Green Chemistry in Materials Design

John C. Warner

President and Chief Technology Officer
Warner Babcock Institute for Green Chemistry, LLC

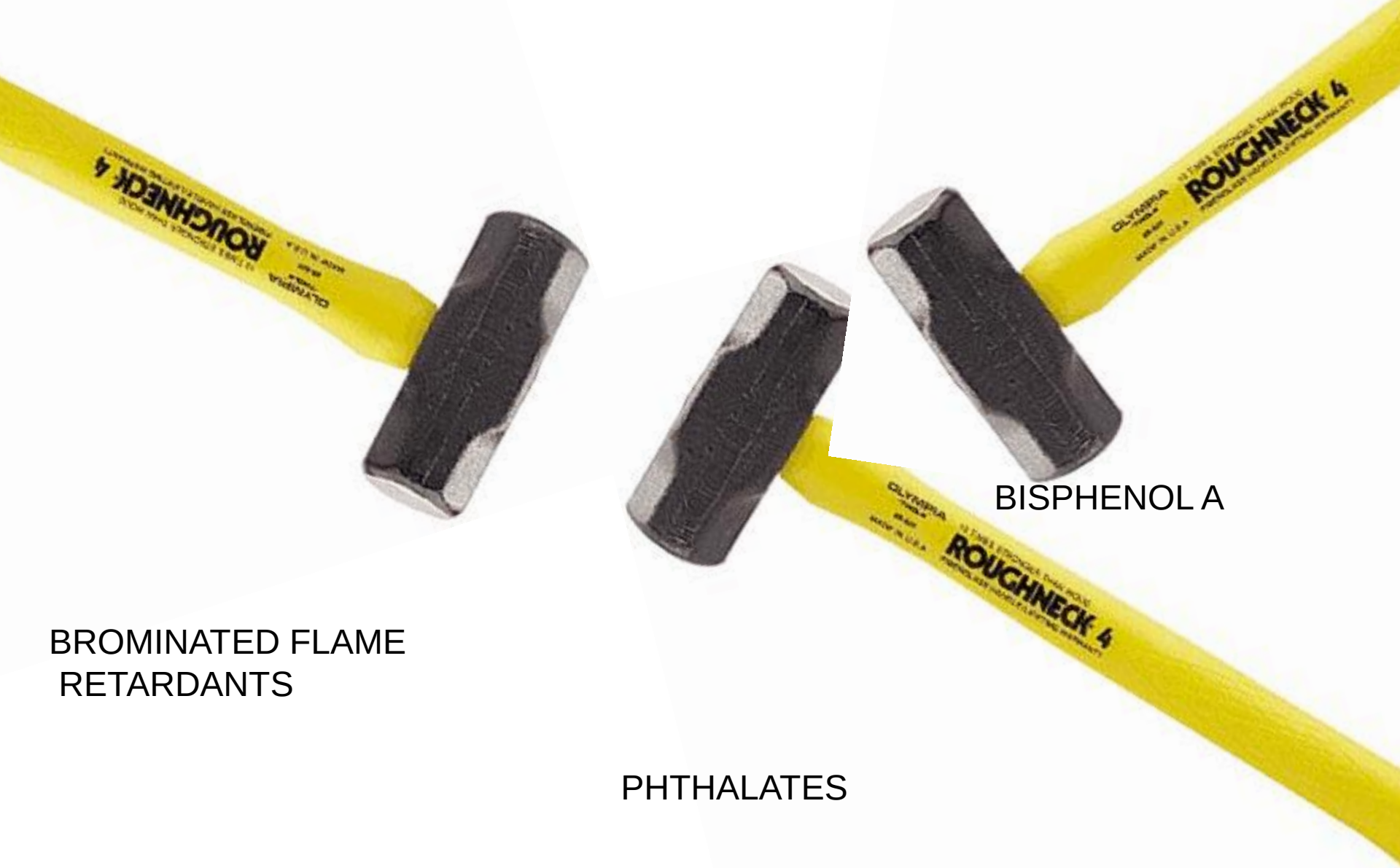
President
Beyond Benign

warnerbabcock
institute for green chemistry

beyondbenign


BBC NEWS
Babie
The Wa
EPA Is Reconsidering
ton Post
hemical
The New York Times
Child obesity is link
to chemicals in plastic
TIME
The Poisoning of America
The Japan Times
Oceans awash in toxic seas of plastic
THE WALL STREET JOURNAL.
Yes, Bisphenol-A Does Enter the Body from Plastic Bottles
CNN.com
erious contaminati
from Africa's m
USA TODAY
5,000 evacuated after
hazardous Pa. acid spill
Chicago Tribune
Chicago's Toxic Air
THE SUNDAY TIMES
Household Dust Contains Highly Toxic Chemicals


WHACK A MOLE!



BISPHENOL A

BROMINATED FLAME
RETARDANTS

PHTHALATES


Despair

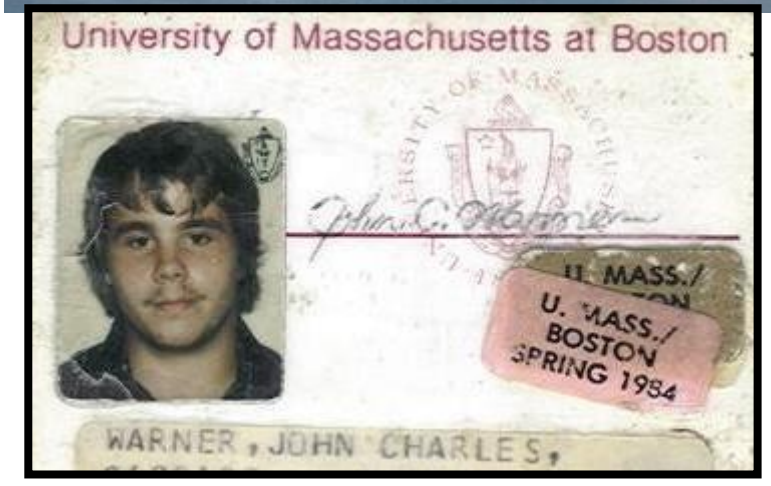
Asking the Right Questions

Why would a chemist make a hazardous material?

How do we train chemists?

Becoming a Chemist…

UMASS Boston – 1980-1984



THE ELEMENTS

Professor J.-P. Anselme

"N-Nitrosamines from the Reaction of N-Chlorodialkylamines with Sodium Nitrite." Nakajima, M.; Warner, J. C.; Anselme, J.-P. *J. Chem. Soc., Chem. Commun.,* **1984**, 451.

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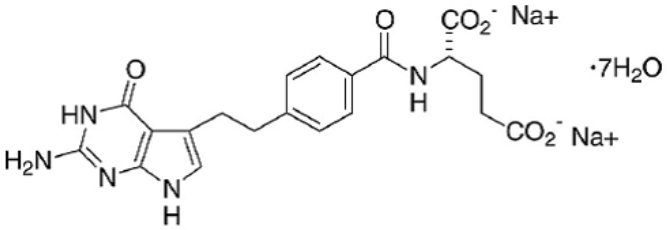
"The Wittig Reaction in the Undergraduate Organic Laboratory." Warner, J. C.; Anastas, P. T.; Anselme, J.-P. *J. Chem. Ed.*, **1985**, *62*, 346.

"Benzoyl Phenyl 1-Methylpyrazoles. Synthesis, Characterization, and Spectra." Kano, K.; Scarpetti, D.; Warner, J. C.; Anselme, J.-P.; Springer, J. P.; Arison, B. H. *Can. J. Chem.*, **1986**, *64*, 2211.

Princeton University – 1984-1988



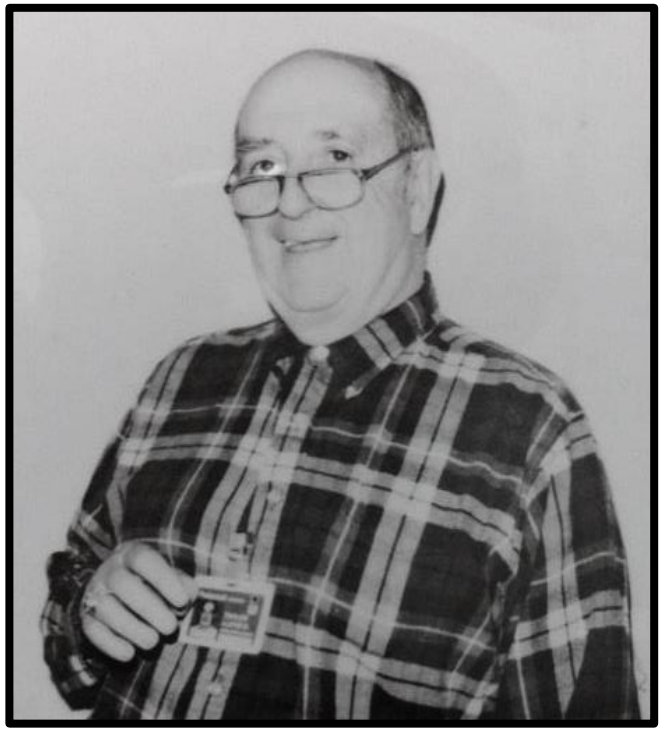
Professor E. C. Taylor

Natalie Warner
[1932 – 2002]

John A. Warner
[1930 – 1988]

Polaroid Corporation – 1988-1997

Edwin Land



Lloyd D. Taylor

For over 180 years of "Modern Chemistry"…

But Nature…

Heat things under high temperature

Runs reactions at "room" temperature

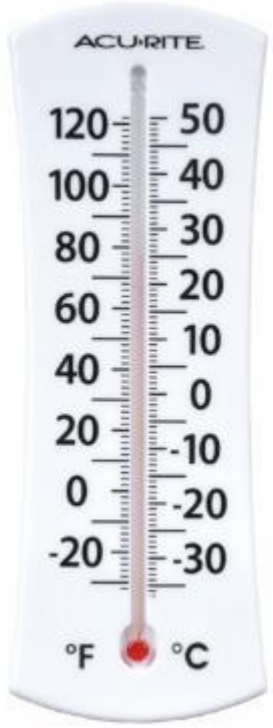
Apply high pressures

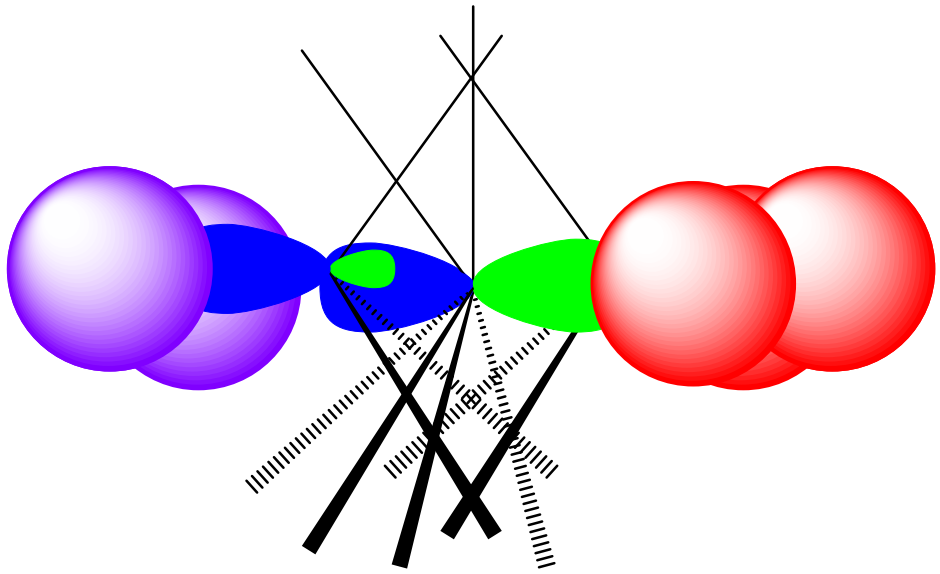
Runs reactions at ambient pressure

Use organic solvents

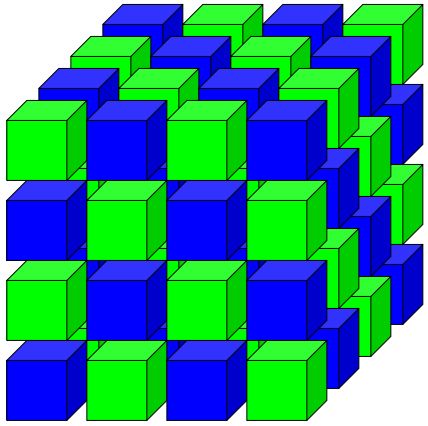
Uses water as a solvent

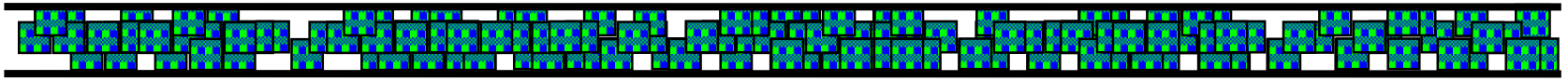
A thermometer is a molecular speedometer…





Non Covalent Derivatization





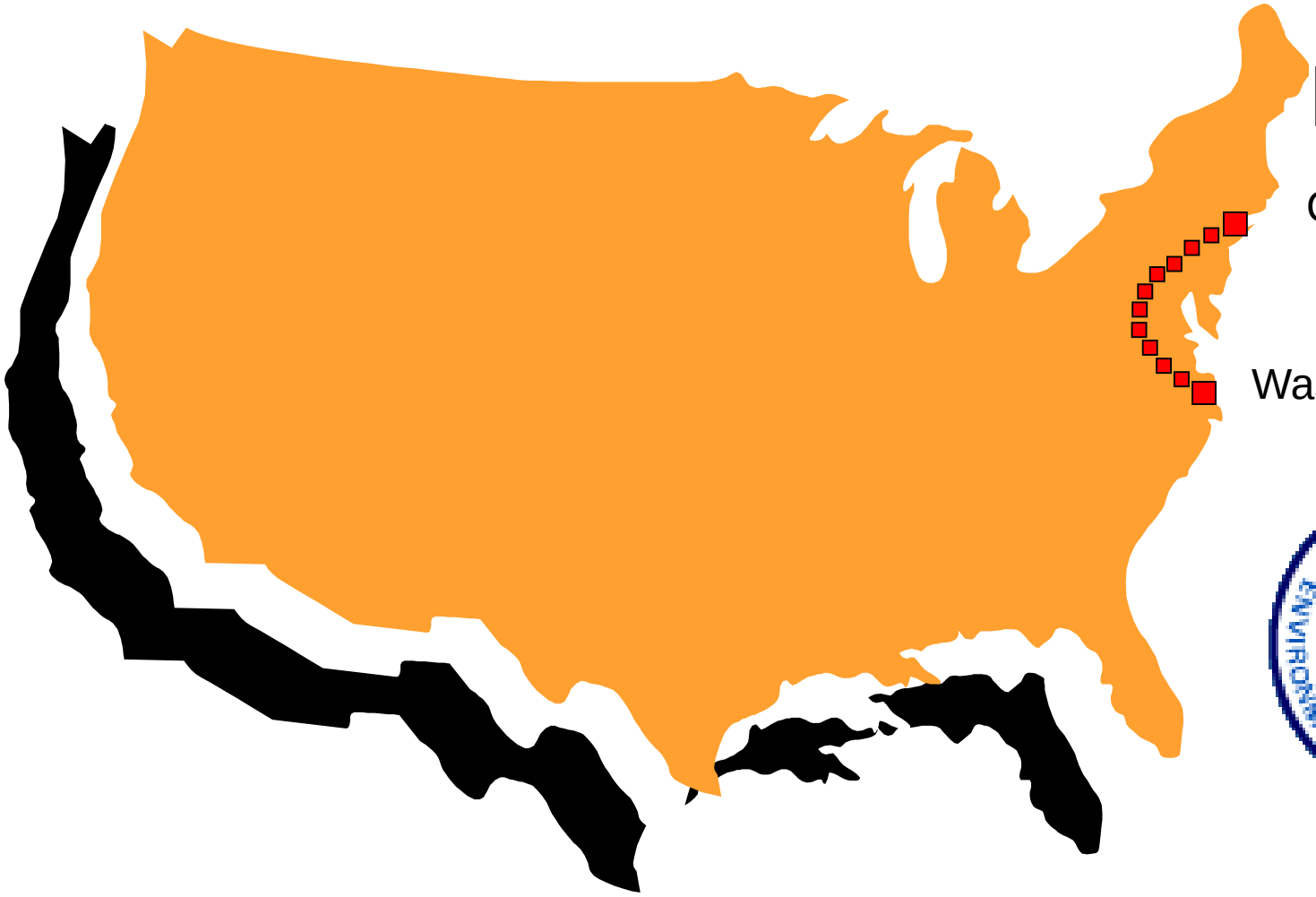
EPA Approval

Low **V**olume **E**xemption

Pre**M**anufacturing **N**otification

"Small particles"?

