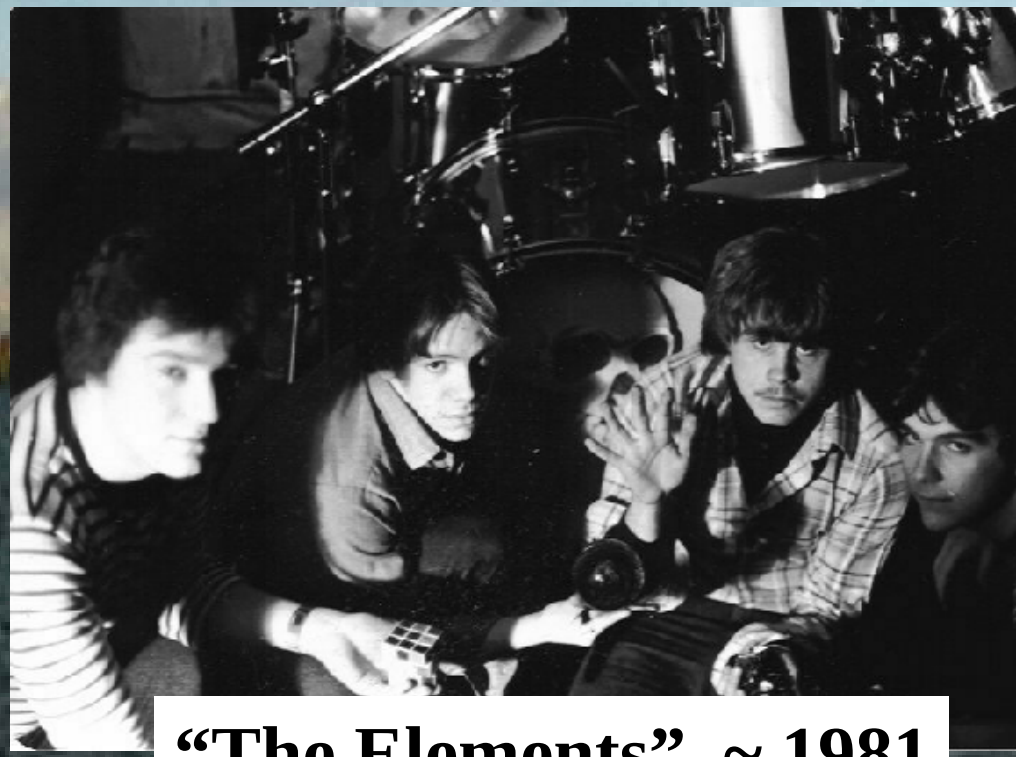
Introduction to Green Chemistry

John C. Warner

Professor, Plastics Engineering

Director, Center for Green Chemistry

University of Massachusetts Lowell

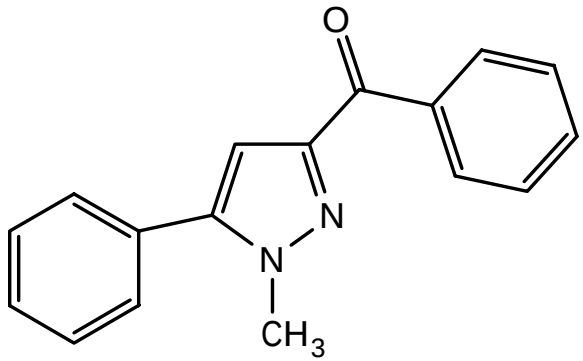


“The Elements” ~ 1981

James “Opie” Neil [1962 – 1981]

CHEMISTRY
1980-1984

Professor J.-P. Anselme



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UMASS®

AS HUB OF U.S. EDUCATION, AND THESE STUDENTS ARE AMONG THE AREA'S BEST AS SCHOOL YEAR ENDS

JOHN WARNER

Mixing music with chemistry at UMass Boston

BOSTON SHINES/

By JOE HEANEY

FROM THE COUNTRY'S beginning, Greater Boston — birthplace of the public school system and home to more than 20 colleges and universities — has been America's Athens.

Aided by its museums, libraries, music halls, parks and sports events, Boston became a Mecca for talented students to flourish, a place where excellence in education became the highest value.

It began in the 1600s and continued until Boston became known as the educational Hub. It produced generation after generation of the best and brightest students, a resource so constant, it was sometimes taken for granted.

U-Mass Boston senior John Warner of Quincy, a chemistry wizard, is typical. He wrote a doctorate-type thesis for his bachelor's degree, "just for the fun of it."

Boston Latin senior Matt Solit of Brighton, dropped soccer to gain more study time and retain his title as the school's No. 1 student.

Karl Reid of Roosevelt, L.I., became one of the top engineering students at MIT by "never settling for average, because average isn't enough."

Many are foreign students — like Helen Lin of Hong Kong — they arrive here from all over the world to be educated in medicine, engineering, the arts and every other important discipline.

She attended Milton Academy and then Boston College, graduating cum laude last

Some of the Boston area's best and brightest gather at The Herald. From left standing are Matt Solit, Boston Latin; Karl Reid, MIT; Jeanette Caramanga, Boston University; Matthew Buckley, Suffolk University; John Warner, UMass Boston; Thomora Fishel, Brockton High. Seated are Paula Guerin, left, Malden High and Chris Kiah, Newton South High.

