Green Chemistry is the *design* of chemical products and processes that reduce or eliminate the *use and/or generation* of hazardous substances.
The Twelve Principles of Green Chemistry

1. **Prevention.** It is better to prevent waste than to treat or clean up waste after it is formed.

2. **Atom Economy.** Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.

3. **Less Hazardous Chemical Synthesis.** Whenever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

4. **Designing Safer Chemicals.** Chemical products should be designed to preserve efficacy of the function while reducing toxicity.

5. **Safer Solvents and Auxiliaries.** The use of auxiliary substances (solvents, separation agents, etc.) should be made unnecessary whenever possible and, when used, innocuous.

6. **Design for Energy Efficiency.** Energy requirements should be recognized for their environmental and economic impacts and should be minimized. Synthetic methods should be conducted at ambient temperature and pressure.

7. **Use of Renewable Feedstocks.** A raw material or feedstock should be renewable rather than depleting whenever technically and economically practical.

8. **Reduce Derivatives.** Unnecessary derivatization (blocking group, protection/deprotection, temporary modification of physical/chemical processes) should be avoided whenever possible.

9. **Catalysis.** Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

10. **Design for Degradation.** Chemical products should be designed so that at the end of their function they do not persist in the environment and instead break down into innocuous degradation products.

11. **Real-time Analysis for Pollution Prevention.** Analytical methodologies need to be further developed to allow for real-time in-process monitoring and control prior to the formation of hazardous substances.

12. **Inherently Safer Chemistry for Accident Prevention.** Substance and the form of a substance used in a chemical process should be chosen so as to minimize the potential for chemical accidents, including releases, explosions, and fires.
The past 25 years of green chemistry publications

Publication Year

Cumulative Publications

Publications

Patents

Cumulative Publications

(SciFinder Data Collected September 30, 2015)
Of all the products and processes...

Maybe 10% are benign...

Maybe 25% have alternatives available...

65% Still have to be invented!
More environmentally benign than alternatives

Perform better than alternatives

More economical than alternatives
Green Chemistry

- Safety
- Performance
- Cost
Chemists have ALWAYS cared about Human Health and the Environment.
Risk = Exposure × Hazard
The cost of using hazardous materials:

- Storage
- Transportation
- Treatment
- Disposal
- Regulatory Costs
- Liability
- Worker Health and Safety
- Corporate Reputation
- Community Relations
- New Employee Recruitment
Environmental Regulations

Number of Laws

- 1870
- 1880
- 1890
- 1900
- 1910
- 1920
- 1930
- 1940
- 1950
- 1960
- 1970
- 1980
- 1990
- 2000

- Silent Spring
- Rachel Carson

[Graph showing the number of environmental regulations over time, with a significant increase in the early 20th century.]
Carbon-Carbon Bonds

Oxidations

Reductions

Hydroxylations

Polymer Syntheses

Traditional Processes

Green Alternatives
2007 onward...

John Warner  Amy Cannon

James & Jim Babcock  Joe Pont, CEO

100 Research Drive
Wilmington, MA 01887
Science

Explore
Observe and define structure and dynamics.

Basic Research
Identify and characterize impact of changes of structure on dynamics and dynamics on structure.

Understand
Design alterations in structure and/or dynamics to purposefully control response.

Parameterize

Create
Create a potentially useful prototype.

Develop
Develop a potentially successful product.

Commercialize
Commercialize a successful product.

Business

Explore
Observe and define a product and market.

Market Analysis
Identify and characterize market history and likely future trends.

Understand
Identify and characterize market history and likely future trends.

Parameterize
Design potential products and assess potential markets and parameters for success.

Create
Create a potentially useful prototype.

Develop
Develop a potentially successful product.