"Molecular Complexes"?



Polaroid

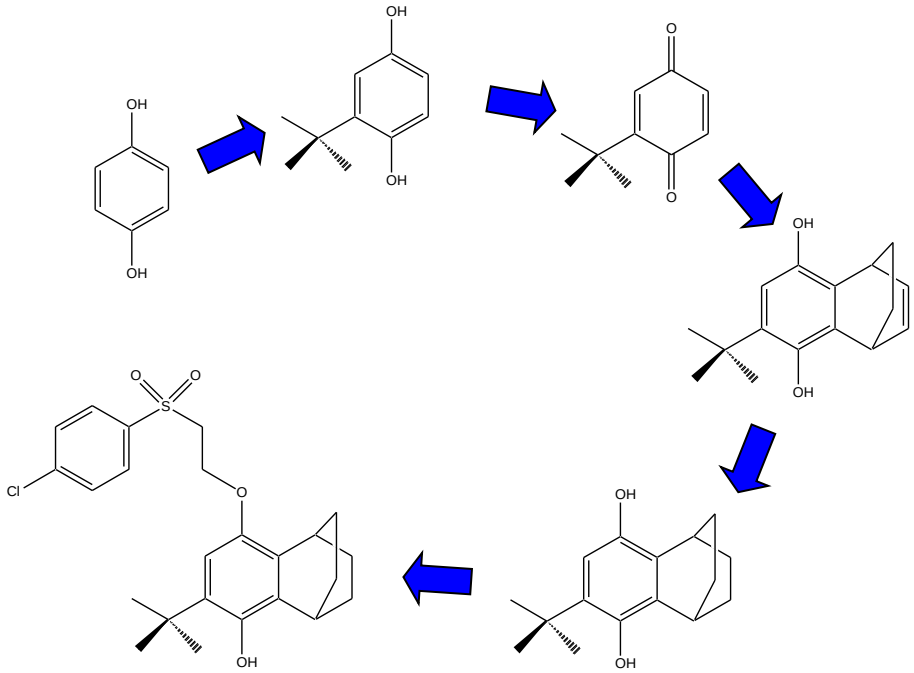
Cambridge, MA

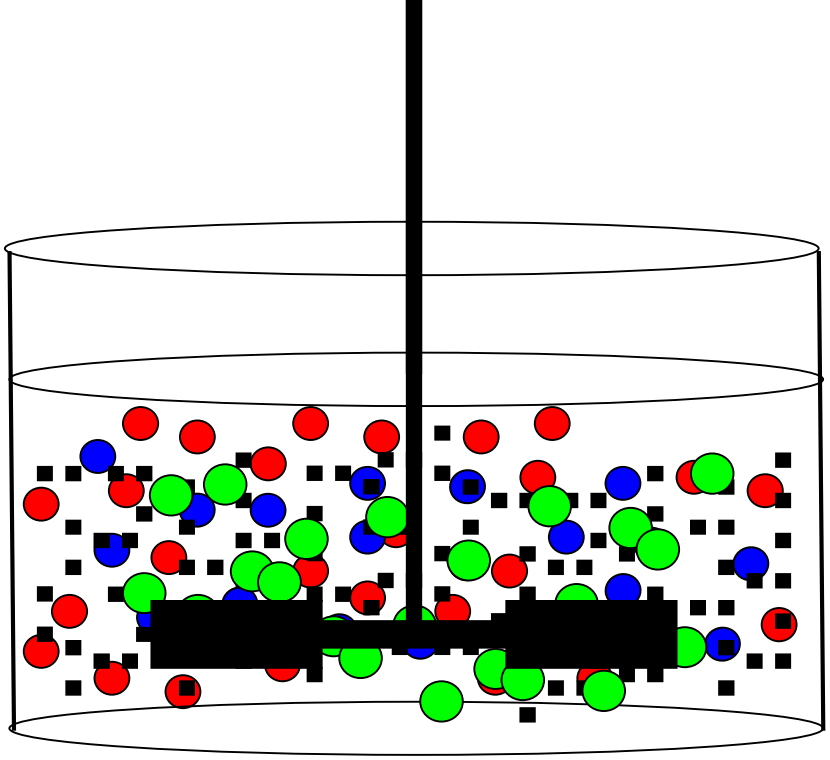
Washington, DC

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Paul Anastas

Office of Pollution Prevention and Toxics

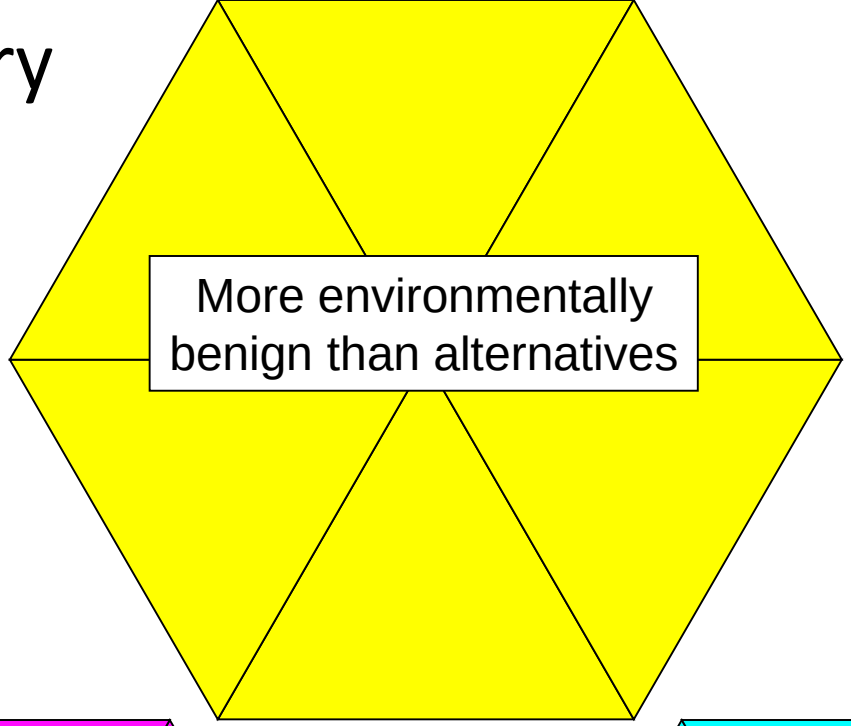


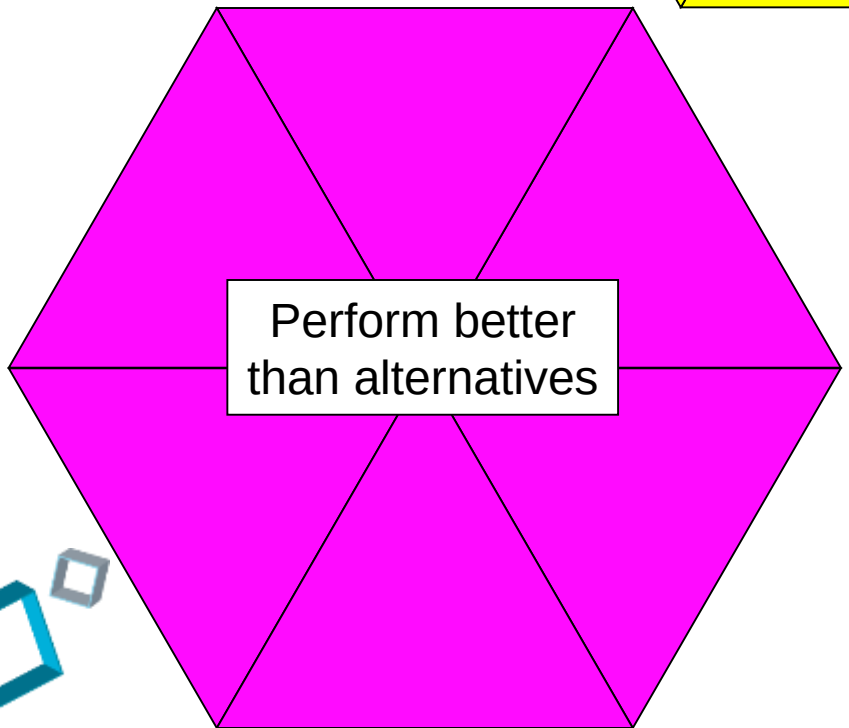


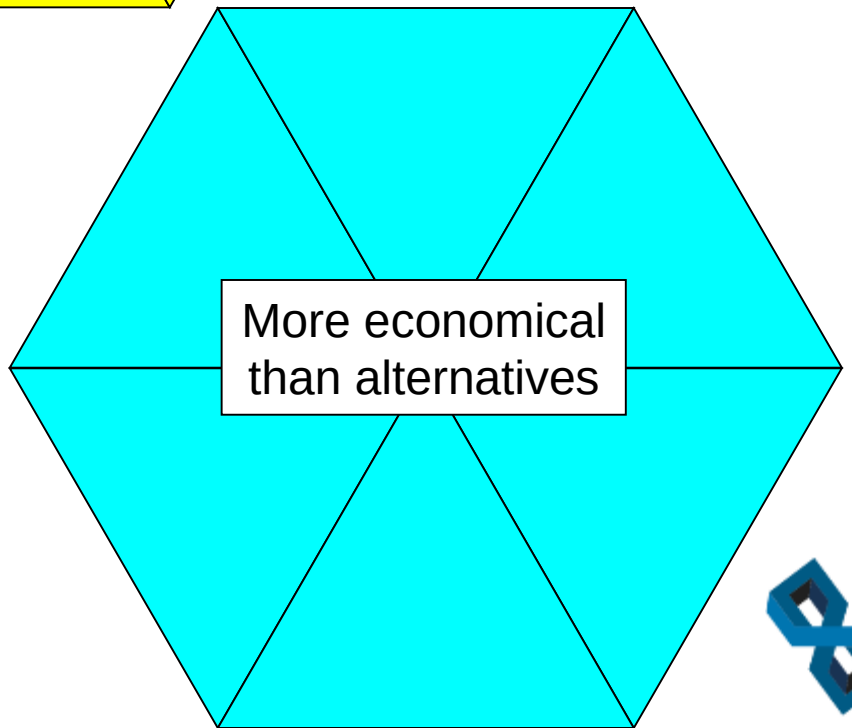
Old Technology
Several Solvents
High Energies
Hazardous Reagents

New Technology
Aqueous Conditions
Low Energies
Non-hazardous Reagents

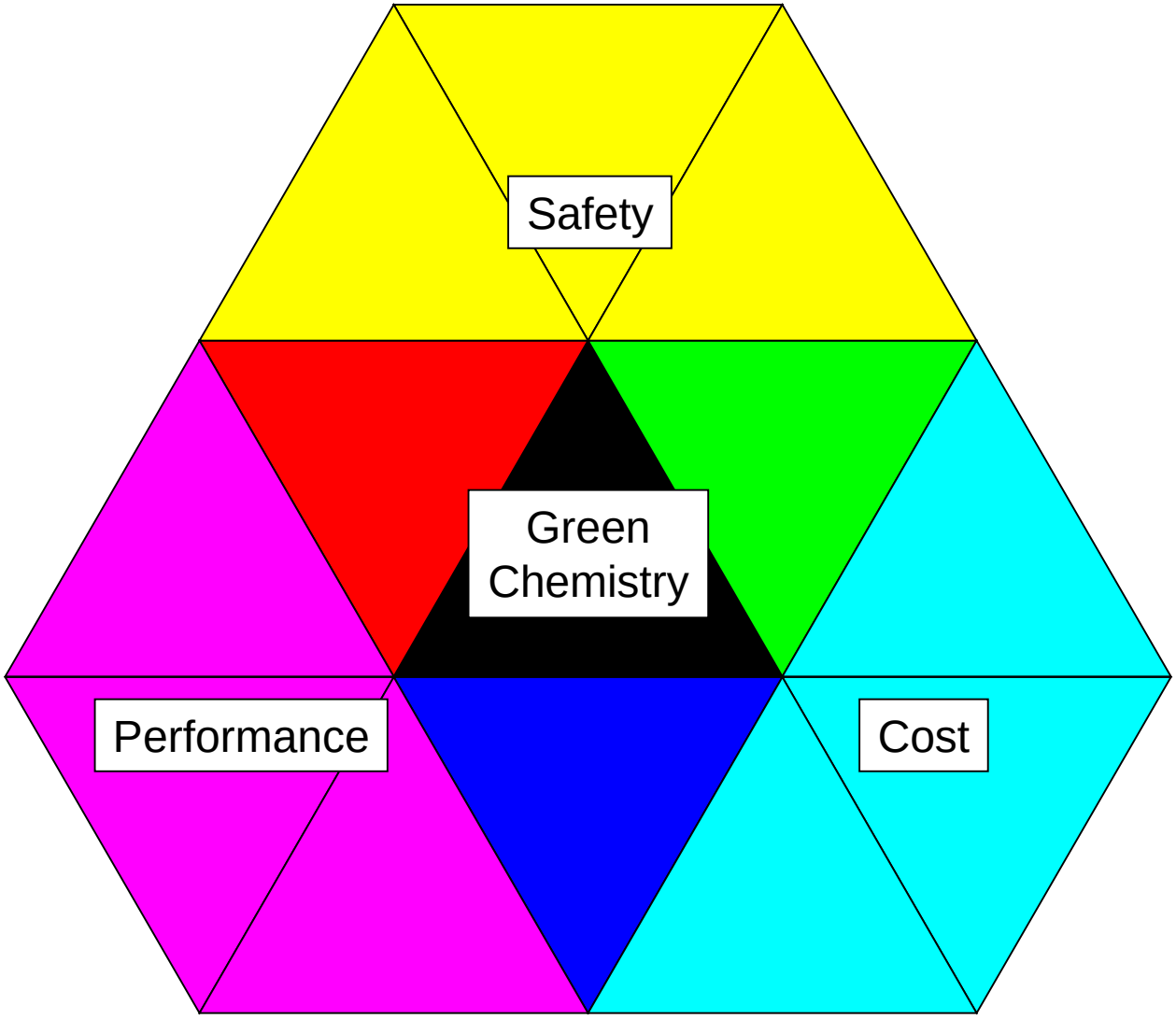
Green Chemistry







Green Chemistry



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.