1984-1988 Princeton University

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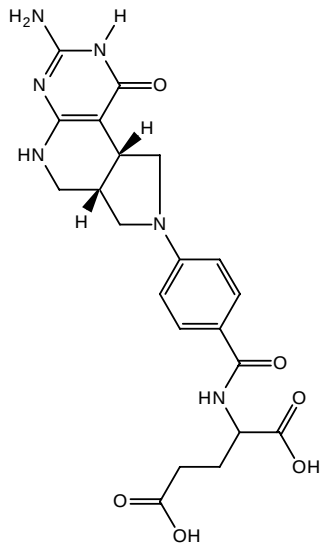
Professor E. C. Taylor



“Alimta”

Natalie Warner [1932 – 2002]

John Warner "knocking 'em dead" at Princeton grad school

It's one of the nicest scenes in academia--the former student returning to visit his mentor. This happened the other day when John Warner, 22, of Quincy reported back to Chemistry professor J.P Anselme on his progress in graduate school at Princeton University.

"He's knocking 'em dead," said Professor Anselme, using the vernacular.

He is, indeed. Warner, who had a 3.4 academic average his senior year at the Harbor Campus, logged three As and an A+ in the Fall Term, the last grade achieved in Heterocyclic Chemistry under world-famed Dr. E.C. Taylor, Jr.

"I'm studying with a large number of Ivy League graduates, and I guess I'm holding my own," said Warner, modestly.

Warner, a graduate of Quincy High School, is one of three sons of John, an electrician and Natalie. He was president of the school band and seemed headed for a career in music—until he discovered chemistry.

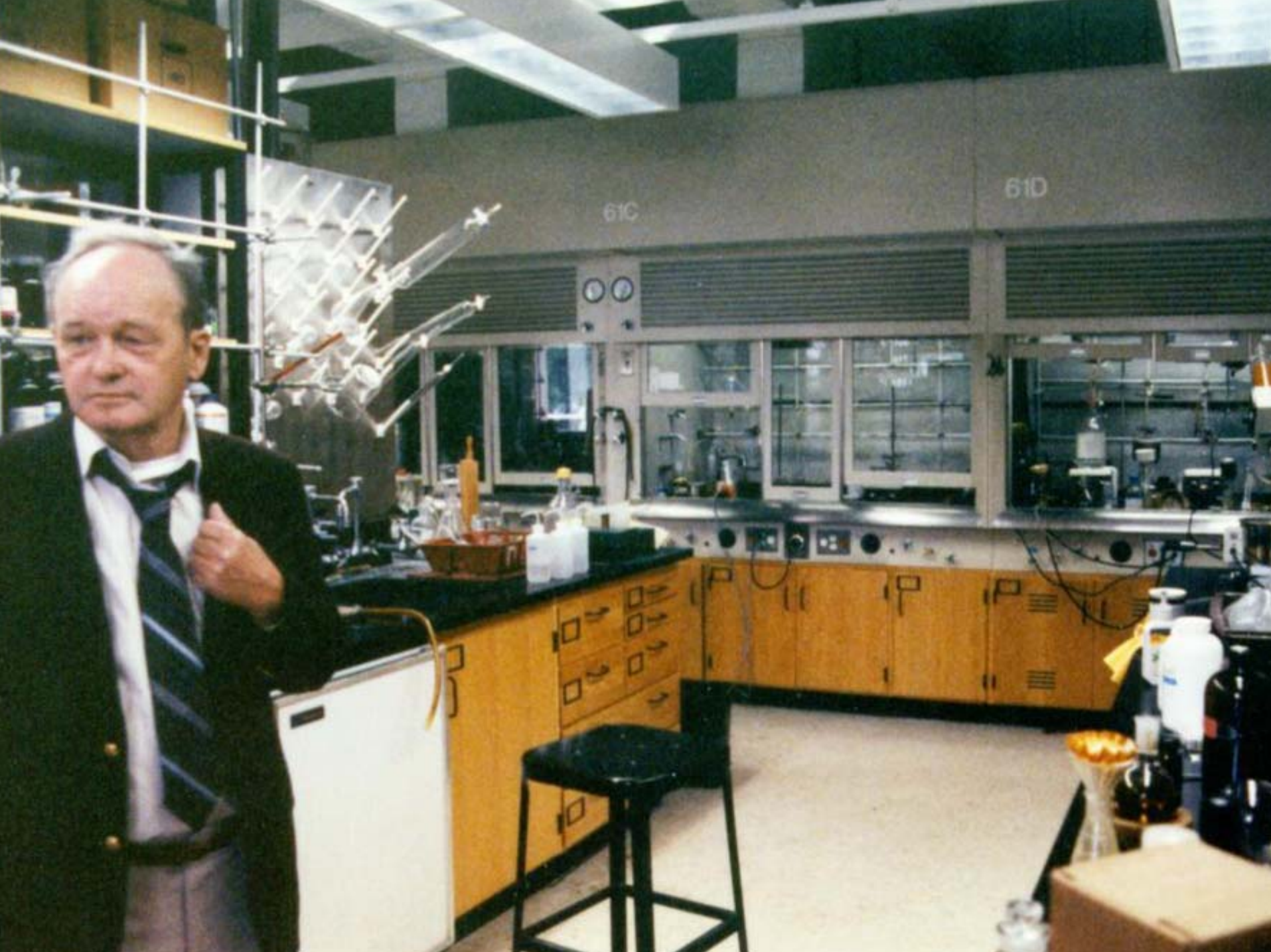
"Research is my strong point. I like the laboratory," said Warner. "I found it a place for the creativity and imagination I used to devote to music."

