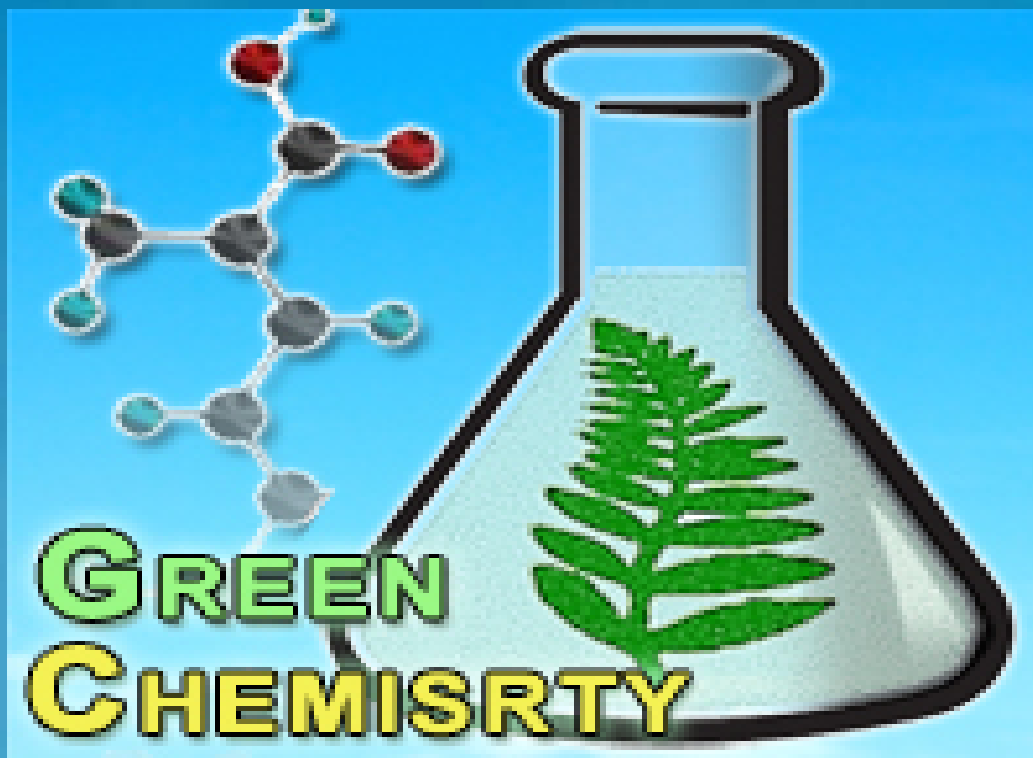


What is

**GREEN**  
**CHEMISRTY**



Ken Geiser, PhD

Lowell Center for Sustainable Production

University of Massachusetts Lowell

December 12, 2007



# Green Chemistry Initiatives

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- **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
- **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

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- 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

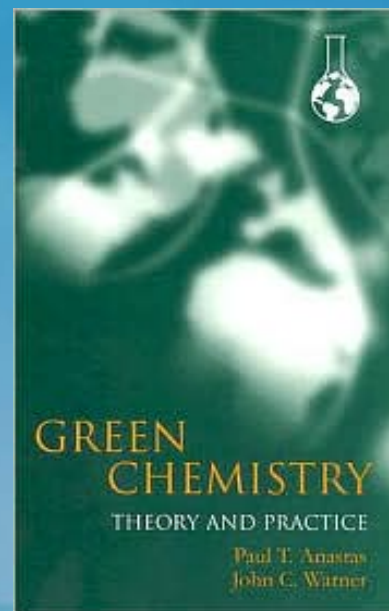
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**Green Chemistry is a chemistry response to the drive for a sustainable world**

## **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

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- **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

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- **Clear terms—hazardous substances**
- **Single idea—avoiding hazardous substances**
- **Comprehensive universe—chemical life cycle**
- **Testability—hazardous substances can be measured**
- **Relevant to chemists—avoids issues of exposure and risk**



# Sustainable Chemistry

## OECD Definition

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**“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

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**“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?

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- **Conventional environmental chemistry**
- **Non-hazardous products produced with hazardous production processes**
- **Process chemical substitutions if the chemical product is hazardous**

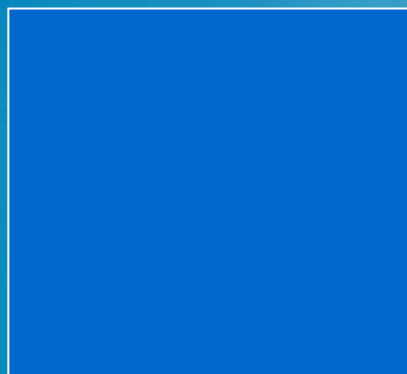


# The Need for Green Chemistry

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 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



# The Focus for Green Chemistry

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## Available Substitutes

	Many	Few
Less Toxic	Conventional Substitution	Conventional Chemistry
More Toxic	Toxics Use Reduction	<b>Green Chemistry</b>



# Opportunities for Green Chemistry

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- 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



# Green Chemistry Techniques

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- **Green Reagents**
- **Aqueous-Phase Reactions**
- **Solvent-less Reactions**
- **Solid phase organic synthesis**
- **Reactions in ionic liquids**
- **Renewable feedstocks**
- **Biodegradable products**
- **Non-covalent derivatization**
- **Atom-efficient reactions**
- **Biocatalysis**
- **Polymer-supported reagents**
- **Use of blocking/protecting groups**
- **Enzyme-mediated reactions**
- **Ultrasound-assisted Reactions**
- **Microwave Induced Reactions**
- **Microbial oxidations**
- **Supercritical fluid intermediates**
- **Ambient processing**



# 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

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## 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

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## 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

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- 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

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- 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 in California

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- **2005—Release of University of California report, “Green Chemistry in California”**
- **2007—Governor Scharzenegger launches the Green Chemistry Initiative, seeking to**
  - **Move towards a Cradle to Cradle framework**
  - **Stimulate the Green Chemistry challenge**
  - **Identify Toxics in Products by Design**
  - **Identify Toxics in Products by Accident**
- **Program Report due in April**



# Green Chemistry in Massachusetts

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- **Four annual conferences on Green Chemistry Research**
- **Green Chemistry laboratory at University of Massachusetts Lowell**
- **PhD in Green Chemistry at University of Massachusetts Boston**
- **Warner-Babcock Institute for Green Chemistry**
- **Beyond Benign**



# International Initiatives for Green Chemistry

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- **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**



# **Barriers to the Adoption of Green Chemistry**

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- 1. Inadequate health and environmental effects data for most chemicals**
- 2. Limited experience with many alternative chemical processes and synthesis pathways**
- 3. Industrial “lock in” on conventional processes**
- 4. Resistances from mainstream chemists**



# Policy Options for Promoting Green Chemistry

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



# Executive Administrative Programs

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- **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
- **Labeling and product declaration**
  - Establish product labels for green chemistry and agriculture derived products





# **Research and Development Support**

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- **Government Funding Programs**

- Offer seed funding for green chemistry research or demonstrations

- 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)



# Technical Assistance

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- **Sector-specific 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

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- **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



# Green Chemistry

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## An Opportunity for the State of Michigan