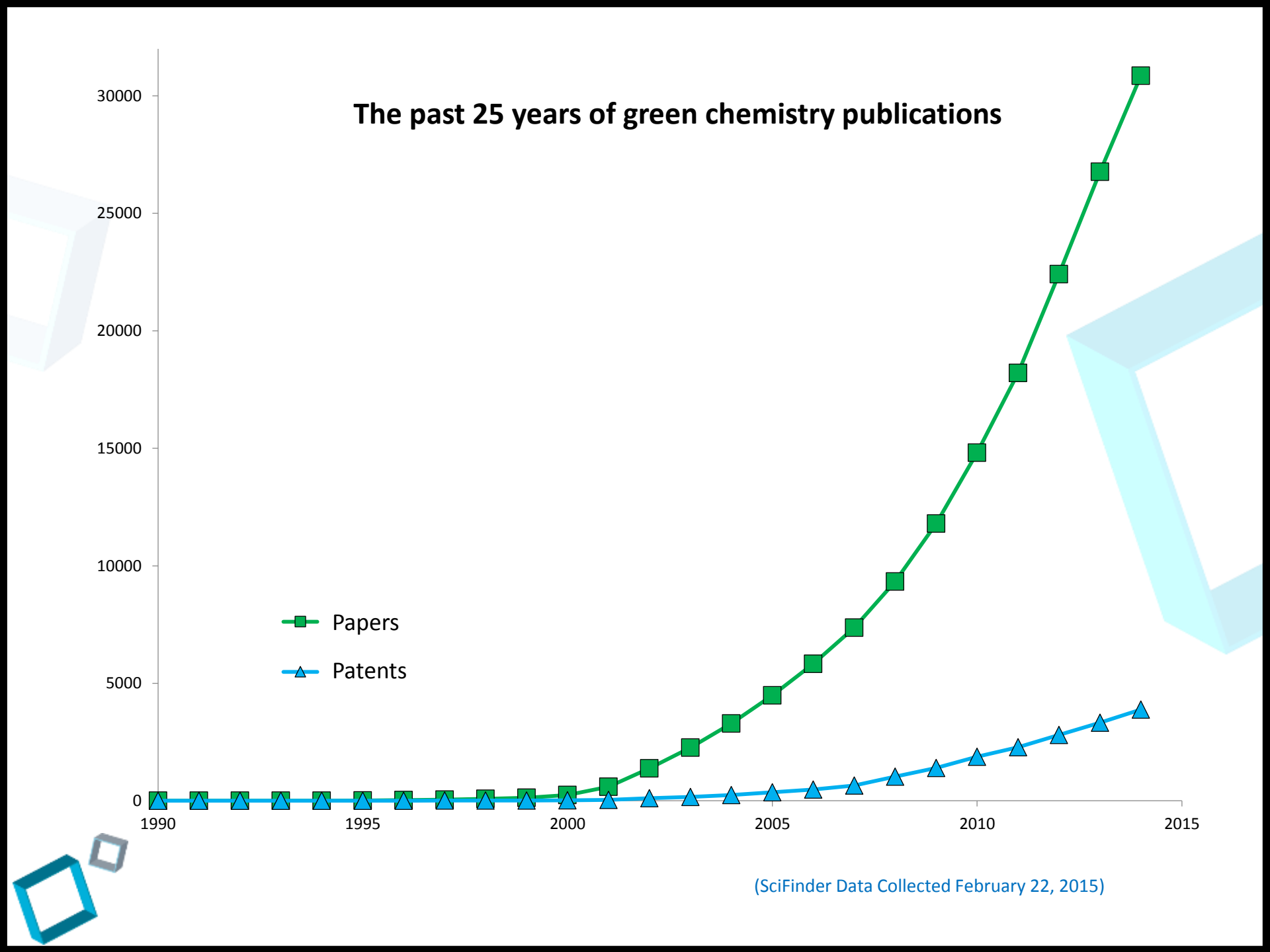
8. Reduce Derivatives. Unnecessary derivatization (blocking group, protection/deprotection, temporary modification of physical/chemical processes) should be avoided whenever possible .

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.



(SciFinder Data Collected February 22, 2015)

Polaroid

1988-1997

Lloyd Taylor

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"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**.
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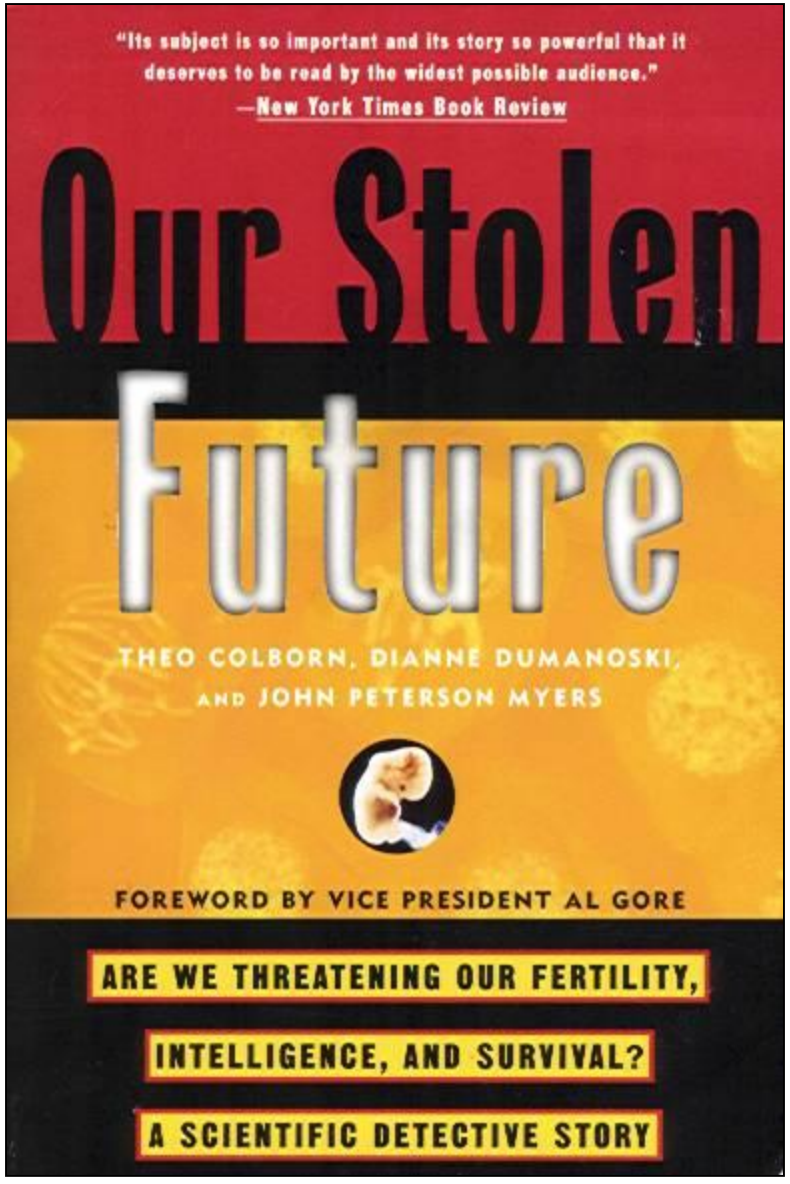
"Imaging Medium and Process." Fehervari, Agota F.; Gaudiana, Russell A.; Kolb, Eric S.; Mehta, Parag G.; Taylor, Lloyd D.; Warner, John C., US Patent 5,424,268. June 13, **1995**.
"Thermally-Processable Image Recording Materials Including Substituted Purine Compounds."Ford, M.; Guarrera, D. J.; Mischke, 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**.

John Patrick Warner

[Nov 12, 1991- Mar 20 1993]



I have synthesized over 2500 compounds!!!!!

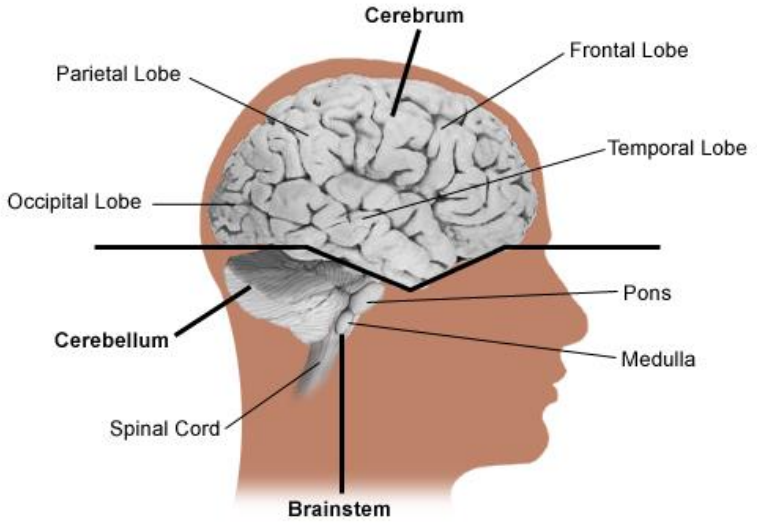
I have synthesized over 2500 compounds!

I have never been taught what makes a chemical toxic!
I have no idea what makes a chemical an environmental hazard!

I have synthesized over 2500 compounds!

I HAVE NO IDEA WHAT MAKES A CHEMICAL TOXIC!

STANFORD
CANCER CENTER
Stanford Hospital & Clinics



What causes brain tumors?

The majority of brain tumors have abnormalities of genes involved in cell cycle control, causing uncontrolled cell growth. These abnormalities are caused by alterations directly in the genes, or by chromosome rearrangements which change the function of a gene.

Patients with certain genetic conditions (i.e., neurofibromatosis, von Hippel-Lindau disease, Li-Fraumeni syndrome, and retinoblastoma) also have an increased risk to develop tumors of the central nervous system. There have also been some reports of people in the same family developing brain tumors who do not have any of these genetic syndromes.

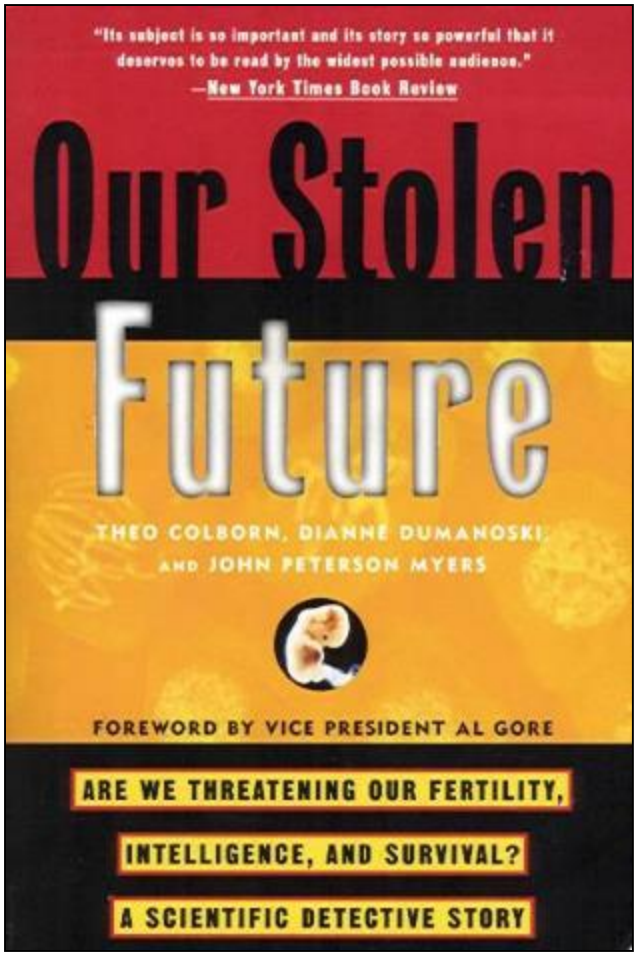
Research has been investigating parents of children with brain tumors and their past exposure to certain chemicals. Some chemicals may change the structure of a gene that protects the body from diseases and cancer. **Workers in oil refining, rubber manufacturing, and chemists have a higher incidence of certain types of tumors.** Which, if any, chemical toxin is related to this increase in tumors is unknown at this time.

http://cancer.stanfordhospital.com/healthInfo/cancerTypes/brain/default

Women's Health Information

Recent scientific research has clearly demonstrated an association between organochlorines and breast cancer. An analysis of chemical plant workers in Hamburg, Germany discovered a two-fold increase in breast cancer among the women workers who had been exposed to dioxin contamination. Significantly higher levels of breast cancer have been found in separate studies of women living near organochlorine chemical plants in Minnesota and Long Island. **Other studies have revealed elevated breast cancer mortality among professional chemists.**

http://www.fwhc.org/health/xeno.htm



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Walrath, J., F. P. Li, et al. (1985). "**Causes of death among female chemists**." Am J Public Health 75(8): 883-5.

Christie, D., K. Robinson, et al. (1991). "**A prospective study in the Australian petroleum industry. II. Incidence of cancer**." Br J Ind Med 48(8): 511-4.

Persson, B., M. Fredriksson, et al. (1993). "**Some occupational exposures as risk factors for malignant lymphomas**." Cancer 72(5): 1773-8.

Berlin, K., C. Edling, et al. (1995). "**Cancer incidence and mortality of patients with suspected solvent- related disorders**." Scand J Work Environ Health 21(5): 362-7.

Persson, B. (1996). "**Occupational exposure and malignant lymphoma**." Int J Occup Med Environ Health 9(4): 309-21.

Lynge, E., A. Anttila, et al. (1997). "**Organic solvents and cancer (review).**" Cancer Causes Control 8(3): 406-19.

Every Year: (United States)

Chemistry and Chemical Engineering Graduates

15,000 Undergraduate Degrees

3,000 Masters Degrees

3,000 Doctoral Degrees

50.9 % Women Undergraduate Degrees (2004)

To get a degree in Chemistry…

No universities require any demonstration of knowledge regarding toxicity or environmental impact!

UMASS – 1996-2007

1997 Assistant Professor
1998 Associate Professor (Tenure)
1999 Director of Biochemistry
2000 Full Professor
2001 Chair Chemistry Department
2001 Director Green Chemistry PhD Program
2004 Professor Plastics Engineering (UML)

PHOTO BY ROB SHERMAN

INCUBATOR The University of Massachusetts, Boston, houses the first Ph.D. program in green chemistry.

GREEN CHEMISTRY EARNS A PH.D.

The University of Massachusetts, Boston, now offers a Ph.D. track in green chemistry

SINCE LAST FALL, THE UNIVERSITY of Massachusetts, Boston (UMB), has been accepting students into a new program called the green chemistry Ph.D. track. It is offered by the department of environmental sciences but administered by the department of chemistry.

The first of its kind in the world, the program is the brainchild of its director, UMB chemistry professor John C. Warner. Students in the program, he explains, will be trained much like other Ph.D. chemistry students, although their education will emphasize skills to design materials and processes that have minimal impact on human health and the environment. Areas of concentration include environmentally benign synthesis, environmental monitoring and detection, biodegradation, and bioremediation.