A high point in Warner's promising career was his junior year selection to speak at a Washington, D.C. meeting of the American Chemistry Association. His subject: heterocyclic chemicals, dealt with a series of compounds important to pharmaceuticals.

John Warner

Currently, Warner is in the running for a fellowship from the National Science Foundation.

The nice part is that he remembers where much of it started.


61C
61D

Polaroid

1988-1997

Lloyd Taylor

Donna Guarrera

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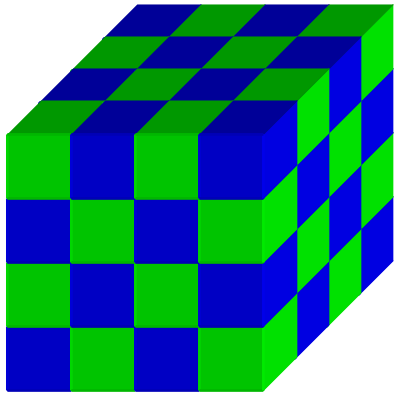
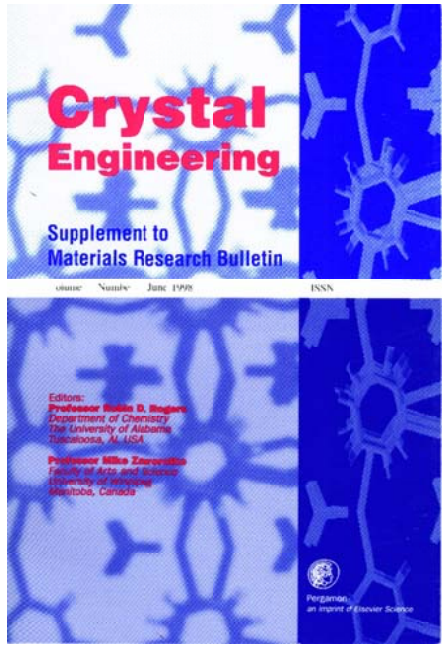
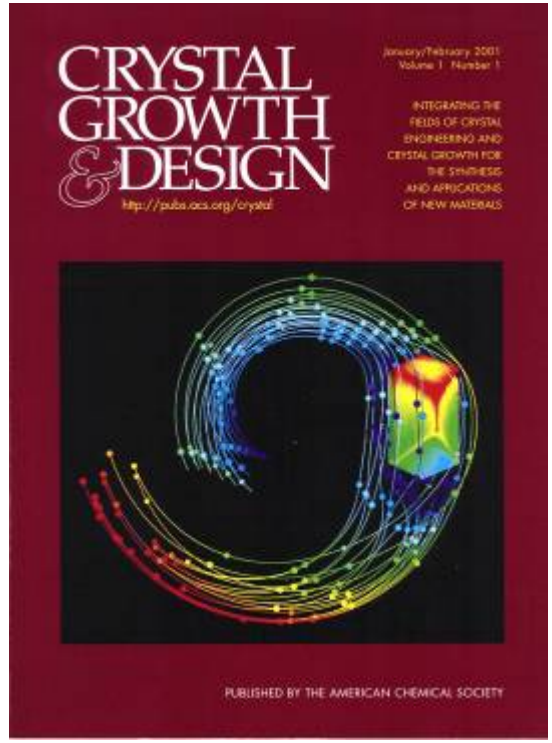
Noncovalent Derivatization



