

What is



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Green Chemistry Initiatives

- **Green Chemistry Programs in 23 Countries**
- **U.S. and U.K. Green Chemistry Awards**
- **ACS Green Chemistry Institute/U.K. Green Chemistry Network/Japanese Chemical Innovation Institute**
- **U.S. State Governor's Green Chemistry Initiatives**
 - Michigan, California, Maine, Oregon
- **University Green Chemistry Curricula**
 - 16 U.S. colleges offer green chemistry classes
 - U. of Massachusetts Green Chemistry Ph.D.
- **Two Green Chemistry Journals**



History of Green Chemistry

- 1990** Council for Chemical Research— begins "environmentally-benign chemical synthesis and processing program"
- 1992** U.S. NSF Environmentally Benign Chemistry Program
- 1996** ACS Green Chemistry and Engineering Conference
First U.S. Presidential Green Chemistry Awards
First Gordon Conference on Green Chemistry
IUPAC-- Int. Conference on Green Chemistry-Venice
- 1998** OECD Workshop on Sustainable Chemistry- Venice
- 1999** Royal Chemistry Society launches *Green Chemistry*



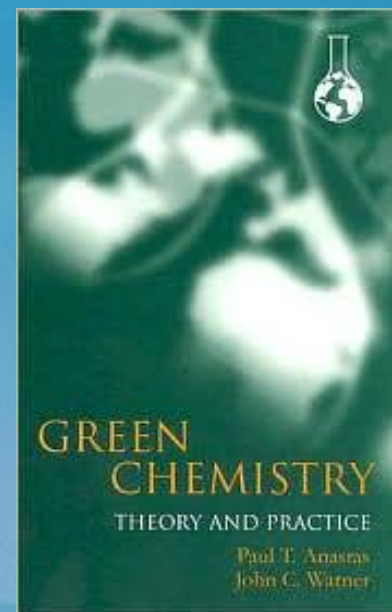
Green Chemistry

Green Chemistry is a chemistry response to the drive for a sustainable world

Definition:

“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 and Warner, *Green Chemistry: Theory and Practice*, 1998



Twelve Principles of Green Chemistry

- Prevent waste (unconverted feedstock, spent reaction fluids)
- Maximize the incorporation of all process materials into the finished product
- Use and generate substances that possess little or no toxicity
- Preserve efficacy of function, while reducing toxicity
- Minimize auxiliary substances (e.g. solvents, separating agents)
- Minimize energy inputs (process at ambient temperatures and pressures)
- Prefer renewable materials over non-renewable materials
- Avoid unnecessary derivations (e.g. blocking groups, protection/de-protection steps)
- Prefer catalytic reagents over stoichiometric reagents
- Design products for natural, post-use decomposition
- Use in-process monitoring and control to prevent formation of hazardous substances
- Select substances and processes so as to minimize the potential for accidents



Green Chemistry Definition

- **Clear terms—hazardous substances, but can include energy/resource reductions**
- **Single idea—avoiding hazardous substances, hazard reduction**
- **Comprehensive universe—Consider all the stages of the life cycle of a chemical.**
- **Testability—hazardous substances can be measured**
- **Relevant to chemists—avoids issues of exposure and risk**
- **Focus on “hazard reduction” as the primary impact category of interest in each life cycle stage with a focus on the design stage. Other life cycle impacts of innovation should also be considered.**
- **Reduce hazards to human and ecosystem health**



Sustainable Chemistry

OECD Definition

“Sustainable chemistry is the design, manufacture and use of efficient, effective, safe and more environmentally benign chemical products and processes.”

- Organization for Economic Cooperation and Development, Brochure



Green Engineering

“Green engineering is the design, commercialization, and use of processes and products, which are feasible and economical while minimizing 1) generation of pollution at the source and 2) risk to human health and the environment.”

- U.S. Environmental Protection Agency, 2005




What is Not Green Chemistry?