What makes the program different from anything else available so far, Warner says, is the requirement of courses in toxicology, environmental law and policy, environmental fate and transport, and industrial chemistry. Through these courses, he explains, "we broaden the students' understanding of environmental realities—such as what makes a molecule toxic, what laws have been established to govern synthetic procedures, and what happens in the environment—which conventional chemistry programs don't teach."

Terrence J. Collins, a chemistry professor at Carnegie Mellon University, notes that "we do not live in a sustainable civilization, sustainability meaning that what we do every day can be carried on to the indefinite future without causing damage." Collins was a recipient of the 1999 Presidential Green Chemistry Challenge Academic Award. The UMB program, he tells C&EN, is one way to call attention to the fact that "a sustainable civilization needs the intimate engagement of chemistry."

The UMB program "is timely, as there has been a distinct shift in focus in chemistry," says Janet Scott, deputy director of the Centre for Green Chemistry at Monash University, in Australia. "Even those who might not consider themselves 'green chemists' are beginning to focus on issues of sustainability and the design of benign products and processes to prevent pollution at the source. The chemical industry is beginning to demand a wider knowledge of and attention to issues of sustainability."

Mary Kirchhoff, assistant director of the Green Chemistry Institute, in Washington, D.C., agrees that the time is right for a green chemistry Ph.D. program. It might have been met with skepticism 10 years ago, when the term "green chemistry" first surfaced, she tells C&EN. Warner is the ideal person to lead such a program, she adds. "He's got the research credentials, the teaching credentials, the commitment to students, and the passion."

Particularly in organic synthesis, formal green chemistry training will force chemists to change how they think.

"One of the things that makes organic synthesis so exciting is that, if you draw a molecule, there are probably an infinite number of synthetic pathways that you can follow to make that molecule," Warner says. Traditionally, the focus has been on maximizing yields and stereoselectivities. Considerations of environmental and toxicological impact rarely come into play.

"IF ONE STEP in a synthetic sequence requires a hazardous reagent that's regulated by the federal government, that sequence could be more expensive than an alternative route that might give less yield," Warner explains. Regulatory and environmental realities often decide the economic viability of a synthetic route, he adds.

Chemists usually learn of such considerations when they're working for a company, Warner says. "Industry would like people to come in with some understanding of these issues, because there's economic benefit if processes designed in labs do not have to be reworked to satisfy regulatory requirements."

A green chemistry Ph.D. would be a big plus for chemists interested in process development, notes Berkeley Cue, vice president of pharmaceutical sciences at Pfizer Global Research & Development, Groton, Conn. "What we try to incorporate into the design of manufacturing processes—such as safety, efficient use of raw materials, minimal use of solvents, and online analysis—are aligned to the concepts that Warner and people like him are teaching," he explains. "We just didn't call it green chemistry. We called it process development."

Amy Cannon is the first student enrolled in UMB's green chemistry Ph.D. program. She's working on constructing solar energy devices in a more environmentally benign manner. Currently, she explains, producing solar cells consumes so much energy that a solar panel has to operate for years before it generates as much energy as was used to make it.

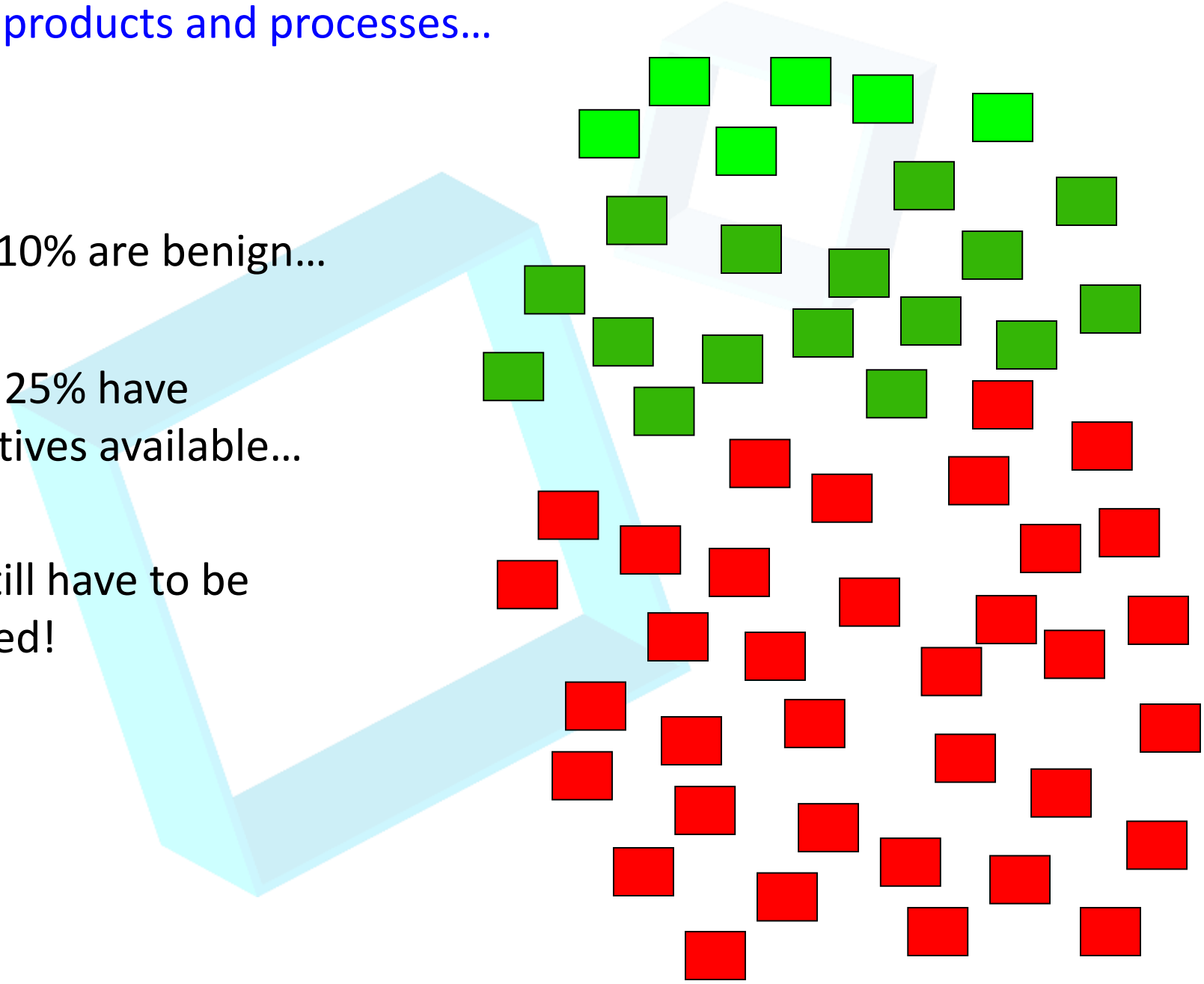
"Alternative energy is one of the most important areas in terms of sustainability," Cannon tells C&EN. Having just completed her master's degree under Warner's guidance, Cannon is passionate about green chemistry. "What could be better than this," she asks, "given that my big goal in life is to help save the world by doing what I can where I am?"—MAUREEN ROUHI

Of all the products and processes…

Maybe 10% are benign…

Maybe 25% have alternatives available…

65% Still have to be invented!



How does Green Chemistry fit into the big picture of Sustainability.

United States
Environmental Protection Agency

Learn the Issues | Science & Technology | Laws & Regulations | About EPA

Green Chemistry

Basics of Green Chemistry

On this page:

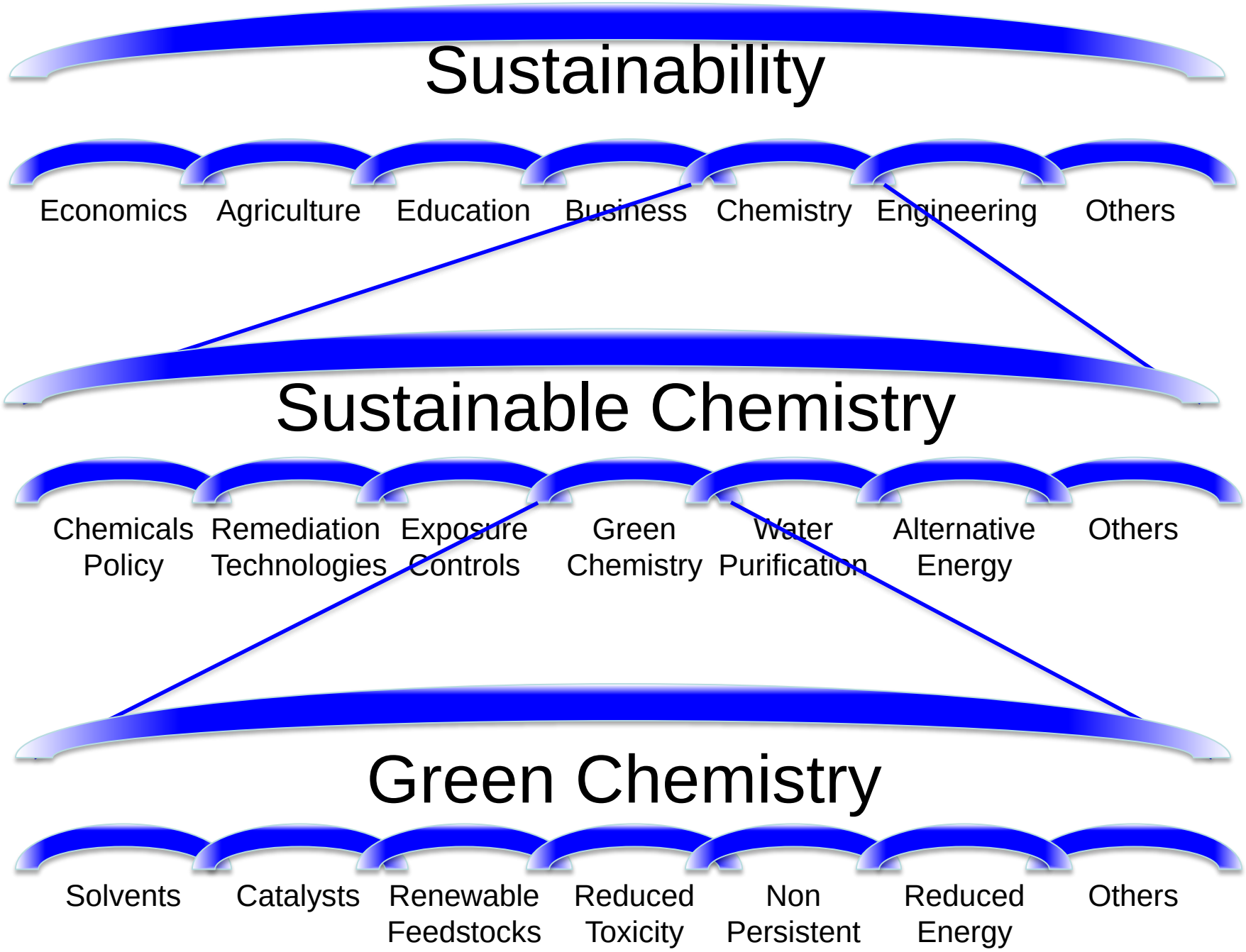
- Definition of green chemistry
- How green ch
- Green chemis
- Twelve princi
- Green chemis

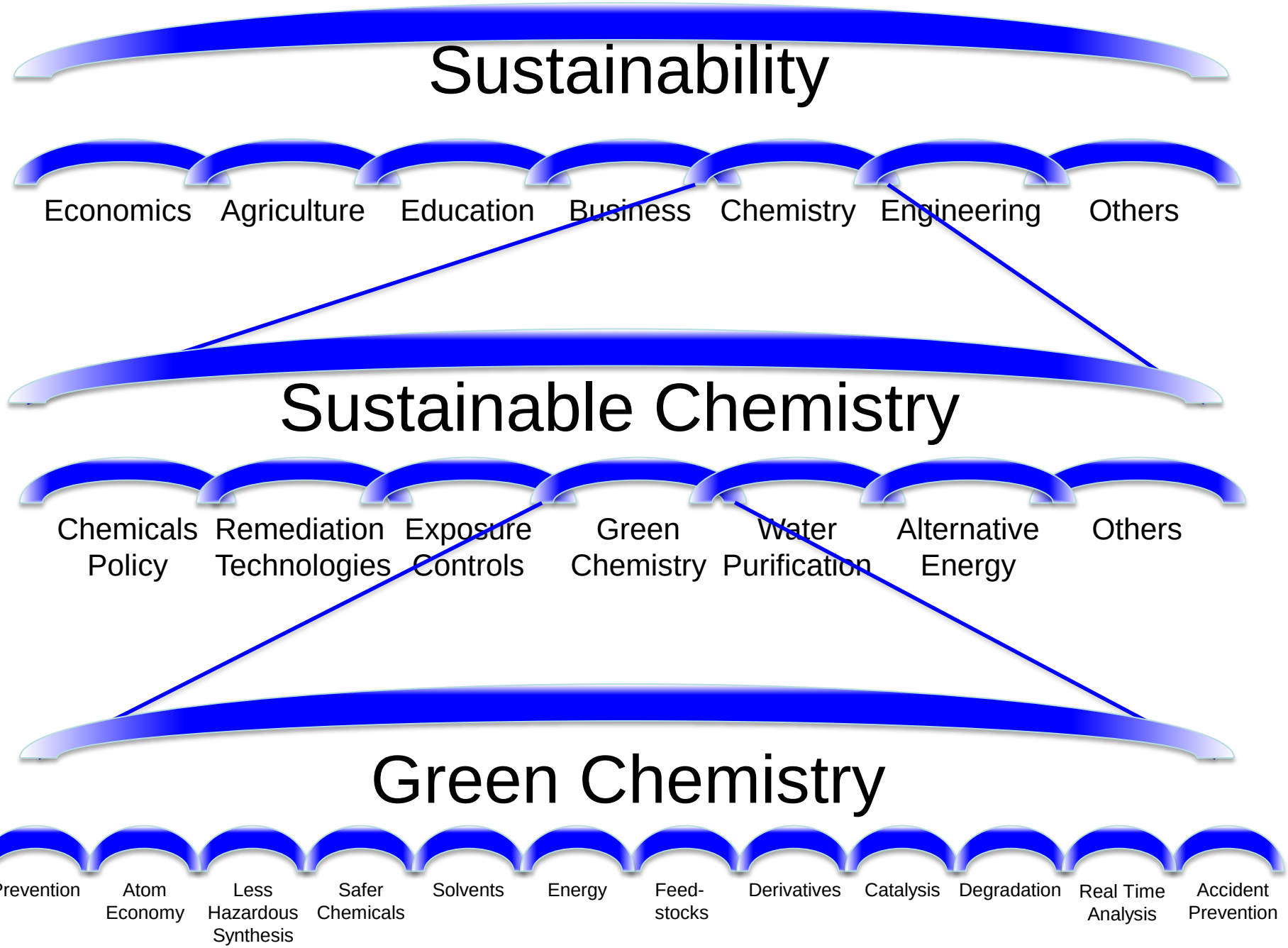
Green Chemistry is also known as sustainable chemistry.

Definition of green chemistry

Green chemistry is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances. Green chemistry applies across the life cycle of a chemical product, including its design, manufacture, use, and ultimate disposal. Green chemistry is also known as sustainable chemistry.