⟵ nanometers ⟶





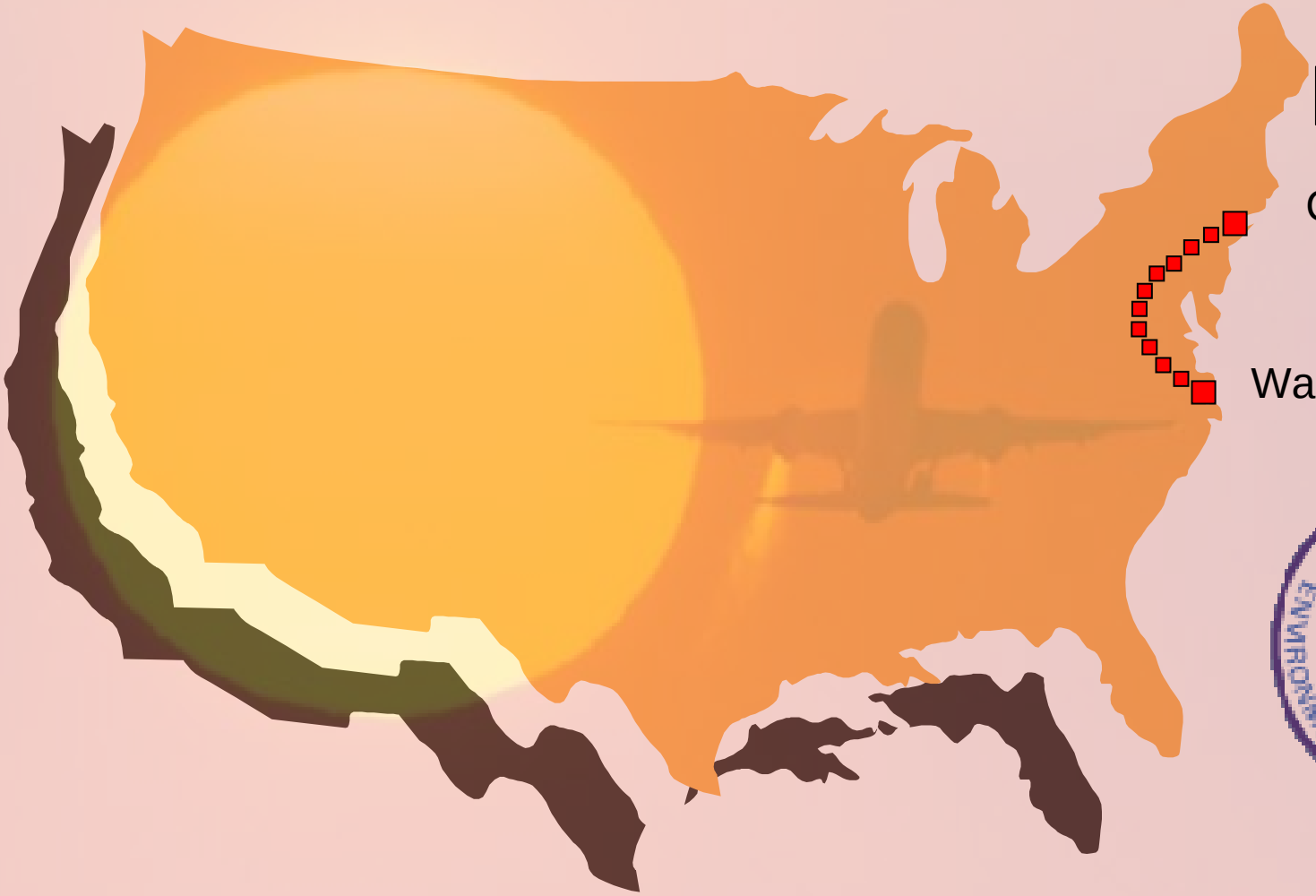
Dr. Warner Goes To Washington

EPA Approval

Low **V**olume **E**xemption
Pre**M**anufacturing **N**otification

Small particles?

Molecular Complexes?