Commercialize
Commercialize a successful product.
Contract Invention

- Pharmaceutical and Agricultural Products
- Films and Coatings

Self-Funded Invention

- Materials and Composites
- Cosmetics, Personal Care and Home Care
- Sustainability Sciences
- Performance Materials

Invent for collaborators

Help with commercialization
Beyond Benign

Warner Babcock Institute for Green Chemistry

Collaborative Aggregates LLC

Cthulhu Ventures

Delta-S

Collaborative Medicinal Development LLC

Oncochel Therapeutics LLC

Procypra Therapeutics LLC
Pharmaceuticals and Agricultural Products

- Pharmaceuticals and Agricultural Products
  - Films and Coatings
  - Materials and Composites
  - Performance Materials
  - Cosmetics, Personal Care and Home Care
  - Sustainability Sciences
“Non-Covalent Derivatives of Metal Complexes and Methods of Treatment”

“Copper (II) bis(N-alkyl-hydrazinecarbothioamide) Complexes as Non-Covalent Derivatives for the Treatment of CNS Conditions”
Alzheimer’s Disease Therapeutic

Lead Development History (Bis ANS)

“Dihydro-6-Azaphenalene Derivatives for the Treatment of CNS, Oncological Diseases and Related Disorders”

Materials and Composites

- Pharmaceutical and Agricultural Products
- Films and Coatings
- Performance Materials
- Cosmetics, Personal Care and Home Care
- Sustainability Sciences
Maltenes undergo photo-oxidation to Asphaltenes making the pavement dryer and more brittle.
This is world’s oldest known photograph made in 1825.

It was made by Joseph Nicéphore Niépce.

He exposed a metal sheet coated with asphalt to light in a camera for 8 hours. The areas irradiated by light washed off!
Construction Materials: Asphalt Paving


Formaldehyde Free Wood Composites

“Lignocellulosic Compositions and Methods of Making Same” Warner, John C. et al. US Patent Filed
Cosmetics, Personal Care and Home Care

- Cosmetics, Personal Care and Home Care
- Pharmaceutical and Agricultural Products
- Films and Coatings
- Materials and Composites
- Performance Materials
- Sustainability Sciences
Hair Color Restoration

Tyrosinase

L-Tyrosine → Tyrosinase → L-DOPA → Tyrosinase → DOPAQuinone → L-DOPAchrome → 5,6-DihydroxyIndole

December 1st, 2015
Hair and Fabric Shaping and Toning


A New Technology Makes Sugar Twice As Sweet, So You Can Eat Half As Much

Trick your tongue into thinking you’re having a much sweeter treat that isn’t nearly as bad for you.
“Bromine-Free Fire Retardant (FR) Agents Capable of Using a Cyclization Mechanism”
Warner, John; Tang, Pui-In; Stewart, Amie; Kelly, Colleen. PCT Int. Appl. WO 2015050542. Filed October 2, 2013. Published April 9, 2015.

Solar and Electronic Applications


“Thermal Recording Media” Chakar, Fadi Selim; Warner, John Charles; Whitfield, Justin Robert; Lugus, Michelle Wanch Li; Banerjee, Deboshri, PCT Int. Appl. WO 2015094630 Published June 25, 2015.


Sustainability Sciences

Pharmaceutical and Agricultural Products

Films and Coatings

Materials and Composites

Performance Materials

Cosmetics, Personal Care and Home Care

Sustainability Sciences
June 29, 2015

Ocean Plastics Recycling and Reclamation
Electronics Recycling and Reclamation


“Sustainable process for reclaiming precious metals and base metals from electronic waste” Korzenski, Michael B.; Jiang, Ping; Norman, James; Warner, John C.; Ingalls, Laura; Gnanamgari, Dinakar; Strickler, Fred; Mendum, Ted. US Pat. Appl. US 20130336857. Filed August 19, 2011. Published December 19, 2013.


“Non-fluoride containing composition for removal of polymers and other organic material from a surface” Korzenk1, Michael B.; Jiang, Ping; Warner, John C.; Mendum, Ted; Lugus, Michelle; Whitfield, Justin; Vanbenschoten, Helen; Payne, Makonnen PCT Int. Appl. WO 2010091045. Filed Feb 3, 2010. Published August 12, 2010.

\[
\text{LiCoO}_2
\]
Water Harvesting Technologies

Hydrophobic ↔ Hydrophilic

[Diagram showing the transition between hydrophobic and hydrophilic surfaces]
Innovation & Creativity

We are successful not **IN SPITE** of green chemistry

But **BECAUSE** of green chemistry