Green chemistry:


Sustainability
Economics
Agriculture
Education
Business
Chemistry
Engineering
Others
Sustainable Chemistry
Chemicals Policy
Remediation Technologies
Exposure Controls
Green Chemistry
Water Purification
Alternative Energy
Others
Green Chemistry
Solvents
Catalysts
Renewable Feedstocks
Reduced Toxicity
Non Persistent
Reduced Energy
Others


Sustainability
Economics
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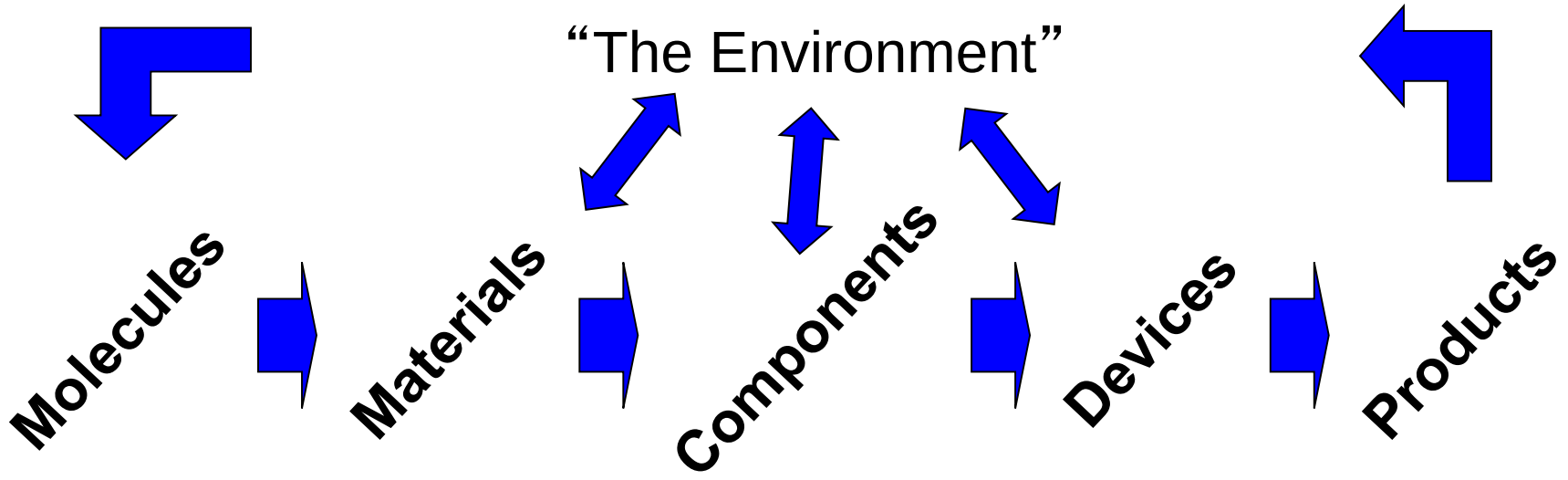
Sustainable Chemistry
Chemicals Policy
Remediation Technologies
Exposure Controls
Green Chemistry
Water Purification
Alternative Energy
Others
Green Chemistry
Prevention
Atom Economy
Less Hazardous Synthesis
Safer Chemicals
Solvents
Energy
Feed-stocks
Derivatives
Catalysis
Degradation
Real Time Analysis
Accident Prevention

Where do products come from?



Basic Research

Applied Research

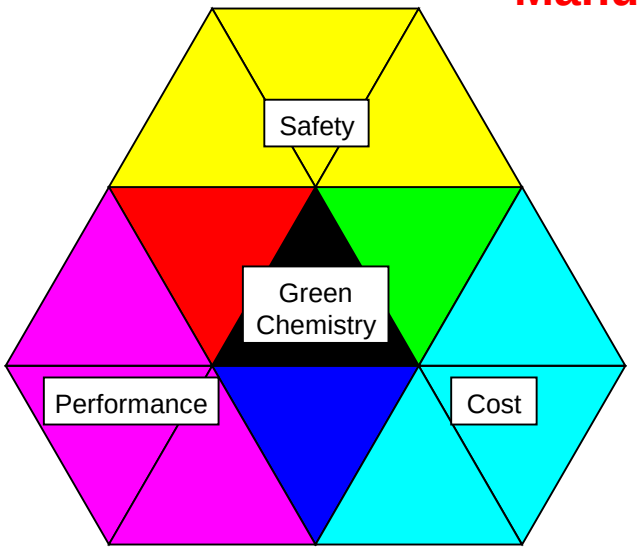
Development

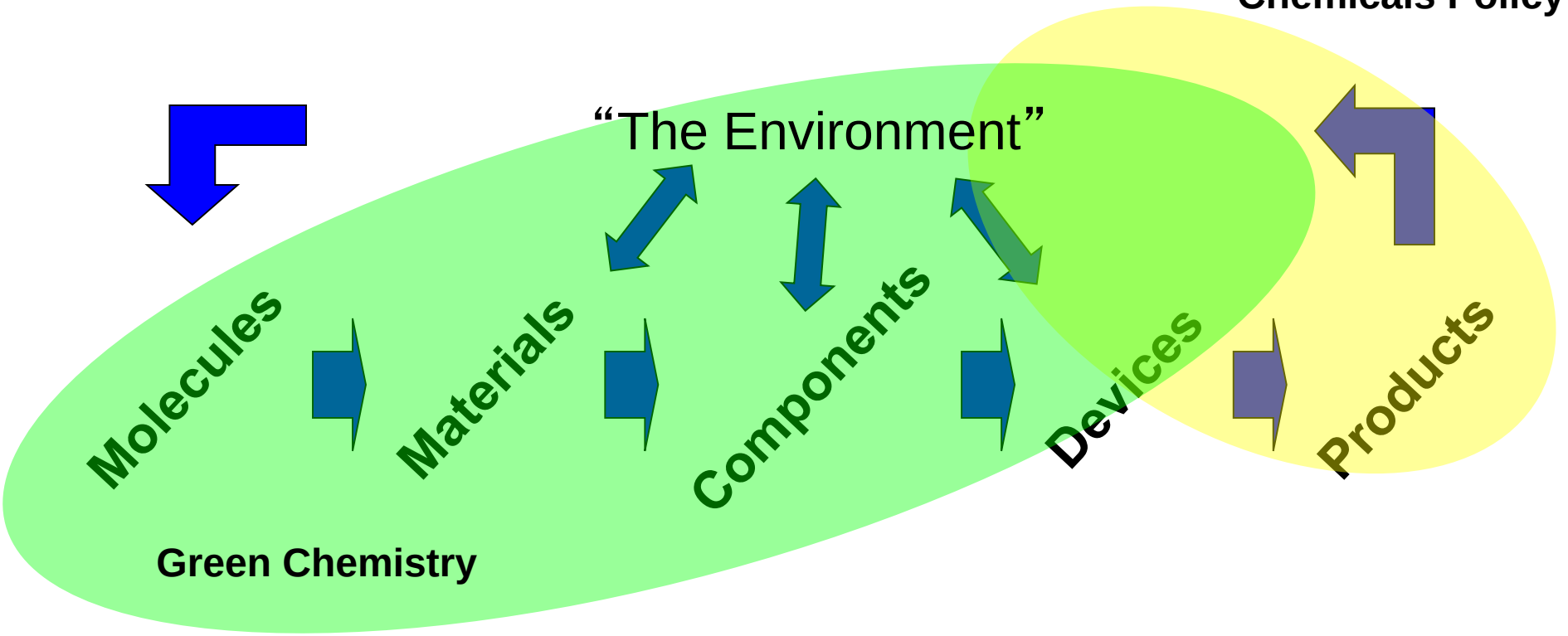
Manufacturing

Performance

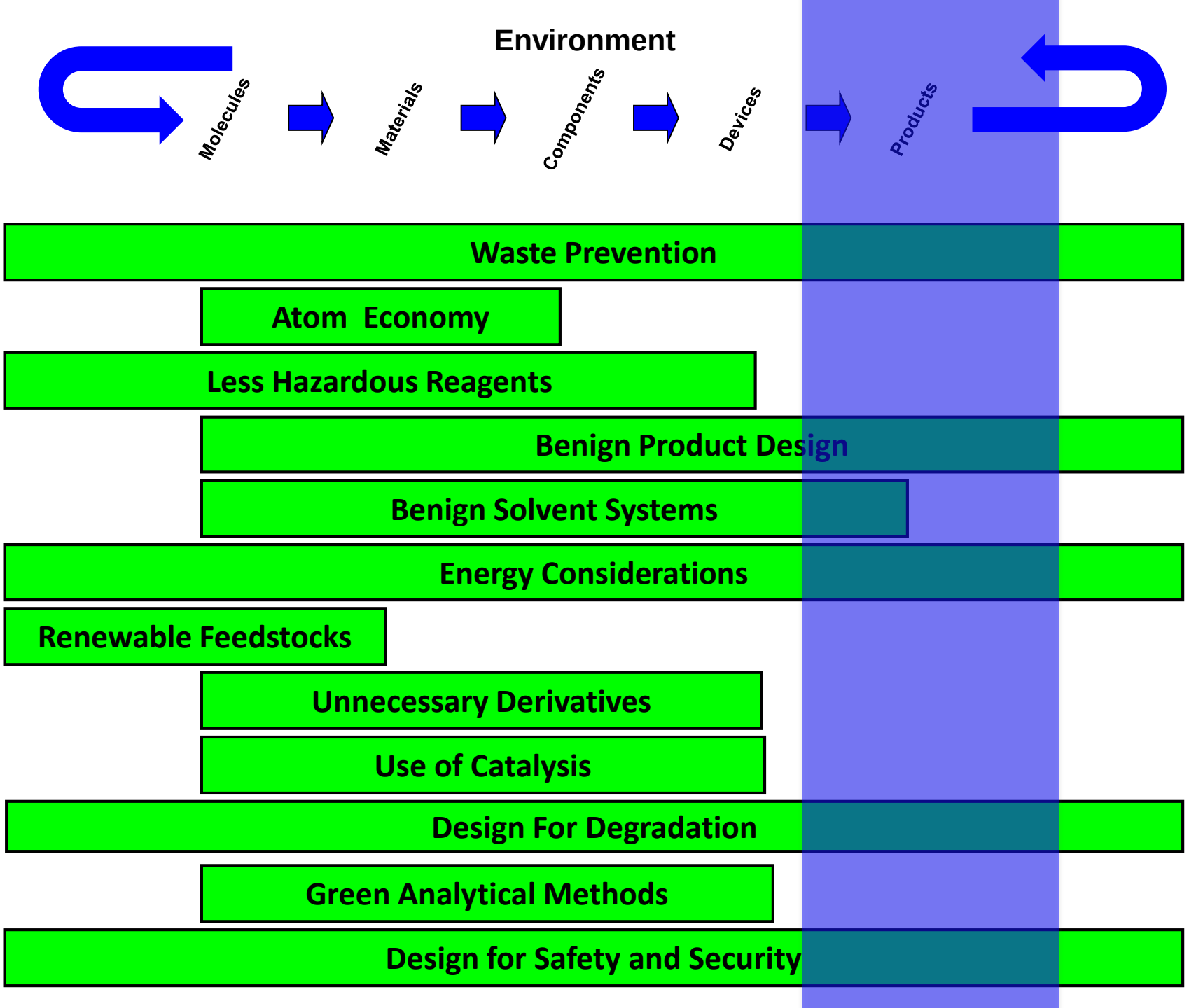
Economics

Social Implications




Chemicals Policy
"The Environment"
Molecules
Materials
Components
Devices
Products
Green Chemistry

How does Green Chemistry relate to Life Cycle Analyses?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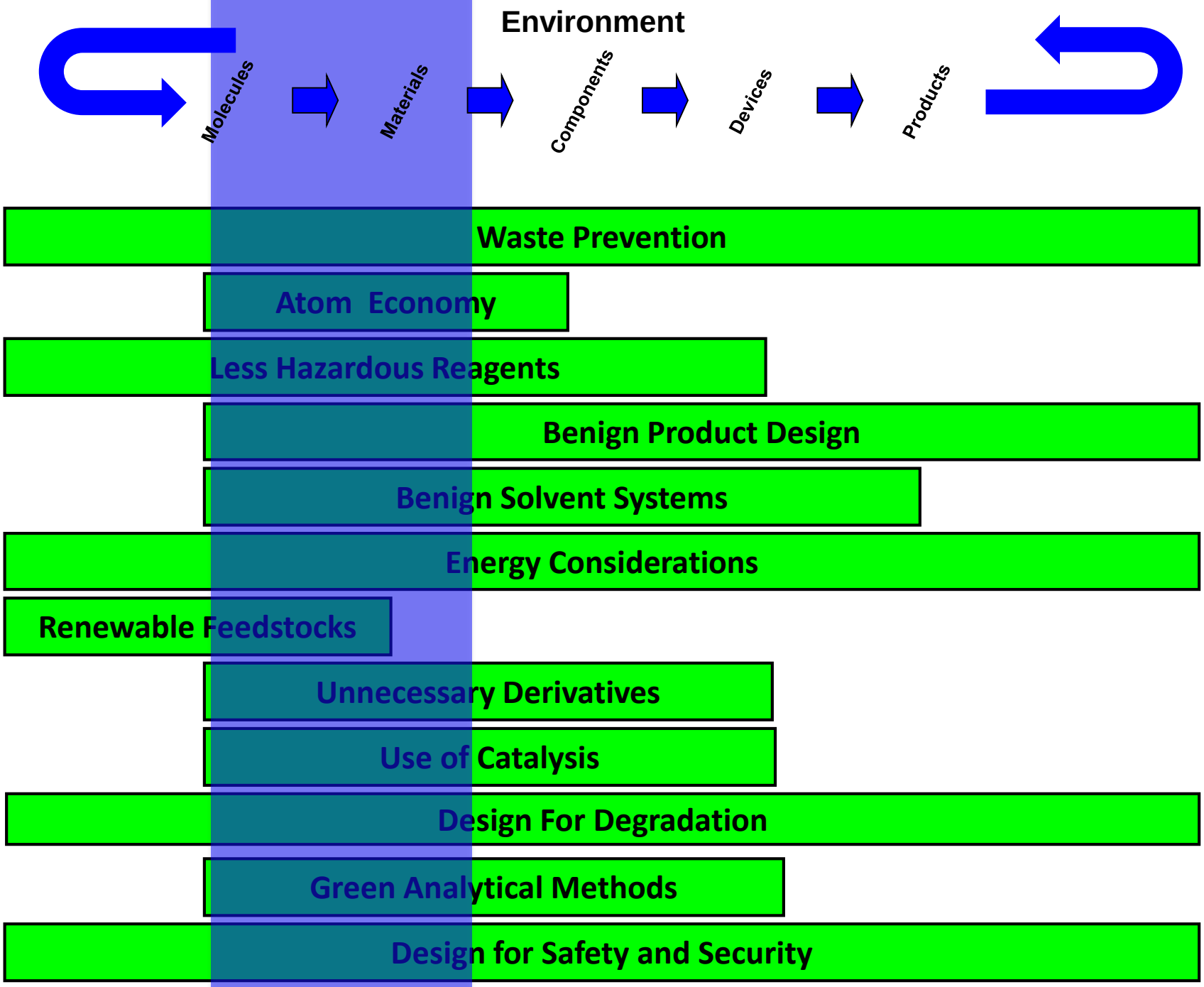
Materials
Components
Devices
Products
Waste Prevention
Atom Economy
Less Hazardous Reagents
Benign Product Design
Benign Solvent Systems
Energy Considerations
Renewable Feedstocks
Unnecessary Derivatives
Use of Catalysis
Design For Degradation
Green Analytical Methods
Design for Safety and Security


