programs that (1) prioritize chemicals of concern in particular uses, and (2) provide incentives for the commercialization of new chemistries help create solutions while increasing awareness and capacity in Washington State.

Unfortunately, green chemistry is not a well-known or broadly understood concept in Washington State. Research conducted by Washington State University (WSU) revealed that no four-year universities/colleges in Washington offer green chemistry curricula or degree programs.

WSU research revealed that 34 community technical colleges offer chemistry courses, but fewer than six implement green chemistry curriculum institutionally. Only a few middle schools and high schools are trying to integrate green chemistry principles into curricula.

While businesses are generally aware of, and are leaders in green chemistry, barriers to implementing green chemistry programs and practices continue to exist<sup>1</sup>. These barriers include economic, regulatory, technical, organizational, cultural, and metrics.

The near-term goal for Washington State is to facilitate partnerships among industry sectors, businesses, academia, NGOs, and state agencies. These partnerships will serve to increase awareness and capacity through collaborative research, education, and technology transfer.

In discussions with Roundtable attendees and others supporting the Roadmap, there are several key strategies under consideration, including:

- **Fund applied research projects that address existing chemicals of concern through green chemistry solutions.** Possible research areas include, but are not limited to, the design of less hazardous flame retardants, bio-based reagents and solvents as a replacement to chlorinated reagents and solvents in pigments and dyes, research on phthalate alternatives, and developing molecular design criteria that will lead to safer chemicals and products.
- **Seek approximately \$1 million in regional seed funding to establish a Pacific Northwest Green Chemistry Research Center for a period of three to five years.** A public-private partnership could be the catalyst that brings together business, higher education, government, and nonprofit organizations to coordinate and facilitate green chemistry research, economic development, education, and technology transfer.
- **Pursue federal grant funding from the U.S. Environmental Protection Agency's Office of Research and Development (EPA-ORD) and National Science Foundation (NSF) to address priority green chemistry research needs.** These funds should be used to support research into green and sustainable chemistry, which will lead to clean, safe, and economical alternatives to traditional chemical products and practices.
- **Establish a public-private sector and foundation partnership to advise and seek financial support to leverage federal funding opportunities.**
- **Expand green chemistry education and workforce training opportunities.**

Establishing a green chemistry center will position Washington State industry and university researchers for future federal grant opportunities. One near-term action is to leverage the U.S. EPA's Region 10 National Estuary Program (NEP) to solicit grants to support green chemistry research for Puget Sound and help establish a Washington Green Chemistry Center.

Federal funds are allocated by Congress to support the protection and cleanup of Puget Sound, including taking preventative actions to reduce water pollution from many sources. This includes toxic chemical loading from contaminated storm water. For example, copper

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<sup>1</sup> Matus, Kira J.M., Paul T. Anastas, William C. Clark, and Kai Itameri-Kinter. "Overcoming the Challenges to the Implementation of Green Chemistry." CID Working Paper No. 155. Center for International Development at Harvard University, December 2007.

dust from brake pads that wash off our roadways into Puget Sound. Copper is very toxic to fish, including salmon. Using NEP and federal funds to solve these types of problems will benefit Puget Sound and help achieve the goals of the 2011 Puget Sound Action Agenda.

This is supported through the near-term actions listed in the Puget Sound Action Agenda to promote the development of safer alternatives to toxic chemicals and create a green chemistry center.

It's also important to recognize the toxic threats to the Columbia River watershed. The Columbia River, the largest North American River draining to the Pacific Ocean, is one of the world's most important rivers for economic and environmental vitality. There is public and scientific concern about the health of the Basin ecosystem, especially with regard to potential impacts from the presence of toxic contaminants. Of particular concern are several persistent, bioaccumulative and toxic (PBT) pollutants, including heavy metals like mercury and lead, as well as industrial chemicals and wastes that can accumulate in the food-chain and wildlife. Green chemistry solutions will benefit all of Washington by identifying and eliminating pollution at the source.