Polaroid

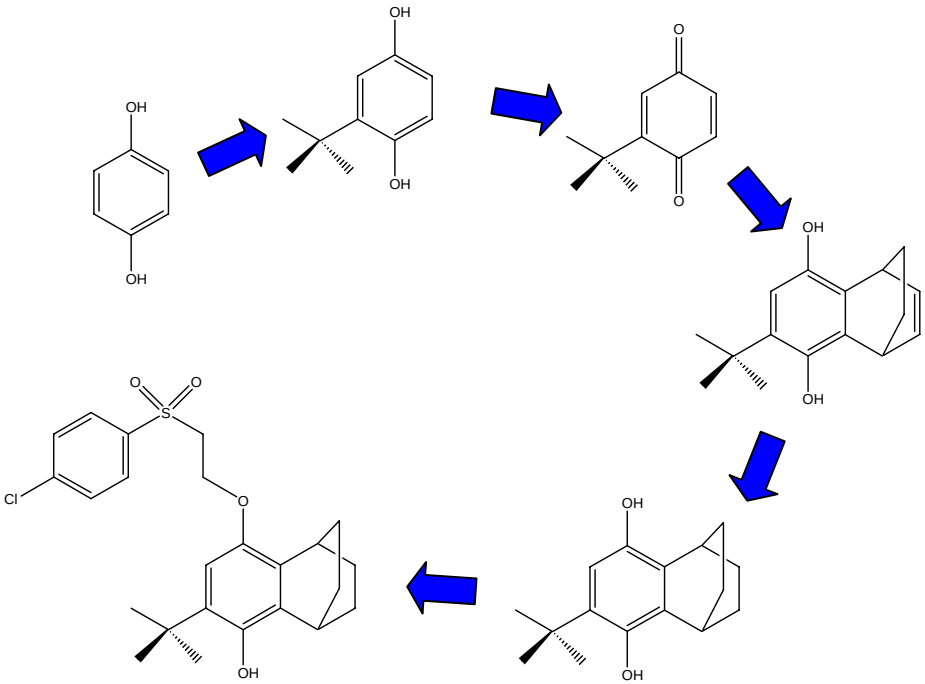
Cambridge, MA

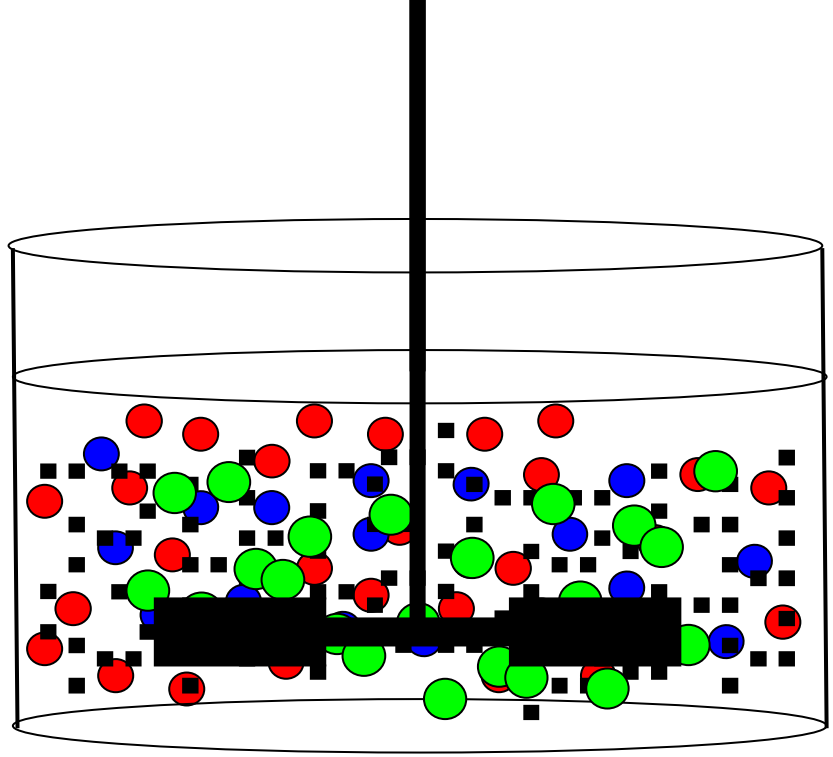
Washington, DC

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

“Reinventing Government”

$75,000.00

The beginning of an idea.

EPA United States Environmental Protection Agency

Presidential Green Chemistry Challenge

The Presidential Green Chemistry Challenge

Awards Opportunities

The Pollution Prevention Act of 1990 established a national policy to prevent or reduce pollution at its source whenever feasible. The Pollution Prevention Act also provided an opportunity to expand beyond traditional EPA programs and devise creative strategies to protect human health and the environment. Green chemistry, or the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances, is a highly effective approach to pollution prevention. Green Chemistry applies innovative scientific solutions to real-world environmental situations, all through voluntary partnership programs. In order to successfully effect the technical and behavioral changes necessary to accomplish wide-spread pollution prevention through green chemistry, the benefits of the approach must be clearly demonstrated and communicated.

Objective:

The Presidential Green Chemistry Challenge seeks to recognize outstanding accomplishments in green chemistry through an annual awards program in order to demonstrate the scientific, environmental, and economic benefits that green chemistry technologies offer.

Background:

The Presidential Green Chemistry Challenge was implemented as a voluntary EPA Design for the Environment (DfE) partnership with the chemical community. DfE partnerships encourage changes that both promote economic development and benefit industry by identifying cost-effective ways to prevent pollution.

Description:

The Presidential Green Chemistry Challenge Awards Program is an opportunity for individuals, groups, and organizations to compete for annual awards in recognition of innovations in cleaner, cheaper, smarter chemistry. The Challenge Awards Program provides national recognition for outstanding chemical technologies that incorporate the principles of green chemistry into chemical design, manufacture, and use, and that have been or can be utilized by industry to achieve its pollution prevention goals.

Nominations received for the awards are judged by an independent panel of technical experts convened by the American Chemical Society. Typically, five awards are given annually to industry and government sponsors, an academic investigator, and a small business, for this program. Individual projects selected for support may be funded by EPA, NSF, or jointly by both agencies. This is at the option of the agencies, not the grantee.