Environment
Molecules
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Atom Economy
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Benign Product Design
Benign Solvent Systems
Energy Considerations
Renewable Feedstocks
Unnecessary Derivatives
Use of Catalysis
Design For Degradation
Green Analytical Methods
Design for Safety and Security

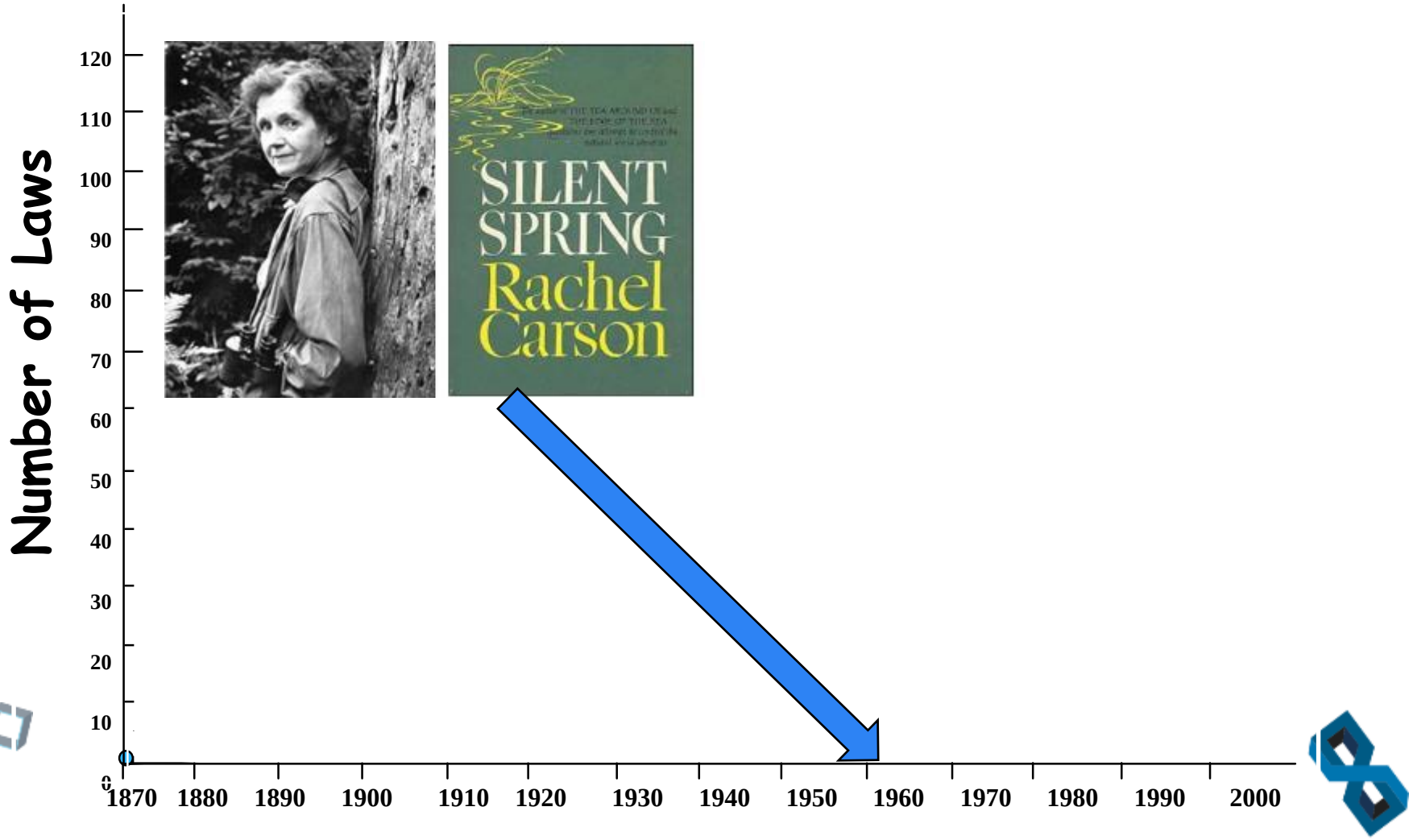
Chemists have ALWAYS cared about Human Health and the Environment.

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

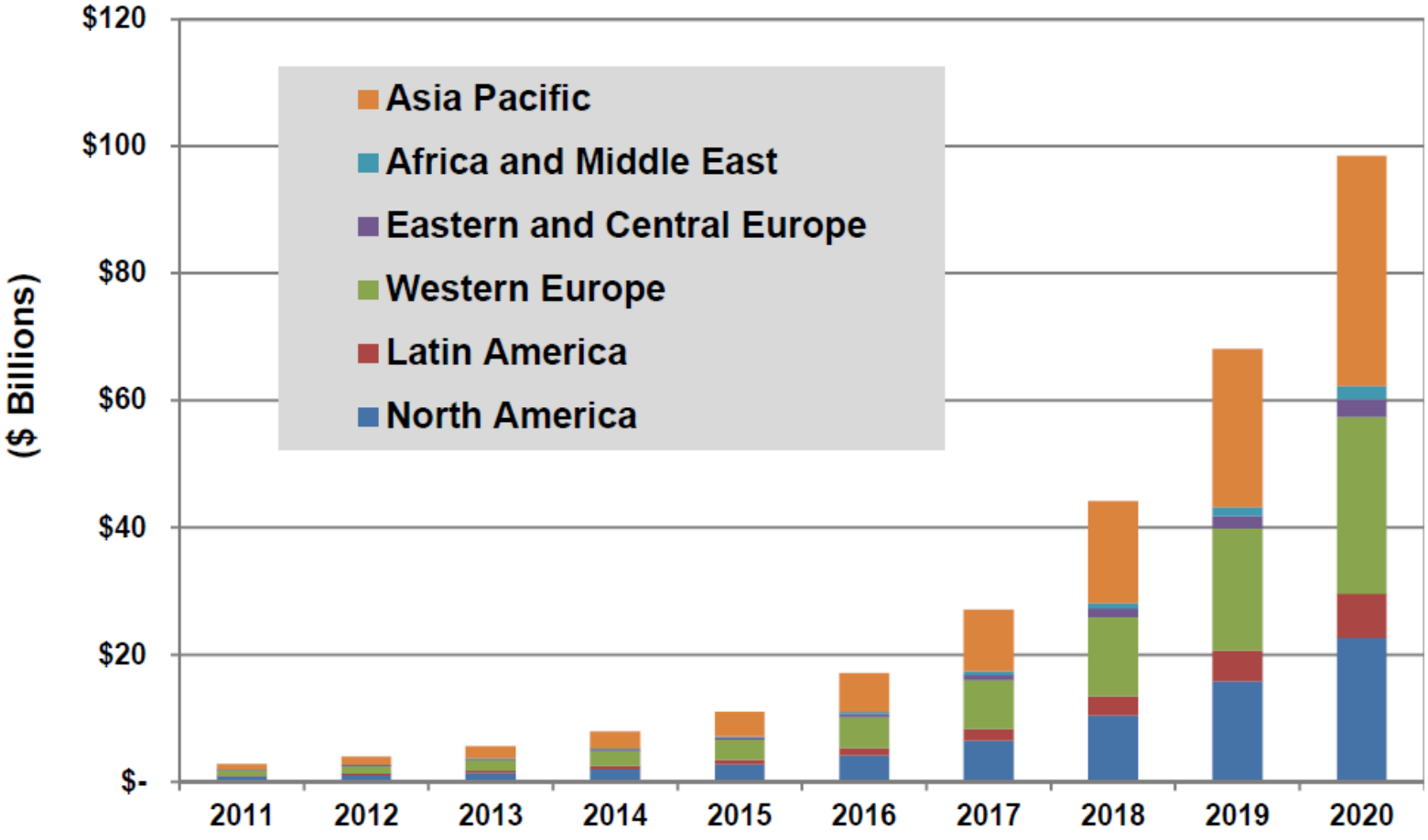
Environmental Regulations



Traditional Processes

Green Alternatives

Chart 1.1 Green Chemical Market by Region, World Markets: 2011-2020



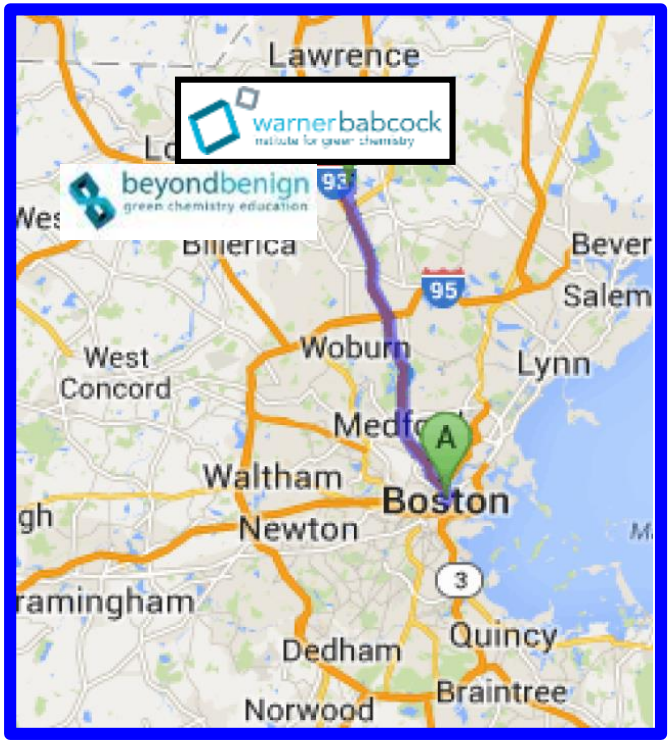
(Source: Pike Research)

2007 onward…

John Warner Amy Cannon

Jim Babcock

Joe Pont, CEO



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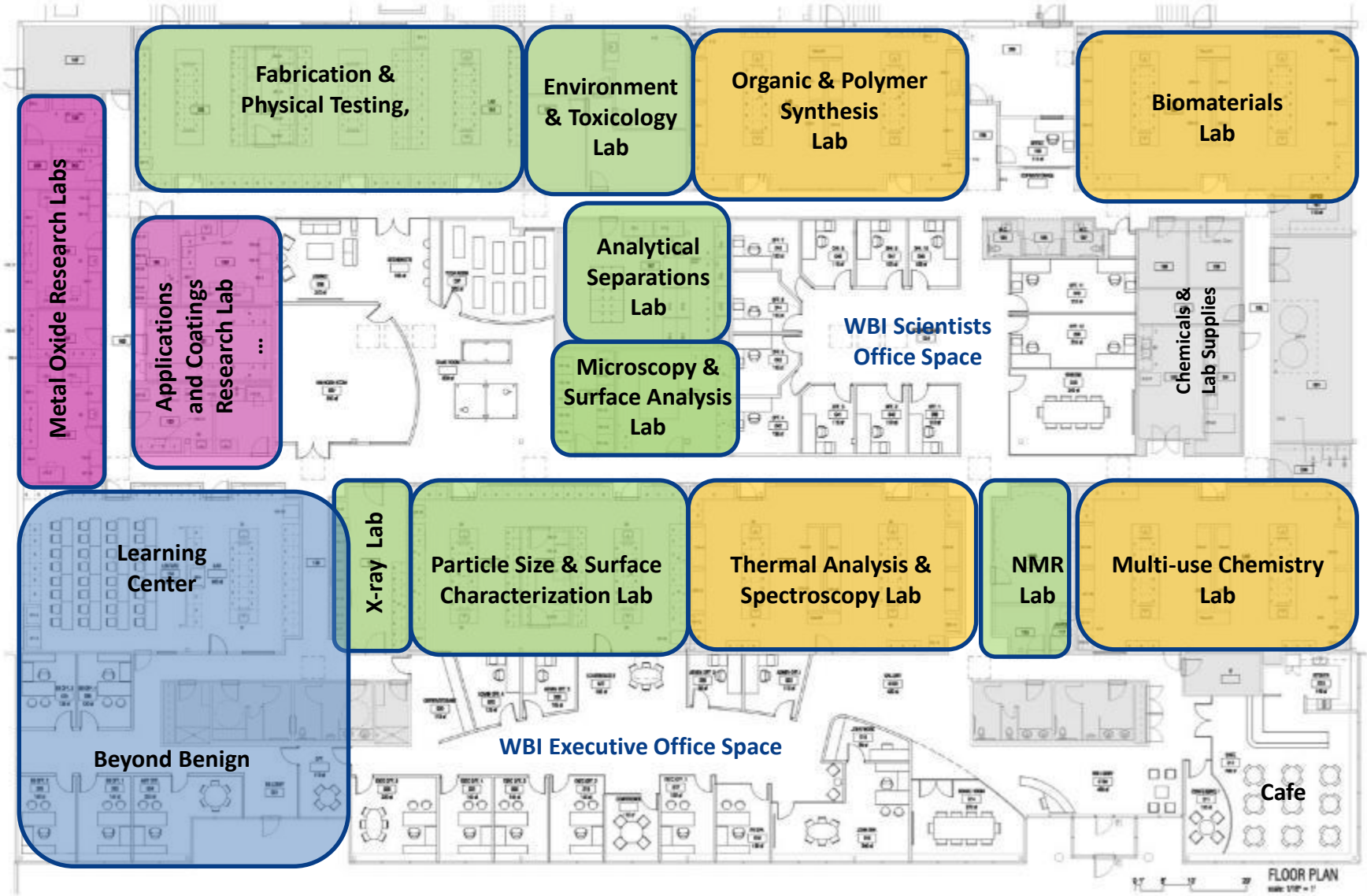
Wilmington, MA 01887