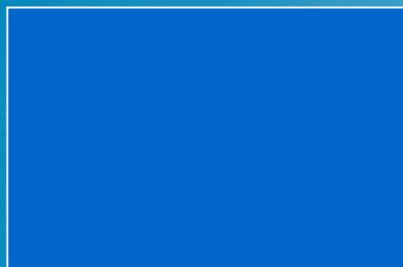
- **Conventional environmental chemistry**
- **Non-hazardous products produced with hazardous production processes**
- **Process chemical substitutions if the chemical product is hazardous**
- **Risk Reduction**
- **Chemical Restrictions/Chemicals Policy**



The Need for Green Chemistry

 10% of chemicals in production are low hazard

 25% of hazardous production chemicals could be substituted with currently available, low hazard substitutes

 65% of hazardous production chemicals have no currently available low hazard substitutes

Reference: John Warner,
Warner,-Babcock Institute



Opportunities for Green Chemistry

- Reducing the use of hazardous chemicals
- Reducing or eliminating chemical process wastes
- Reducing chemical production energy consumption
- Converting from oil, gas and coal to renewable feedstocks
- Generating chemical products that are biodegradable or recyclable
- Clean up of hazardous sites



Green Chemistry Example

New Synthesis in Manufacturing Sertraline

2002 Presidential Green Chemistry Award

- Sertraline--active ingredient in Zoloft
- Pfizer's conventional 3 step process reduced to a single step
- Imine formation of monomethylamine with tetralone reduced with mendelic acid
- Increased purity and yield and cut monomethylamine by 60% and tetralone by 45%
- Resulted in significant raw material cost savings



Alternative Solvents in Manufacturing PLA

2002 Presidential Green Chemistry Award

- Cargill makes Nature Works with poly lactic acid
- New process generates lactic acid, lactide & PLA
- Water is used in fermentation while molten lactide is used as the reaction media in the monomer and polymer production
- Reduces energy and increases yield
- PLA product is readily hydrolyzed into lactic acid for recycling



Water-based Ink

2005 Presidential Green Chemistry Award Nominee

- Highland Supply Corporation makes quality floral wrap packaging
- Developed its own water-based inks to replace solvent-based inks
- Resulted in
 - 95% reduction in VOC emissions
 - reduced fire hazards
 - eliminated hazardous process wastes
- Generated a \$100,000/yr savings in avoided waste treatment costs and a 40% savings in ink costs



Green Chemistry at the National Level

- **Presidential Green Chemistry Awards**
- **ACS Green Chemistry and Engineering Conference**
- **U.S. EPA Green Chemistry Program**

- **U.S. Congress, *H.R. 1215, Green Chemistry Research and Development Act*, pending**



Green Chemistry Institute

- Est. in 1997, adopted into the American Chemical Society (ACS) in 2001
- *“The mission of the ACS Green Chemistry Institute (ACS GCI) is to advance the implementation of green chemistry principles into all aspects of the chemical enterprise.”*
- The ACS GCI promotes green chemistry through
 - Research
 - Education
 - Information dissemination
 - Conferences and symposia
 - International collaboration
- ACS GCI Pharmaceutical Roundtable



Green Chemistry Pharmaceutical Roundtable

- **Founded in 2005 to promote green chemistry in the pharmaceutical industry**
- **Involves 8 companies**
(AstraZeneca, Eli Lilly, GlaxoSmithKline, Merck, Wyeth, Johnson & Johnson, Pfizer, Schering-Plough)
- **Hosted by American Chemical Society**
- **Provides workshops, Green Chemistry Highlights Papers, Solvent Selection Guide, research papers, and research grants**



International Initiatives for Green Chemistry

- **European Platform for Sustainable Chemistry (SusChem)**—*Vision for 2025 and Beyond*
- **UK Chemistry Leadership Council**—*Vision for Sustainable Production and Use of chemicals*
- **Crystal Faraday.**—*Green Chemical Technology, 2004 Roadmap*
- **Green Chemistry Networks established in Japan, Canada, United Kingdom..and more**



The Precursors to Change

- **Willingness**
(motivation, compliance, fear, courage, commitment)
- **Opportunity**
(awareness, interest, learning, access, timing)
- **Capacity**
(resources, intelligence, knowledge, assistance)



Barriers to Green Chemistry Development

- **Lack of public awareness**
- **Limited professional drivers**
- **Limited research funding**
- **Inadequate information on chemical hazards**
- **Limited education and training programs**
- **Lack of corporate awareness**
- **Corporate resistance to change – industrial lock in of technologies**
- **Lack of market signals in the supply chain**
- **Limited experience with many alternative chemical processes and synthesis pathways**
- **Resistances from mainstream chemists**
- **Weak regulations on chemicals of high concern**