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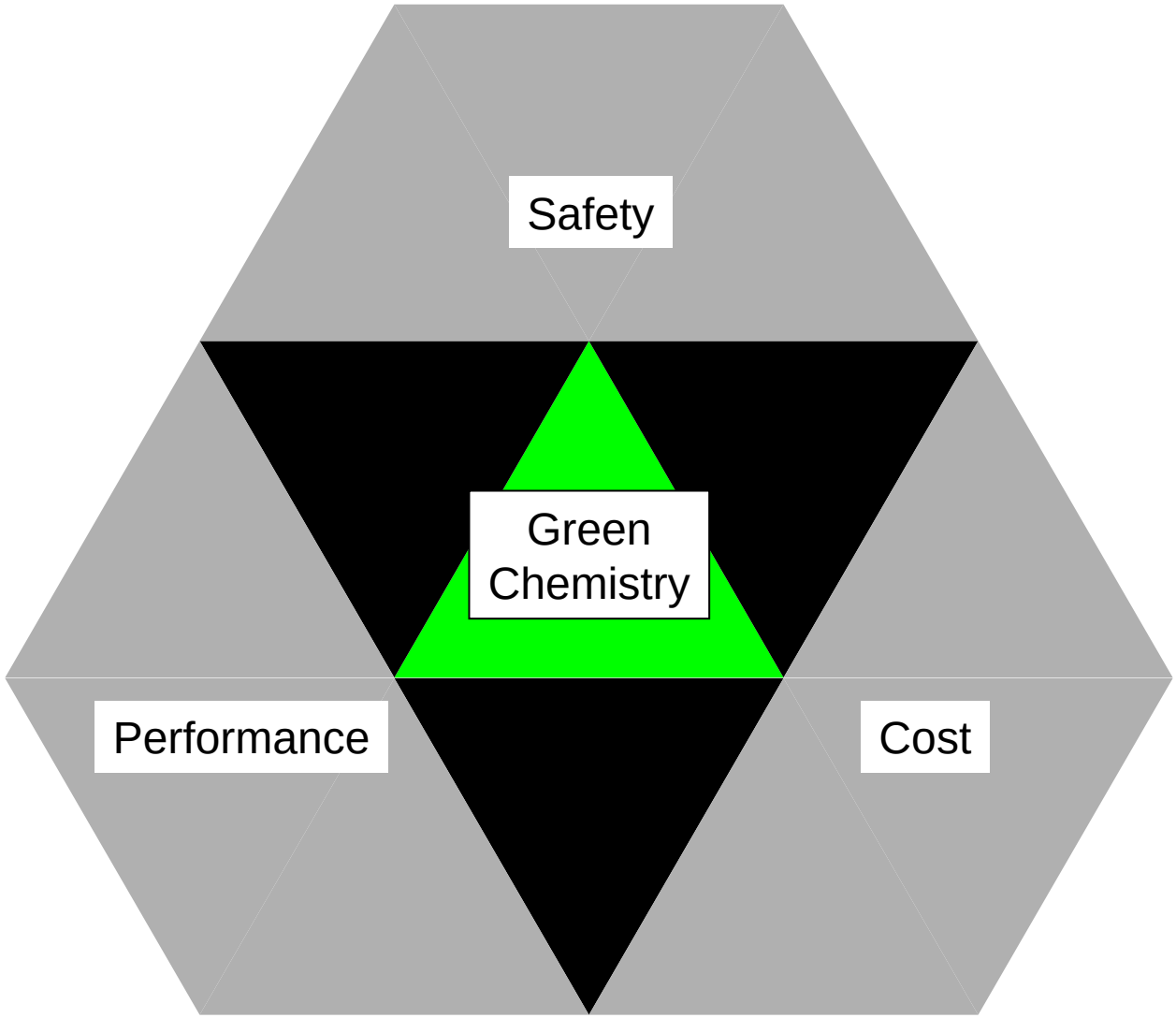
GREEN CHEMISTRY CHALLENGE