Fabrication & Physical Testing,
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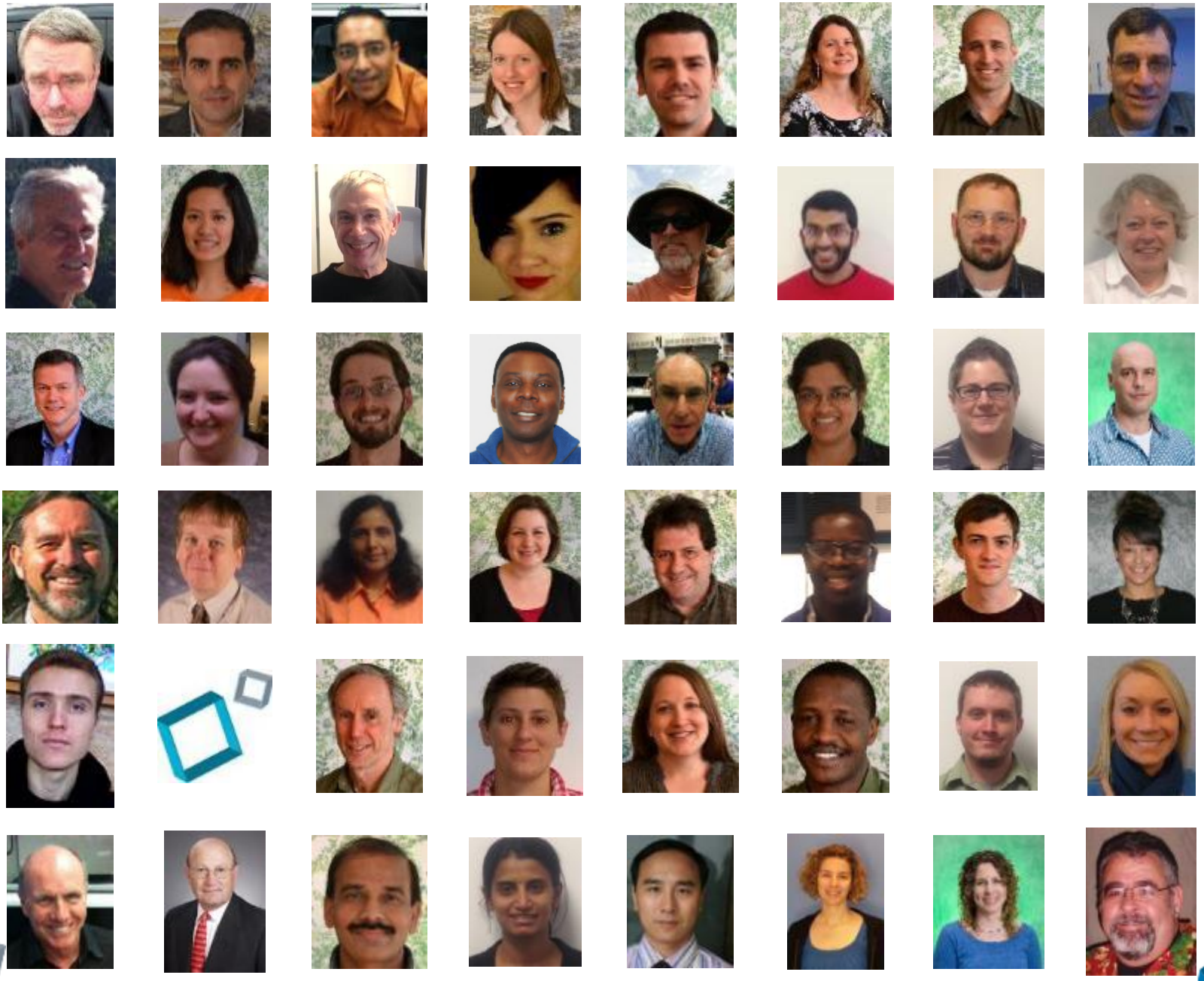
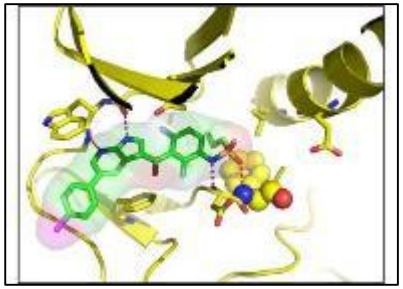
Biomaterials Lab
Metal Oxide Research Labs
Applications and Coatings Research Lab
...
Analytical Separations Lab
Microscopy & Surface Analysis Lab
WBI Scientists Office Space
Chemicals & Lab Supplies
Learning Center
X-ray Lab
Particle Size & Surface Characterization Lab
Thermal Analysis & Spectroscopy Lab
NMR Lab
Multi-use Chemistry Lab
Beyond Benign
WBI Executive Office Space
Cafe
FLOOR PLAN



Business Sectors at WBI



Pharmaceuticals, Agriculture and Biotechnology

Chemical Sciences, Development and Manufacturing

Textiles, Materials and Coatings

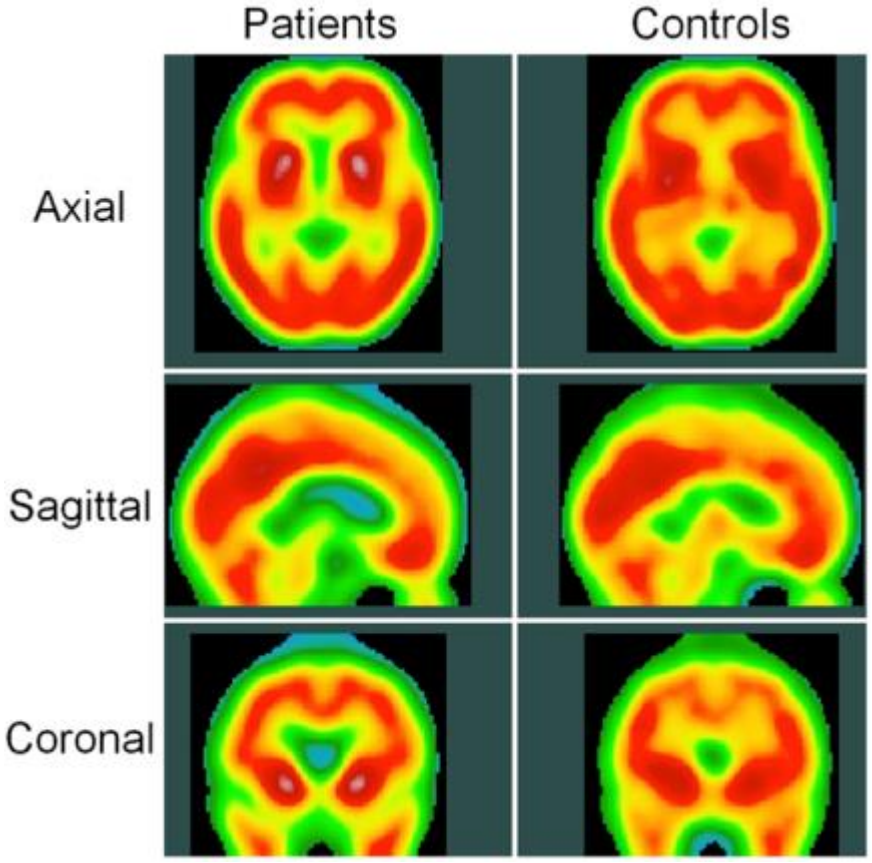
Energy, Natural Resources and Environment

Cosmetics, Personal Care and Consumer

Pharmaceuticals: Neurochemistry

- WBI and its sister company, Collaborative Medicinal Development LLC, are advancing into Phase I clinical trials leads for Parkinson's disease, amyotrophic lateral sclerosis (ALS) and cancer

- WBI has substantially contributed to these programs through formulation development and the creation of new compositions of matter



"Non-Covalent Derivatives of Metal Complexes and Methods of Treatment"
Warner, John C., Cheruku. Srinivasa R.; *US Pat Application* No. 61/932,348 January 28, **2014**.
"Copper (II) bis(N-alkyl-hydrazinecarbothioamide) Complexes as Non-Covalent Derivatives for the Treatment of CNS Conditions"
Warner, John C., Cheruku. Srinivasa R.; *US Pat Application* No. 61/902,682 November 11, **2013**.

Parkinson's Disease Therapeutic

THE MICHAEL J. FOX FOUNDATION
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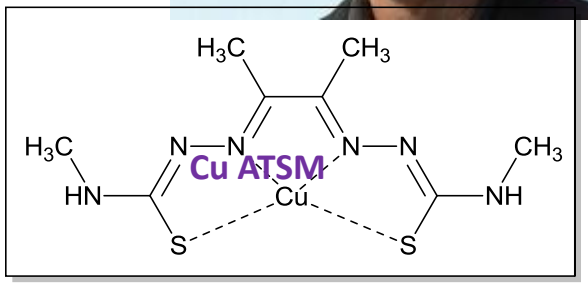

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PARKINSON'S FUNDED GRANT

Lead Optimization for a Parkinson's Disease Therapeutic

GRANT ABSTRACT

Objective/Rationale:
CuII(atsm) has the potential to delay disease progression in Parkinson's disease, based on extensive pre-clinical model data. CuII(atsm) has been shown to significantly improve motor function in standard models of Parkinson's disease. The observed motor improvement correlates with preservation of dopaminergic neurons in the brain and biomarkers of neuronal health and function.

Project Description:
CuII(atsm) is sparingly soluble and requires formulation for oral administration prior to entering human clinical development. Procypra will pursue two parallel approaches to develop a proprietary oral formulation: (1) Procypra will work with the Warner Babcock Institute for Green Chemistry to develop a proprietary formulation of CuII(atsm) incorporating GRAS (Generally Regarded As Safe) excipients; and (2) Procypra will evaluate the solubility of proprietary CuII(atsm) analogues. The utility of these formulations will be evaluated using standard solubility and bioavailability assays and efficacy will be compared to the parent formulation in the MPTP toxic lesion pre-clinical model of Parkinson's disease.

Relevance to Diagnosis/Treatment of Parkinson's Disease:
CuII(atsm) has the potential to delay disease progression in Parkinson's disease. Successful clinical development of an optimized formulation of CuII(atsm) would provide Parkinson's disease patients, on diagnosis, the opportunity to delay the progression of their disease and maintain their quality of life for a much extended period of time. In

(atsm) with the

will have al directed

parent drug show an how promise demonstrating , using in the cypra son's disease.

Related news

Video: Dr. Charles Adler Discusses His Search for a Parkinson's Biomarker

Recording Brain Activity Could Lead to Personalized Deep Brain Stimulation

How Fast Your Eyes Move Could Predict Cognitive Impairment

Read More On This Topic

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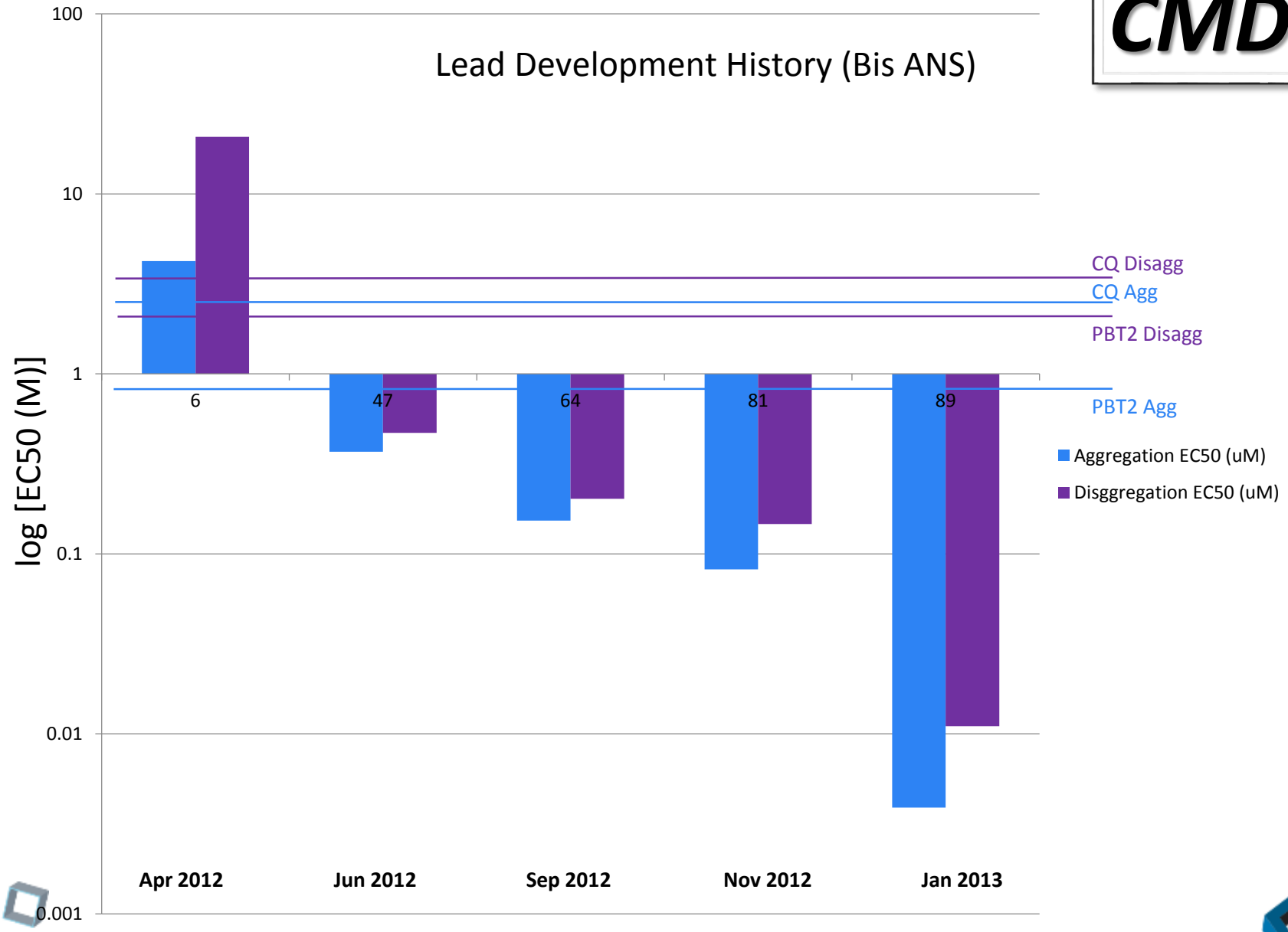
University Activities Medicine and Health Science

University of Melbourne enters agreement to develop therapy for Parkinson's disease

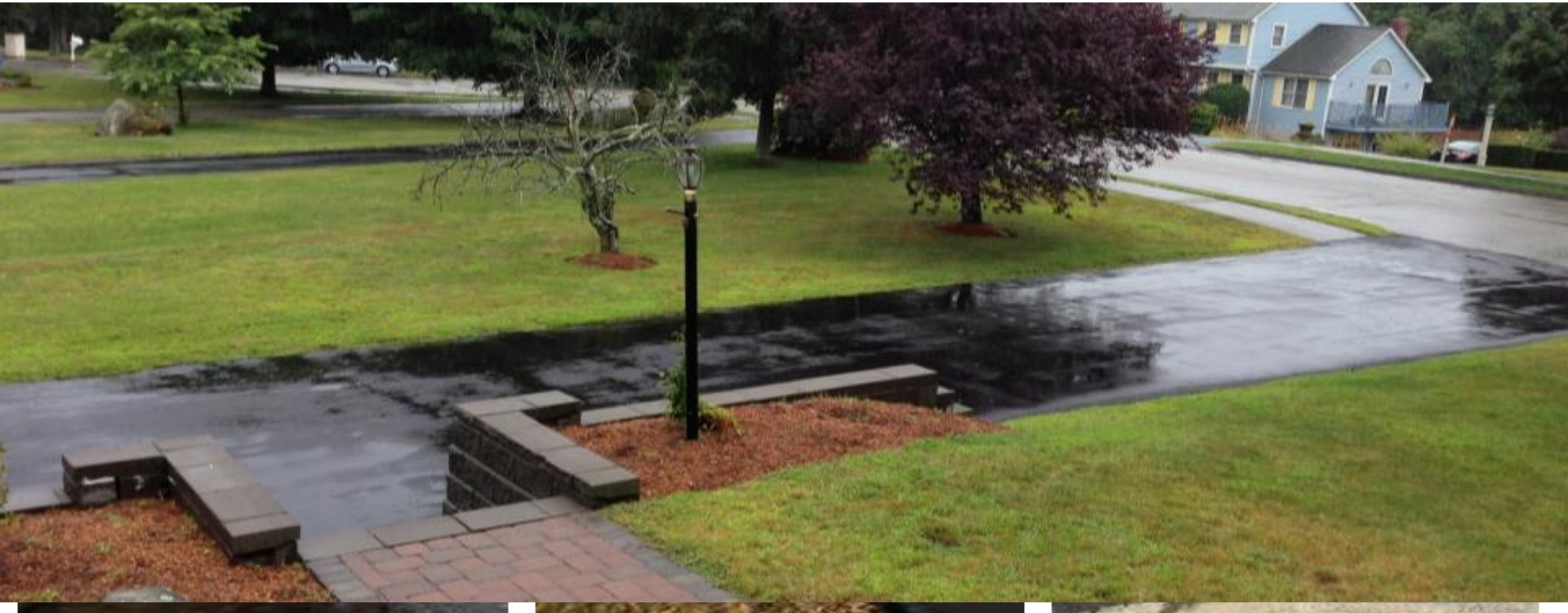
11 October 2013

Alzheimer's Disease Therapeutic



"Dihydro-6-Azaphenalene Derivatives for the Treatment of CNS, Oncological Diseases and Related Disorders" Warner, John C. et al., US PCT Application No.: PCT/US13/62429. September 27, **2013**.