It is important to pursue federal green chemistry research funding in the near future. The NSF envisions a green chemistry program that will fund research to discover the basic science needed to:

- (a) Use new sources of raw materials.
- (b) Replace rare, expensive, and/or toxic chemicals and materials with earth-abundant, inexpensive, and benign alternatives.
- (c) Economically recycle chemicals that cannot be replaced such as phosphorus and the rare earth elements.
- (d) Devise environmentally friendly chemical reactions and processes that require significantly less energy, water, and organic reagents and solvents than current practices.

If awarded, NSF grants could be used to fund collaborative research partnerships among universities, industry sectors, businesses, and nonprofit organizations.

Clearly, the business value proposition is to establish a green chemistry center by the end of 2013 as an investment for future job growth potential. Washington State should pursue federal funds in partnership with private sector support to leverage existing state funds.

Establishing a Green Chemistry Roundtable Steering Committee will help prioritize research needs and guide the development of the center, while building awareness and recognition for green chemistry results. The Steering Committee should include an interdisciplinary team that includes members from the public and private sector, foundations, and other nongovernmental partners.

## **Building the Green Chemistry Program (FY2013-2015)**

The second phase of the Roadmap is to build state and regional capacity. By the end of 2015, the vision for Washington State is to support ongoing projects to advance green chemistry research and education, safer products innovation, economic development incentives, and chemical policy options.

The Green Chemistry Program should leverage the partnerships and knowledge gained to deliver concrete and measurable results. By the end of the second biennium, the program should be able to document success in each of the areas outlined above and on each of the recommendations outlined later in this report. Documenting and then communicating the accomplishments of the program will be important for the long-term success of the Green Chemistry Program in Washington State.

Additional sources of continued funding will be identified to support the green chemistry center's ongoing activities.

## **Sustaining the Program (FY2015 -2017)**

While fully implementing green chemistry is a long-term project, it is hoped that after several years of sustained and coordinated effort, much of the infrastructure needed to support the advancement of green chemistry will be in place. It is envisioned that at this time there will be ongoing, meaningful communication and collaboration between Ecology, Commerce, research institutions, businesses, industry sectors and NGOs that will facilitate and accelerate the adoption of green chemistry in Washington State and throughout the Pacific Northwest.

This long-term objective is designed to help keep Washington State in the forefront in advancing green chemistry. Green chemistry complements the state's Cleantech and green jobs initiatives and is an important component for educating the workforce.

### **Recommendations:**

The following suggestions support the creation of a green chemistry program in Washington State given limited resources and budget constraints. Many of these recommendations can be further developed in the short-term and others in the years ahead.

#### **Recommendation 1: Fund research and establish a Green Chemistry Technology Center**

A Green Chemistry Technology Center (GCTC) is necessary to advance green chemistry efforts in Washington State and facilitate collaborative research, education, and technology transfer.

- 1.1 The GCTC will establish a statewide point-of-contact related to collaborative green chemistry research and development, education, and technical assistance.

The center should engage with other business and environmental leaders, regional centers, state programs, federal agencies, as well as national and global green chemistry programs. A steering committee should be established to guide the creation and development of the center, and include representatives from the public and private sector, academia, and non-profit organizations.

- 1.2 A portion of the funds should be reserved for research on targeted safer alternatives as well as existing and emerging pollution concerns in Washington. Possible research areas include, but are not limited to, design of less hazardous flame-retardants, bio-based solvents as a replacement to chlorinated solvents in pigments and dyes, research on phthalate alternatives, and design criteria for endocrine disrupting chemicals.
- 1.3 The center will work closely with the Puget Sound Partnership and Washington Stormwater Center as a near-term objective. Targeted research will help reduce toxics loading of high priority chemicals of concern in stormwater and Puget Sound. As resources allow, research and challenge grants should be made available to accelerate safe chemicals, processes and products in the 12-county Puget Sound Region.
- 1.4 The center will host an annual green chemistry research conference and in partnership with the Roundtable, facilitate the development of best practices, tools, and training. The GCTC should serve as the organizing entity to bring together regional, national, and international expertise. Washington State is part of the Pacific Rim and well positioned to collaborate with Japan, Korea, India, and China on the implementation of green chemistry.
- 1.5 The center, as resources allow, will establish a green chemistry awards and recognition program.
- 1.6 Ecology, using available private, federal funds and foundation grants, will develop a competitive request for proposals to establish and manage the center. It is recommended the center should be established as a separate entity from Ecology.

