Introduction to Green Chemistry

John C. Warner

Professor, Plastics Engineering
Professor, Community Health and Sustainability

Director, Center for Green Chemistry

University of Massachusetts Lowell

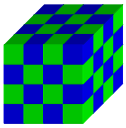
Polaroid

1988-1997 *Lloyd Taylor*

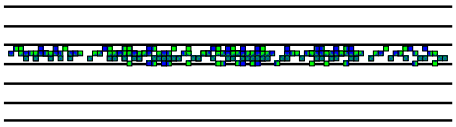
"Thermographic Recording Film." Dombrowski, Edward J.; Guarrera, Donna J.; Jones, Robert L.; Mischke, Mark R.; Warner, John C.; Yang, Jiyue. US Patent 5,750,464. May 12, **1998**.
"Thermographic Recording Films." Dombrowski, Edward J.; Jones, Robert L.; Warner, John C.; Yang, Jiyue. US Patent 5,750,463. May 12, **1998**.
"Process for Fixing an Image, and Medium for Use Therin." Marshall, John L.; Shon Baker, Rita S.; Takiff, Larry C.; Telfer, Stephen J.; Warner, John C., US Patent 5,741,630. April 21, **1998**.
"Copolymers Having Pendant Functional Thymine Groups." Grasshoff, J. Michael; Taylor, Lloyd D.; Warner, John C., US Patent 5,708,106. January 13, **1998**.
"Photographic Development" Guarrera, Donna J.; Mattucci, Neil C.; Mehta, Avinash C.; Taylor, Lloyd D.; Warner, John C. US Patent 5,705,312. January 6, **1998**.
"Photographic System" Guarrera, Donna J.; Mattucci, Neil C.; Mehta, Avinash C.; Taylor, Lloyd D.; Warner, John C. PCT Int. Appl. WO 9,729,405. August 14, **1997**.
"Method of Imaging Using a Polymeric Photoresist Having Pendant Vinylbenzyl Thymine Groups" Grasshoff, J. Michael; Taylor, Lloyd D.; Warner, John C., US Patent 5,616,451. April 1, **1997**.
"Process for Fixing an Image, and Medium for Use Therin." Marshall, John L.; Shon Baker, Rita S.; Takiff, Larry C.; Telfer, Stephen J.; Warner, John C., US Patent 5,582,956. December 10, **1996**.
"Low-Volatility, Substituted 2-Phenyl-4,6-bis[Halomethyl]-1,3,5-triazine for Lithographic Printing Plates." Fitzgerald, Maurice J.; Kearney, Frederick R.; Liang, Rong-Chang; Schwarzel, William C.; Guarrera, Donna, J.; Hardin, John M.; Warner, John C., US Patent 5,561,029. October 1, **1996**.
"Process for Fixing an Image, and Medium for Use Therin." Marshall, John L.; Shon Baker, Rita S.; Takiff, Larry C.; Telfer, Stephen J.; Warner, John C., PCT Int. Appl. WO 9,529,067. Nov 2, **1995**.
"Vinylbenzyl Thymine Monomers and Their Use in Photoresists." Grasshoff, J. Michael; Taylor, Lloyd D.; Warner, John C., US Patent 5,455,349. October 3, **1995**.
"Imaging Medium and Process." Fahrenani, Agota F.; Gaudiana, Russell A.; Kolb, Eric S.; Mehta, Parag G.; Taylor, Lloyd D.; Warner, John C., US Patent 5,424,268. June 13, **1995**.
"Thermally-Processable Image Recording Materials Including Substituted Purine Compounds."Ford, M.; Guarrera, D. J.; Mischke, M.; Pai, R.; Warner, John C., US Patent 5,411,929. May 2, **1995**.
"Copolymeric Mordants and Photographic Products and Processes Containing Same." Grasshoff, J. Michael; Taylor, Lloyd D.; Warner, John C., US Patent 5,395,731. March 7, **1995**.
"Process and Composition for Use in Photographic Materials Containing Hydroquinones. Continuation in Part." Taylor, Lloyd D.; Warner, John. C., US Patent 5,338,644. August 16, **1994**.
"Process and Composition for Use in Photographic Materials Containing Hydroquinones." Taylor, Lloyd D.; Warner, John. C., US Patent 5,177,262. January 5, **1993**.

Donna Guarrera

Noncovalent Derivatization



nanometers



EPA Approval

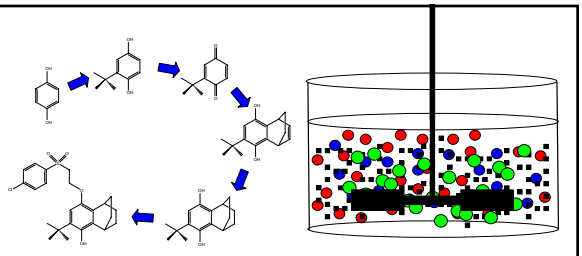
Low **V**olume **E**xemption
PreManufacturing **N**otification

Small particles?

Molecular Complexes?