More environmentally benign than alternatives

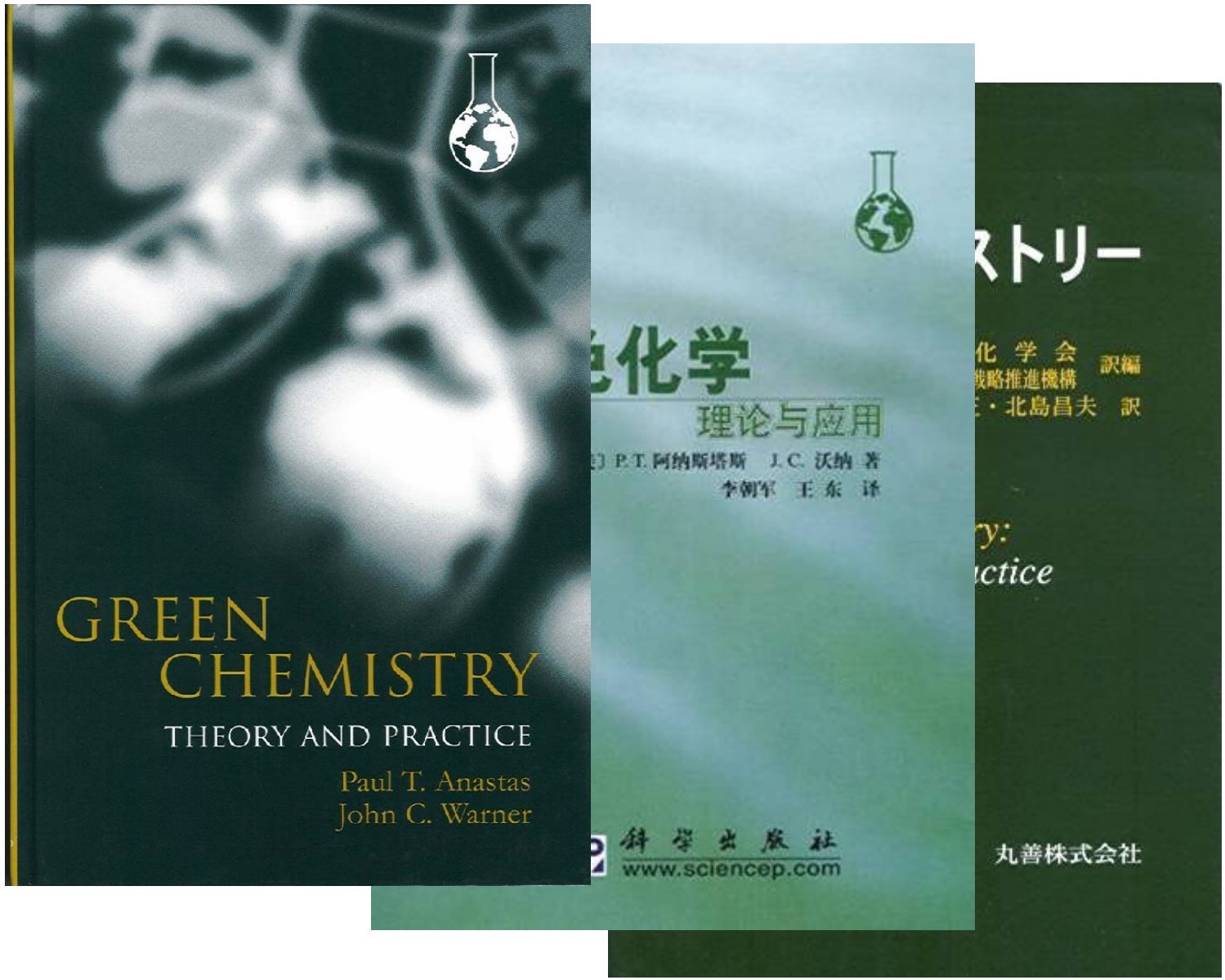
Perform better than alternatives

More economical than alternatives


Safety
Green Chemistry
Performance
Cost

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Academic	Mark Holzapple	Joseph DeSimone	Barry Trost Karen Draths John Frost	Terry Collins	Chi Hue Wong	C.-J. Li	Eric Beckman	Richard Gross	Charles Eckert Charles Liotta	Robin Rogers	Galen Suppes
Small Business	Donlar Corporation	Legacy Systems	PYROCOOL Technologies	Biofine	RevTech	Eden Bioscience	SC Fluids	AgraQuest	Jeneil Biosurfactant Co.	Metabolix	Akron Cons. Nupro Tech.
Alternative Synthetic Pathway	Pharmacia	BHC Company	Flexsys America	Lilly Research Laboratories	Roche Colorado	Bayer Corporation	Pfizer	Sud-Chemie	Bristol-Myers Squibb Co	Archer Daniels Midland and Merck	Merck
Alternative Solvents and Reaction Conditions	Dow	Imation	Argonne National Labs	Nalco Chemical Company	Bayer Corporation	Novozymes	Cargill Dow	DuPont	Buckmann Laboratories	BASF	Codexis
Designing Safer Chemicals	Rohm and Haas	Albright and Wilson Associates	Rohm and Haas	Dow AgroSciences	Dow AgroSciences	PPG	CSI	Shaw Industries	Engelhard Co	Archer Daniels Midland	SC Johnson

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.

Polaroid

1988-1997

Lloyd Taylor

Donna Guarrera

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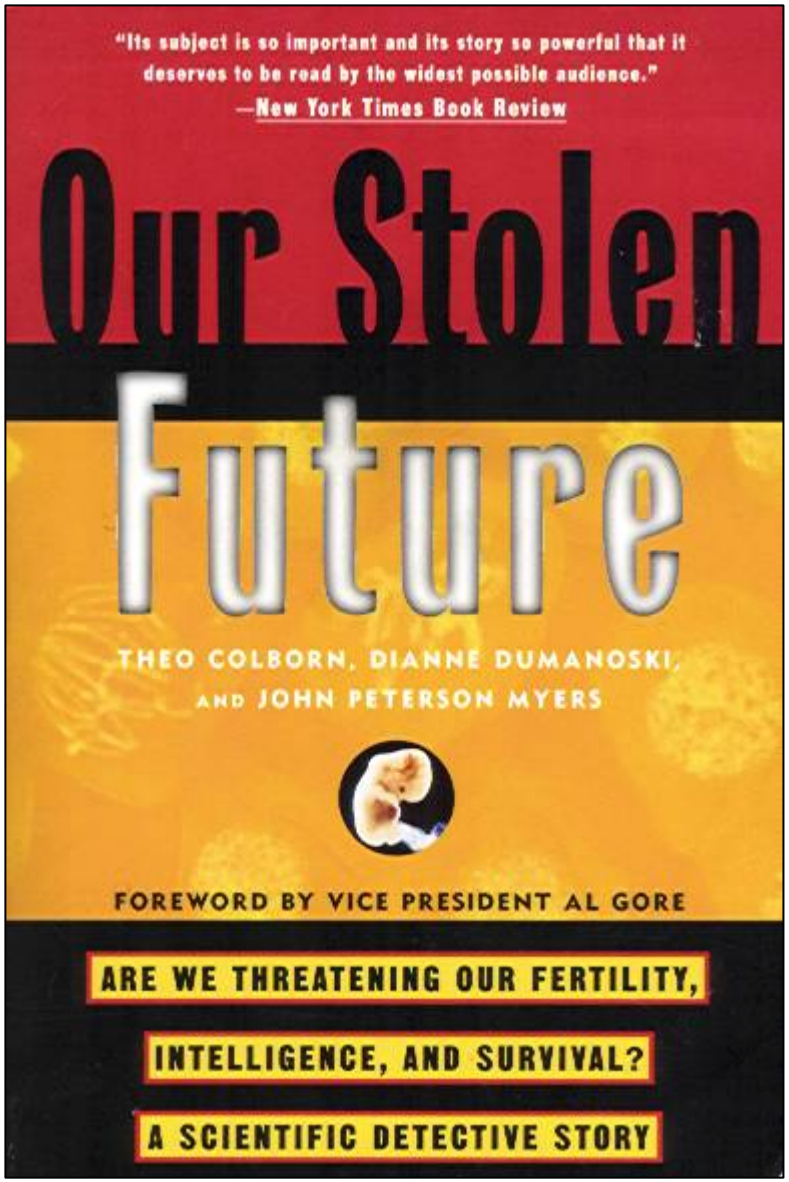
John Patrick Warner [1991-1993]



I have synthesized over 2500 compounds!!!!!