### **Recommendation 2: Enhance Research and Education Opportunities**

The education system in Washington has the potential to provide a long-term strategy for workforce education and integration of green chemistry into Washington's economy. Washington's educational institutions and industry sectors working together on research, development, and commercialization will advance green chemistry approaches. It will also advance environmental sustainability while creating new economic drivers and high-tech business opportunities.

- 2.1 Washington universities and colleges should apply for the National Science Foundation (NSF) green chemistry and sustainability grants. These competitive, merit-based grants support research into green and sustainable chemistry, leading to cleaner, safer, and more economical alternatives to traditional chemical products and processes.

- 2.2 Universities and colleges should establish collaborative industrial and university green chemistry innovation programs. Collaboration through a network of researchers will stimulate creative problem solving and help prepare students to engage in green chemistry in the workforce. Partnerships also facilitate the acceleration of technology transfer and commercialization of intellectual property.
- 2.3 Community and technical colleges should develop green chemistry curricula and include such materials in freshman and sophomore chemistry courses. The 29 colleges that offer complete chemistry degrees should establish goals by the end of 2013 to further integrate green chemistry curricula by 2017.
- 2.4 Washington universities should recruit a green chemistry entrepreneurial researcher as part of the Washington State Strategically Targeted Academic Research (STARS) program at the earliest opportunity. The STARS program has a goal of ten researchers by 2017. Federal funding could help leverage a portion of the funding needs.
- 2.5 The Washington Higher Education Coordinating Board should encourage green chemistry through the statewide strategic master plan for higher education.
- 2.6 Universities should enhance the chemistry curriculum as soon as possible to require all graduating chemists in Washington State to have at least one course in toxicology, lifecycle assessment, or equivalent. Universities should advance green chemistry education through enhanced curricula and degree programs that will attract students interested in sustainability while advancing green technologies through the research enterprise.
- 2.7 GCTC and existing university research and educational centers should partner with Washington-based businesses (both large and small), and other educational institutions. These centers should focus on technical areas of economic interest to the state of Washington, such as clean energy and agriculture. Researchers should pursue federal, private foundation, or other funding sources that support green chemistry, sustainability, energy efficiency, and manufacturing efficiency.
- 2.8 The Office of Superintendent of Public Instruction and Ecology will coordinate on kindergarten through 12<sup>th</sup> grade green chemistry curricula and state standards. Existing science and sustainability models should be used to promote green chemistry as key in achieving sustainability and to assist its implementation into middle and high school science and chemistry programs. The GCTC will provide teacher and professional development training through annual training events and online education.
- 2.9 Regional colleges could focus on targeted green chemistry research in a consortium approach to significantly increase the educational impact of green chemistry activities in the state. Regional colleges are an essential part of the educational enterprise in the state of Washington.

- 2.10 GCTC and Ecology should partner with Washington-based businesses and industry sectors to establish a green chemistry workforce education program. Such a program would facilitate the continuing education of the current workforce, including industrial and scientific workers. It would also aid in the development of a workforce, which can produce safer alternatives and new or improved chemical processes using the twelve principles of green chemistry. Training that includes practical information on the concepts of green chemistry including examples of accomplishments, costs, and benefits should be developed.

**Recommendation 3: Promote Safer Chemicals, Processes and Product Innovation**

Leading companies, from electronics manufacturers to retailers, are highly motivated to identify and use safer alternatives to toxic chemicals, maximize resource efficiency, and minimize waste. Proactive business leaders, retailers, and organizations, including the Green Chemistry and Commerce Council (GC3) and collaborative groups such as BizNGO, are promoting the use of alternatives assessments as well as improving their manufacturing processes.

An alternatives assessment is a process for identifying and comparing potential chemical and non-chemical alternatives that could replace chemicals or technologies of concern. Alternatives assessments can be used to replace existing toxic chemicals in the supply chain to address increasing consumer concerns as well as new business opportunities. .