U.S. States and Corporations emerge as Drivers

- **Limited federal Initiative**
 - U.S. EPA sponsors Presidential Green Chemistry Challenge Program
 - Research support bill stalled in Congress
- **State chemical laws and pollution prevention programs encourage green chemistry**
 - State chemical bans (mercury, BFRs) promote alternative chemistries
 - 23 state pollution prevention programs encourage chemical substitution
- **Some research centers provide support**
 - Academic research centers focus on green chemistry
- **Some corporations provide leadership**
(Pfizer, Nike, Dow, Astra-Zenica, GlaxoSmithKline, True)



State Green Chemistry Education and Research Programs

- **Some 15 higher education schools offer green chemistry programs**
- **University of Massachusetts Boston offers the only Doctoral Degree in Green Chemistry**
- **There are several Green Chemistry Research Centers at the state level:**
 - **Institute for Green Science, Carnegie-Mellon**
 - **Center for Green Chemistry, University of Oregon**
 - **Center for Green Chemistry and Green Engineering, Yale University**
 - **Center for Environmentally Benign Catalysts, University of Kansas**
 - **Warner-Babcock Institute for Green Chemistry, Massachusetts**



Reducing Toxic Chemical Use

- **1989—Massachusetts enacts the Toxics Use Reduction Act**
- **Requires some 500 Massachusetts firms to:**
 - Provide annual chemical use reports on 1200 toxic chemicals
 - Prepare and update facility plans on reducing or eliminating those chemicals
 - Pay an annual fee based on chemical use
- **Provides Office of Technical Assistance services**
- **Provides Toxics Use Reduction Institute research testing, training and policy services**



Promoting Green Chemistry

- Promotes the substitution of chemicals of high concern
- Provides research support for Green Chemistry research
- Hosts annual Green Chemistry Conferences at four University of Massachusetts campuses
- Sponsors multi-state workgroup on Alternatives Assessment
- Safer Alternatives Bill proposal



Michigan Green Chemistry Support Program

Launching the Initiative

- In 2006, Governor Granholm issued an Executive order encouraging implementation of green chemistry
- Lowell Center contracted to help the state to develop a green chemistry strategy
- A stakeholders roundtable convened in 2007
- In 2008 the state Department of Environmental Quality adopted an “Action Plan” and set aside funding



Michigan Green Chemistry Support Program

An Action Plan for Michigan Green Chemistry

- **Three Phase Strategy advised by a Green Chemistry Support Program Roundtable**
- **Phase One: Building Awareness**
 - Define parameters, build a resource base, create an identity, produce a “Michigan Green Chemistry Future” brochure
- **Phase Two: Building the Program**
 - Convene a “Green Chemistry Research and Education Conference”, develop an awards program, establish an educational network
- **Phase Three: Building the Future**
 - Implement a technology innovation program, establish a Green Chemistry Innovation Center



California Green Chemistry Initiative

A Year of Exploration

- **2006 ---University of California, Berkeley publishes Green Chemistry Policy Report**
 - Identifies three gaps: Data, Safety and Technology
- **April, 2007---Department of Toxic Substances Control launches the state Green Chemical Initiative**
 - **Phase One**
 - Sponsor workshops and symposia
 - Hosts “A Conversation with California” an on-line blog
 - **Phase Two**
 - Holds public workshops and discussion fora
 - Convenes a Science Advisory Panel
 - Sets up “Key Element Teams”



California Green Chemistry Initiative Science Advisory Panel Options Report

- **21 member Panel convened in 2007**
- **Produced 38 policy options**
 - **Focused on encouraging “willingness, opportunity and capacity”**
 - **Organized by “demand-side” and “supply-side” options**
 - **Ranging from improving education to promoting research, generating information, targeting procurement, providing awards, informing retailers, and increasing regulations**



California Green Chemistry Initiative

Final Report

- **Expand Pollution Prevention**
- **Develop Education and Training, Research and Development and Technology Transfer**
- **Create an On-Line Product Ingredient Network**
- **Create an On-Line Toxics Clearinghouse**
- **Accelerate the Quest for Safer Products**
- **Move Towards a Cradle to Cradle Economy**