Paul Anastas

Office of Pollution Prevention and Toxics



Old Technology
Several Solvents
High Energies
Hazardous Reagents

New Technology
Aqueous Conditions
Low Energies
Non-hazardous Reagents

"Reinventing Government"

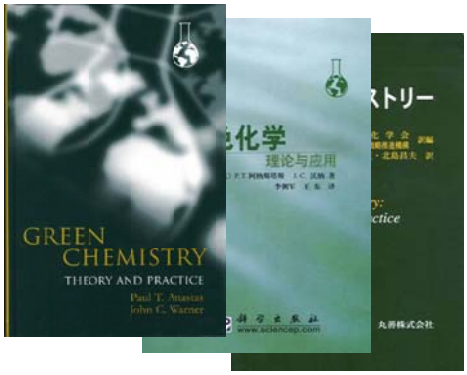
$75,000.00

EPA United States Environmental Protection Agency

Presidential Green Chemistry Challenge

	1996	1997	1998	1999	2000	
Academic	Mark Holzapple	Joseph DeSimone	Barry Trost Karen Draths John Frost	Terry Collins	Chi Hue Wong	
Small Business	Donlar Corporation	Legacy Systems	PYROCOOL Technologies	Biofine	RevTech	Ede
Alternative Synthetic Pathway	Pharmacia	BHC Company	Flexsys America	Lilly Research Laboratories	Roche Colorado	C
Alternative Solvents and Reaction Conditions	Dow	Imation	Argonne National Labs	Nalco Chemical Company	Bayer Corporation	N
Designing Safer Chemicals	Rohm and Haas	Albright and Wilson Associates	Rohm and Haas	Dow AgroSciences	Dow AgroSciences	

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.

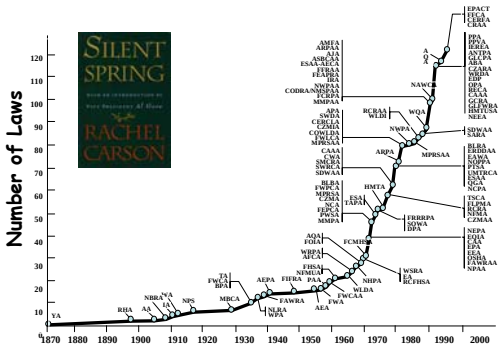
12. Inherently Safer Chemistry for Accident Prevention. Substance and the form of a substance used in a chemical process should be chosen so as to minimize the potential for chemical accidents, including releases, explosions, and fires.

Risk = Exposure x Hazard

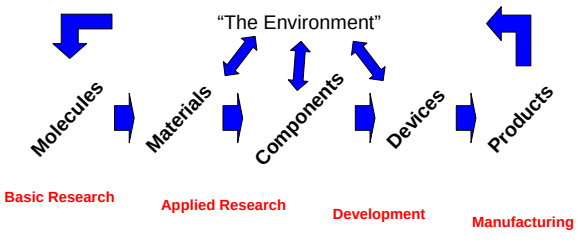
The cost of using hazardous materials:

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

Environmental Regulations



Where do products come from?



Performance

Economics

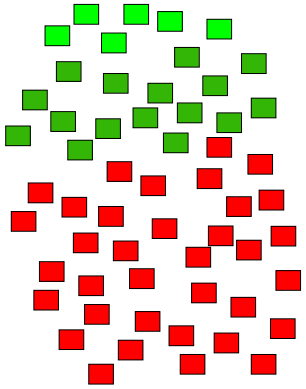
Social Implications

Of all the products and processes…

Maybe 10% are benign…

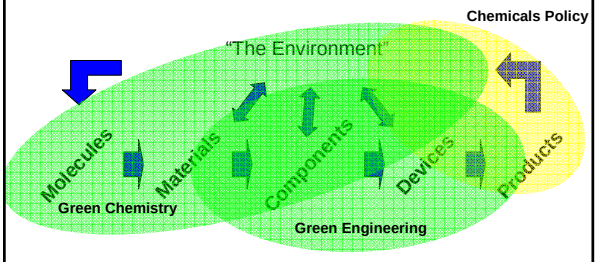
Maybe 25% more are relatively easy to do…

Who is going to invent the other 65%?



To get a PhD in Chemistry…

No universities in the United States require any demonstration of knowledge regarding toxicity or environmental impact!



Carbon-Carbon Bonds
Oxidations
Reductions
Hydroxylations
Polymer Syntheses

Traditional Processes

Traditional Processes Green Alternatives

Green Chemistry Research and Development Act of 2005

Center for Green Chemistry

NonCovalent Derivatization


Satenig Yildrim


Ben Bowers


Felix Epie


Abby Johnson


Jun Wang


Guimy Cesar


Dong Lee


Tianying Jian


Carlos Tassa

Center for Green Chemistry

Bioinspired Polymers

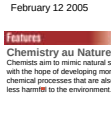
February 12 2005


Marie Flores


Minh Ngoc Nguyen


Shana Dew


Ceclia Kiarie




Hope Foudalakis


Deborah Martinez


Iyore Otabor

Center for Green Chemistry

Materials Design

Medicinal Chemistry


Rami El-Hayek


Laura Ingalls


ManChing Ku


Kei Saito


Alessandra Morelli


Justin Whitfield


Gayatri Munshi


Yelda Hangun-Balkir

Center for Green Chemistry

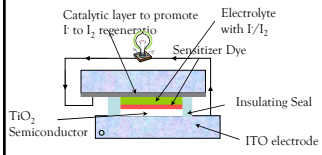
Ambient Metal Oxide Semiconductors


Sivashankari Alagusundaram


Kevin Dye


Sofia Trakhtenberg


Vineet Dua




Tim Cain


Jay Bianchini

Physical properties of a material

- State of Matter
- Color
- Melting Point
- Boiling Point
- Solubility
- Electrical Conductivity
- Toxicity
- Impact on the environment

Green Chemistry Research Group

Thank You !

UMASS Lowell

College of Engineering

School of Health and the Environment