- 3.1 Ecology’s Pollution Prevention Program and partners will provide green chemistry support to assist businesses as part of the state’s pollution prevention planning requirements, when applicable. Ecology’s Toxic Metals Prevention Project is a good model for reducing toxic metals such as lead, cadmium, and mercury.
- 3.2 Ecology and the Department of Enterprise Services (DES) will promote lifecycle assessment (LCA) as a tool to assess the environmental aspects and potential impacts associated with a product, process, or service with the ultimate aim of implementing the green chemistry principles and eliminating the use of chemicals of concern in products or processes.
- 3.3 Business, universities, government, and NGOs, through a stakeholder process, will develop alternatives assessment guidance to help organizations identify safer alternatives to existing chemicals of concern. Washington State should leverage existing alternatives assessment efforts underway by EPA as well as other states (e.g., California) to encourage common approaches.
- 3.4 The GCTC, with support from Ecology, will continue to provide training and technical assistance on the Green Screen, Quick Chemical Assessment Tool, and other screening tools. The GCTC should engage in outreach and education across supply chains and within business sectors.

- 3.5 Ecology and DES should take efforts to purchase goods and services of best value to Washington State, including reduced public health and environmental impacts. State agencies should continue to lead by example in the procurement of safer products.
- 3.6 Washington State should evaluate national green chemistry standards, including the Green Chemistry Institute's Greener Chemicals and Process Information Standard (355-2011) and other related standards.

#### **Recommendation 4: Accelerate Economic Development and Workforce Training**

Green chemistry opens a new pathway for economic development in the state. However, the existing opportunities need to be better identified, analyzed, considered, and integrated into the emerging green economy. There are opportunities for growth in the bioenergy field to create new markets for bio-based chemicals and services.

- 4.1 Ecology and Commerce will leverage green chemistry economic development in coordination with Innovate Washington. This is a new state agency focused on growing the innovation-based economic sectors of the state and responding to the technology transfer needs of existing businesses in the state.
- 4.2 Commerce will conduct Green Chemistry Business Development services to recruit and cultivate green chemistry commercialization and business development opportunities, including Innovation Partnership Zones.
- 4.3 State policymakers should consider creating a Green Chemistry Research Fund to promote green chemistry research, development, and application. A competitive fund could be administered by Commerce and Ecology in consultation with a higher education/business expert review panel.
- 4.4 Commerce should use the Washington Business and Occupational Tax Incentive for High Technology to provide companies annual credits of up to \$2 million for research and development in green chemistry.
- 4.5 The state should provide investment tax credits, access to private sector low-interest loans, loan guarantees, and subsidies for green chemistry manufacturing equipment or products. Make private financial capital available to companies at preferential terms. Create a revolving loan program to offer reduced-interest loans to businesses investing in the production of green products.
- 4.6 State policy makers should expand the Manufacturing Innovation and Modernization Account to help modernize existing manufacturing processes through application of green chemistry principles.

#### **Recommendation 5: Green Chemistry Policy Options**

The State Legislature should consider green chemistry policy options to maintain state competitiveness and support economic development opportunities in Washington. These options include policies designed to promote innovation and education, and facilitate coordination among state agencies, higher education, and businesses to advance green chemistry as a long-term objective for education, research, and workforce development.

- 5.1 To promote economic development in Washington State, the Legislature should consider promoting green chemistry by establishing state policy to:
- Encourage the research and development of innovative chemical technologies.
  - Promote the use of chemical technologies that reduce or eliminate the use or generation of hazardous substances during the design, manufacture, and use of chemical products and processes.
  - Encourage the use of safer, less toxic chemical alternatives to hazardous substances.
- 5.2 State chemical policy legislation should include incentives to promote green chemistry.
- 5.3 Washington State policymakers should encourage Congress to reform the Toxic Substances Control Act (TSCA) of 1976. TSCA is the only major federal legislation that has not been updated and a broad group of stakeholders agree on the need to modernize the law, including green chemistry provisions.
- 5.4 Washington State should consider adopting policies that enhance information disclosure of chemical product ingredients across the supply chain. Ingredient disclosure is a means by which chemical consumers can identify hazards and make informed purchasing decisions.

**Recommendation 6: Establish a Green Nanotechnology Partnership**

Green nanotechnology is in the early stages of development, but there is wide interest in supporting the responsible development of green nanotechnology. Washington State should work with with universities and the private sector, since the Pacific Northwest has significant expertise that could be greatly enhanced through a regional partnership.