Construction Materials: Asphalt Paving



Delta S Asphalt Rejuvenator

- WBI has created a low-cost, environmentally sustainable asphalt rejuvenator that enables the use of substantial quantities of recycled asphalt pavement and shingles

- Several successful use-tests have been conducted on New England roads and driveways

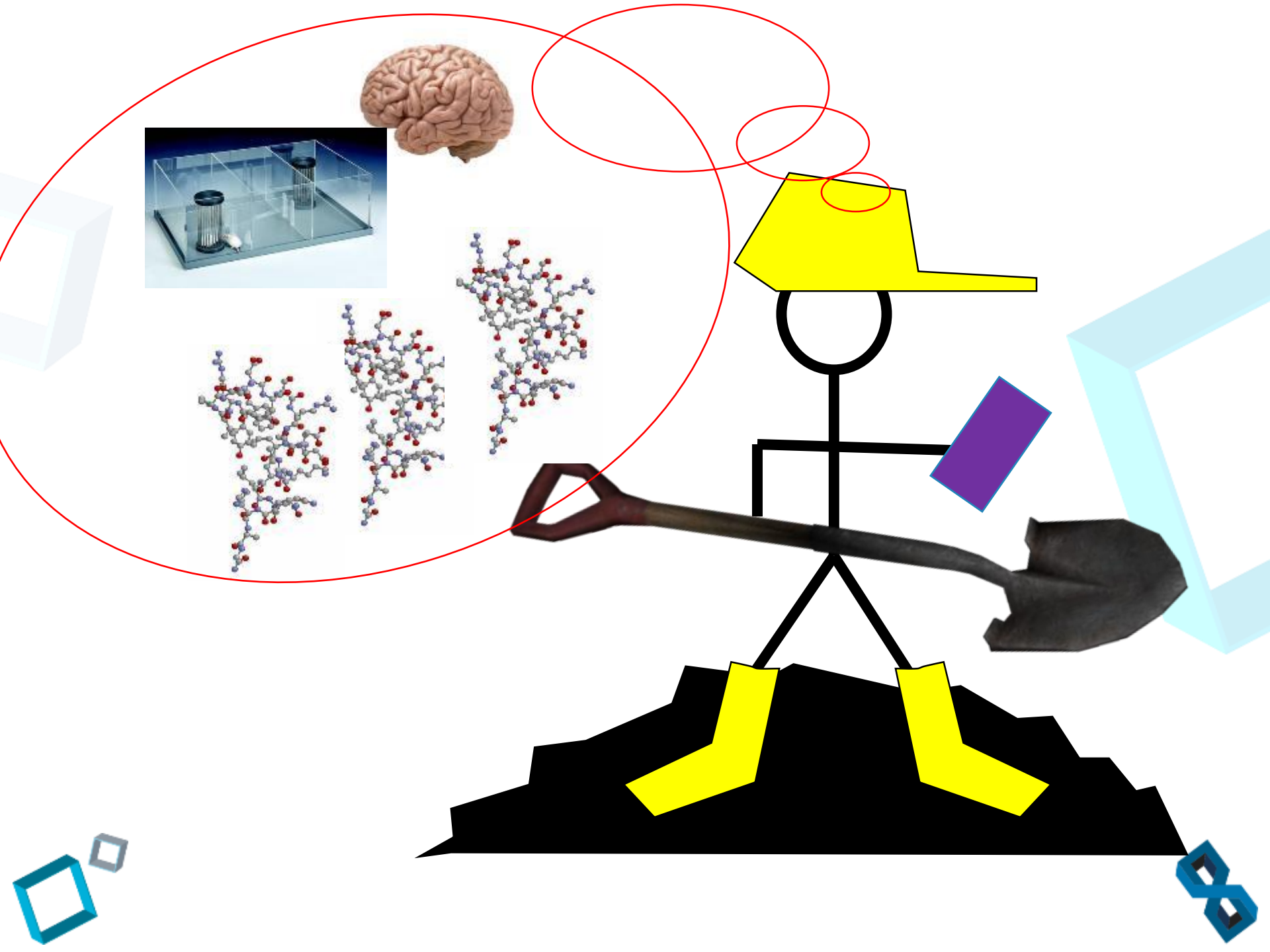
- WBI spin-off, Collaborative Aggre LLC, currently evaluating commercialization options, e.g. licensing vs. direct sales

COLLABORATIVE AGGREGATES LLC

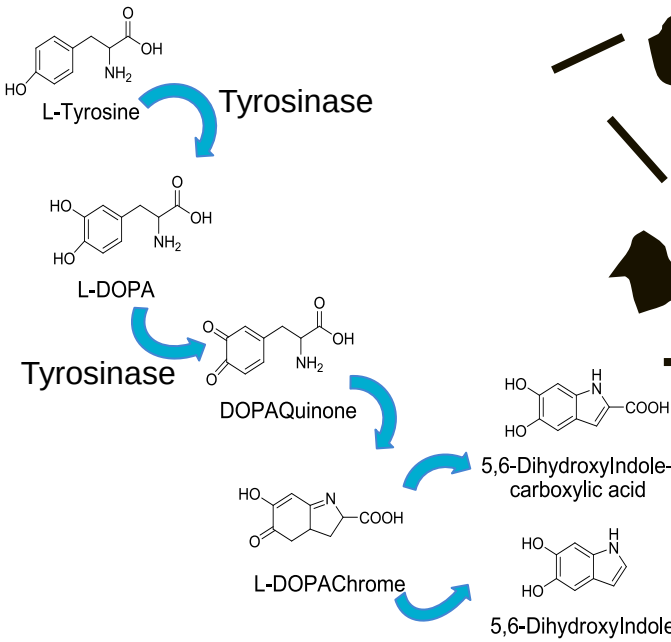
Paving with 113°C (236°F) asphalt at Centerdale School in Providence, RI

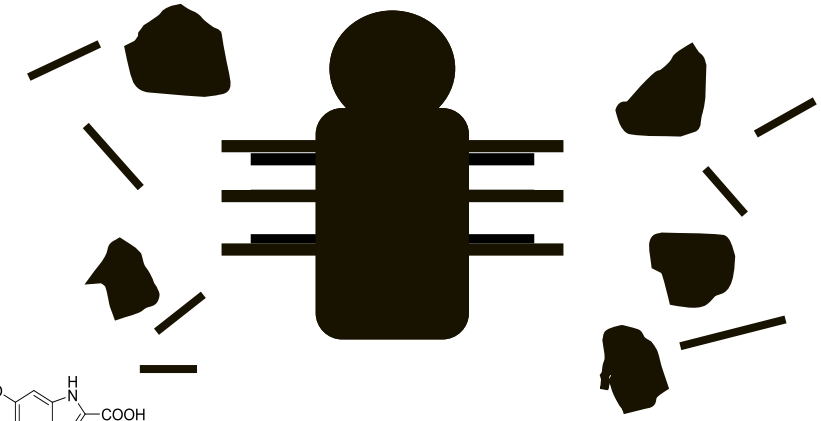
Paving on November 25, 2013 in -8°C (17°F) weather in Wilmington, MA

"Composition to Rejuvenate Asphalt"
Warner, John C., Muollo, Laura R., Walker, Rowan L. *US Pat Application* No. 61/902,706, November 11, **2013**.



Personal Care: Hair Color Restoration





3:45 PM
(Before)

4:45 PM
(After)

"Formulation and Processes for Hair Coloring"
Warner, John C.; Muollo, Laura; Stewart, Amie, U.S. (2014), US 8828100 B1 20140909 filed Oct. 14, **2013.**

Hairprint® hair color restoration

- Foundational IP created at WBI through inspiration from coloring processes in the natural world
- WBI's licensee, Nature of Hair LLC, funded optimization work at WBI to yield commercialization-ready Hairprint™ technology
- Nature of Hair is sublicensing Hairprint™ to global personal care players.

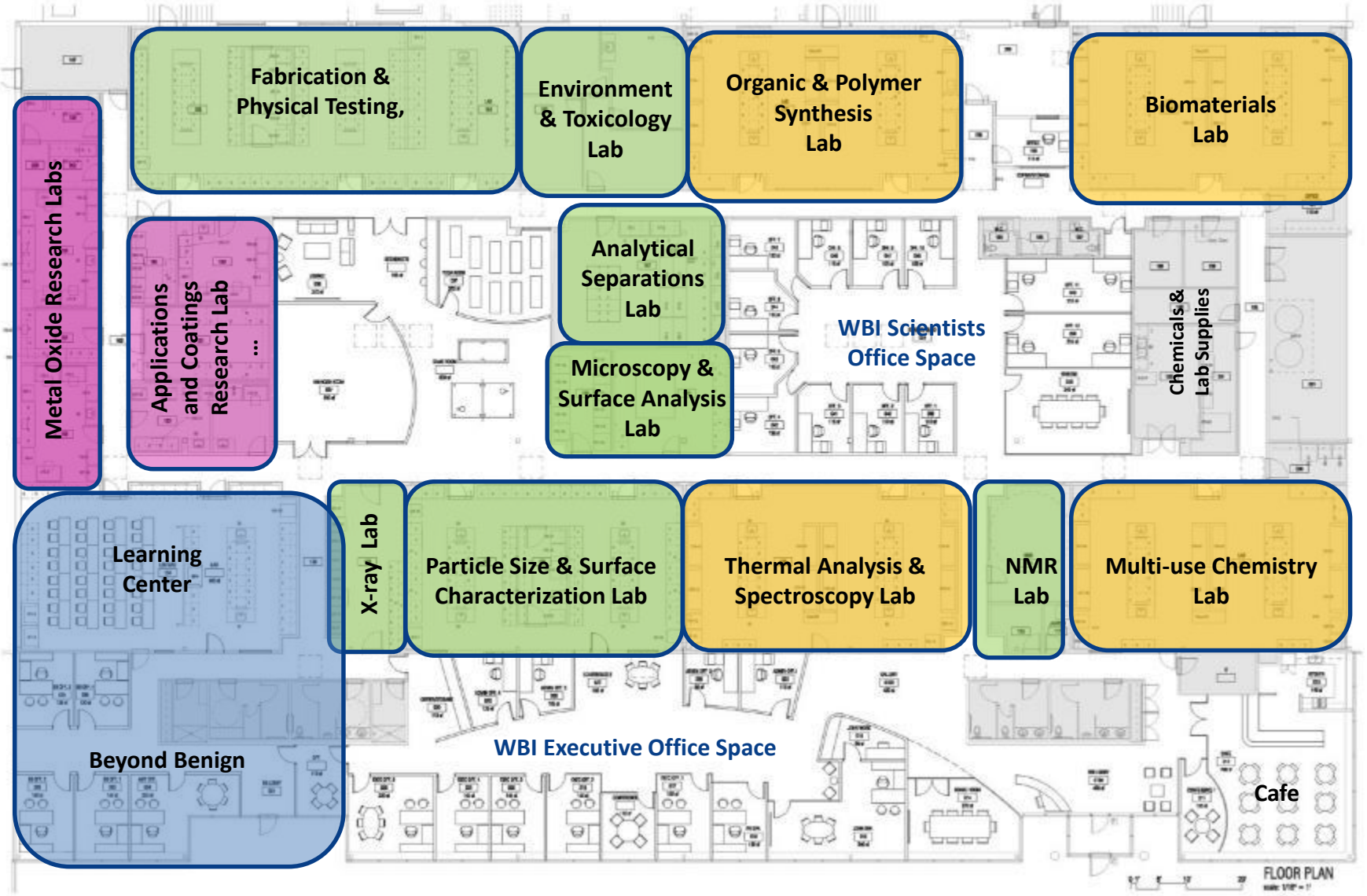
Construction Materials: Wood Composites

- WBI has created a low-cost, environmentally sustainable adhesive technology for use in wood-composite applications
- The technology enables the replacement of expensive, formaldehyde-based incumbent products
- Collaborative Aggregates LLC and WBI currently engaged in pilot-scale use-testing and technology optimization

COLLABORATIVE AGGREGATES LLC

To get a degree in Chemistry…

No universities require any demonstration of knowledge regarding toxicity or environmental impact!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beyondbenign

green chemistry education

Kate Anderson

Amy Cannon

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- K-12 and Community Outreach
- College Student Fellows program

The Green Chemistry Commitment

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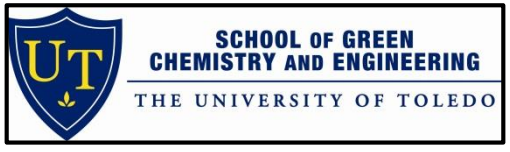
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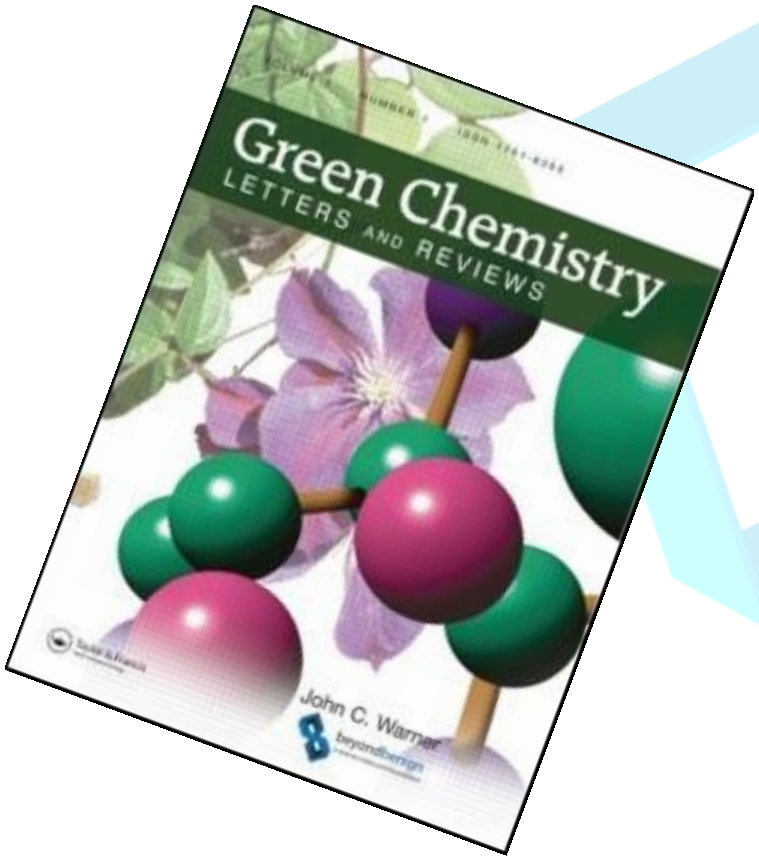
green chemistry education



john.warner@warnerbabcock.com