Legislation

- **Two of the six recommendations are being implemented by statutes passed in 2008**
- **AB 1879 requires the state to identify chemicals of high concern in products, to evaluate alternatives, and to specify appropriate regulatory responses**
- **SB 509 requires the state to establish a public, on-line Toxics Information Clearinghouse on the hazards of chemicals found in products**



Lessons from “the States”

Willingness, Opportunity, Capacity

- **Building public and professional awareness is critical**
- **Policies and definitions must be clear and widely known**
- **Governments should lead, but not mandate**
- **Both incentives and disincentives are needed with a careful balance**
- **Some financial resources are needed**
- **A central focus for promotion is important**
- **Changes in curriculum and teaching is needed to develop the new professionals and workers**



Green Chemistry and Commerce Council

- **Established in 2005 to promote Green Chemistry and Design for the Environment**
- **70 companies**
(e.g. Nike, Walmart, Corporate Express, HP, Coastwide, True, Colgate-Palmolive, Herman-Miller, Timberland, SYSCO, Dow, DuPont, SC Johnson)
- **Hosted by the Lowell Center for Sustainable Production**
- **Annual Conferences**
- **3 Working groups**
 - **Advancing Design for the Environment and Green Chemistry**
 - **Tools for Chemical Assessment and Design**
 - **Drivers for Innovation and Marketing**



Six Policy Areas for Promoting Green Chemistry

- 1. Develop a central institution(s) for promotion**
- 2. Develop capacity and resources for research and innovation**
- 3. Provide public technical assistance**
- 4. Invest in education and training**
- 5. Build procurement and market incentives**
- 6. Tighten hazardous chemical regulations**



Policy Options for Promoting Green Chemistry

- **Administrative Support**
- **Technical Assistance**
- **Research and Development Support**
- **Education and Training**



Executive Administrative Programs

- **Establish administrative coordination and program planning**
 - Convene a high level agency, industry, public interest council
 - Create a state strategy “Roadmap”
- **Environmentally-preferred purchasing**
 - Promote procurement of green chemistry derived products
- **Develop Clean Tech initiatives tied to green jobs and, economic development (MA Clean Tech Project)**



Research and Development Support

- **Government Funding Programs**

 - Offer seed funding for green chemistry research or demonstrations or signature initiatives

 - Organize industry partnership research initiatives

- **Cooperative State Research Programs**

 - Create cooperative agricultural research programs, biobased materials research

- **University-based Center Support**

 - Establish university green chemistry centers (e.g.: Un of Mass Lowell, Carnegie-Mellon, Un of Oregon)

- **Tax incentives/low income loans, extended patent protections for innovators in green chemistry**



Technical Assistance

- **Sector-specific or broad green chemistry workshops and symposia**
e.g. Pharmaceutical green chemistry conference, green chemistry and pollution prevention workshops, etc.
- **On-site industrial technical services**
Integrate green chemistry research into state pollution prevention assistance services
- **Awards and demonstration programs**
Create competitive awards programs for public recognition
- **Guidance documents and brochures**



Education and Training

- **Promote college courses in green chemistry**
 - Support for curriculum development
 - Integrate toxicology and environmental courses in mainstream chemistry programs
- **Provide scholarships and graduate student support**
 - Offer student financial aid
 - Sponsor student competitions and awards
- **Encourage K-12 programs**
 - Provide guest projects and student awards
 - Develop summer teacher training programs



Supportive Policy

- **Action plans for high concern chemicals tied to alternatives assessment processes**
- **Lists of chemicals of concern and “greener” chemicals**
- **Fees of chemicals of higher concern**
- **Supplemental Environmental Projects**



Conclusions

- **Green Chemistry is about reduction of chemical hazards throughout lifecycles and is not constrained by jurisdictional boundaries**
- **Green chemistry is the “supply” of safer chemicals but requires “demand” as well through markets and regulation. BUT: Green chemistry is not synonymous with chemicals policy.**
- **There are great opportunities to advance green chemistry in education, government and industry but great barriers as well.**
- **Hazardous waste managers know the implications of toxic materials and have the knowledge and capacity to be leaders in this area.**