In August 2011, a white paper was issued by the ACS Green Chemistry Institute and the Oregon Nanoscience and Microtechnologies Institute recommended that interdisciplinary cooperation is needed to achieve a better understanding of the potential risks of nanotechnology and the development of appropriate policies to address those concerns.

- 6.1 Ecology should participate in regional and national green nanotechnology partnerships with industry, government, and NGOs to advance education and responsible nanotechnology development in Washington State.
- 6.2 State and federal agencies, especially EPA, need to expand research and facilitate education and data sharing on emerging technologies.
- 6.3 Federal and state policymakers should create nanotechnology market incentives to encourage the development of safer alternatives to existing chemical substances, thereby reducing the use and generation of hazardous substances.

- 6.4 Policymakers should recognize nanomaterials as a special class of chemicals which, due to their unique properties, may make them behave in ways different from conventional chemicals.
- 6.5 State agencies should develop messaging and educational materials to communicate nanotechnology hazard issues throughout the product lifecycle, including end-of-life issues.

**Recommendation 7: Green Chemistry Program Support**

Ongoing program maintenance will be needed to sustain a green chemistry program in Washington State.

- 7.1 Ecology is the lead agency to partner with other state agencies and higher education to promote green chemistry, including Commerce, Innovate Washington, Office of Superintendent of Public Instruction, and higher education.
- 7.2 Ecology will support the Green Chemistry Roundtable, including encouraging participation from industry, education, government, and NGOs. Universities, colleges, and community colleges will be recruited to actively participate by integrating green chemistry principles into existing curricula.
- 7.3 Ecology will work with other states on green chemistry regional efforts. Ecology will coordinate with the Interstate Chemicals Clearinghouse (IC2), Green Chemistry and Commerce Council (GC3), and the ACS Green Chemistry Institute to avoid duplication of efforts, share resources, and build state capacity.
- 7.4 Ecology will support outreach efforts to inform and educate the public on the importance of green chemistry. This will include how chemicals of concern are used in everyday products, how green chemistry supports the economy, and protects the environment.
- 7.5 Ecology will provide oversight of green chemistry program funding, implementation, performance measures, and evaluation.

## Defining Green Chemistry

Washington State's definition of green chemistry is based on the 12 Principles of Green Chemistry that were published in the 1998 book "Green Chemistry: Theory and Practice," by Paul T. Anastas and John C. Warner. Green chemistry reduces or eliminates the need for and generation of hazardous materials during the manufacture, design, and application of chemistry. Washington State is committed to applying the 12 Principles below in chemical process and product design:

1. **Prevent waste:** Design chemical syntheses to prevent waste, leaving no waste to treat or clean up.
2. **Design safer chemicals and products:** Design chemical products to be fully effective, yet have little or no toxicity.
3. **Design less hazardous chemical syntheses:** Design syntheses to use and generate substances with little or no toxicity to humans and the environment.
4. **Use renewable feedstocks:** Use raw materials and feedstocks that are renewable rather than depleting. Renewable feedstocks are made from agricultural products or the wastes of other processes. Depleting feedstocks are made from fossil fuels (petroleum, natural gas, or coal) or are mined.
5. **Use catalysts, not stoichiometric reagents:** Minimize waste by using catalytic reactions. Catalysts are used in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and work only once.
6. **Avoid chemical derivatives:** Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste.
7. **Maximize atom economy:** Design syntheses so that the final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms.
8. **Use safer solvents and reaction conditions:** Avoid using solvents, separation agents, or other auxiliary chemicals. If these chemicals are necessary, use innocuous chemicals.
9. **Increase energy efficiency:** Run chemical reactions at ambient temperature and pressure whenever possible.
10. **Design chemicals and products to degrade after use:** Design chemical products to break down to innocuous substances after use so they do not accumulate in the environment.
11. **Analyze in real time to prevent pollution:** Include in-process real-time monitoring and control during syntheses to minimize or eliminate the formation of byproducts.
12. **Minimize the potential for accidents:** Design chemicals and their forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment.

Source: Anastas, P. T.; Warner, J. C. Green Chemistry: Theory and Practice, Oxford University Press: New York, 1998, p.30. By permission of Oxford University Press.