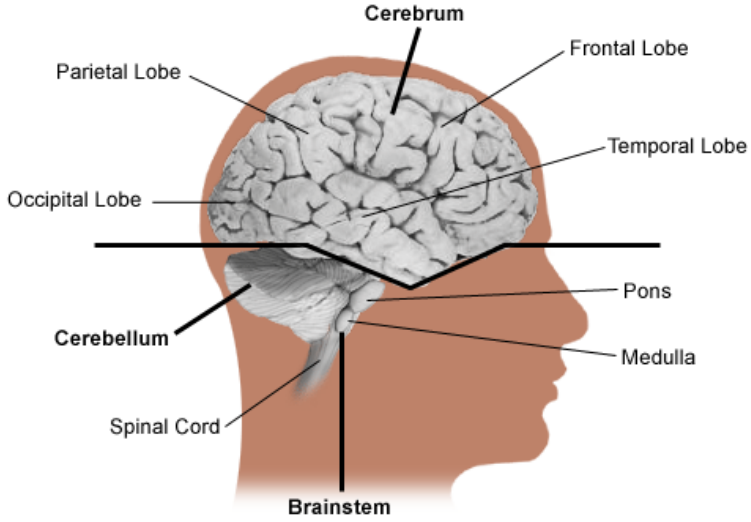
I have synthesized over 2500 compounds!

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.

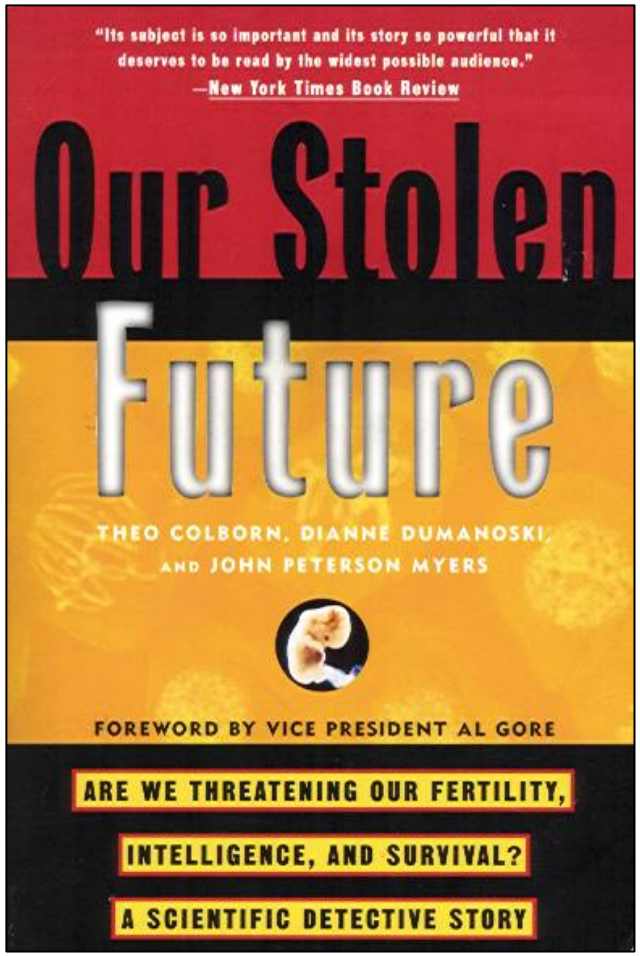
Research has been investigating parents of children with brain tumors and their past exposure to certain chemicals. Some chemicals may change the structure of a gene that protects the body from diseases and cancer. **Workers in oil refining, rubber manufacturing, and chemists have a higher incidence 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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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.

In 2004:

10,155 Undergraduate Degrees in Chemists

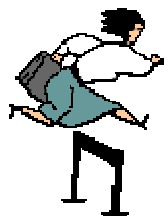
1,840 Masters Degrees in Chemistry

1,963 Doctoral Degrees in Chemistry

50.9 % Women Undergraduate Degrees

French to English

German to English



To get a PhD in Chemistry…

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

Undergraduates in Chemistry often do not learn about environment issues.

There are many classes for “non-science” majors that attract them by talking about environmental issues.

The American Chemical Society “Accredits” chemistry programs…

It requires Calculus, Biochemistry, Instrumentation, Independent work…

But there is NO requirement for Environmental Issues…

Ironically, India’s ministry of education has mandated that all chemistry undergraduates must take 1 year of Green Chemistry.

China has opened a number of Green Chemistry Research Institutes

Chemical and Engineering News, April 22, 2002.

PHOTO BY KEN 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."

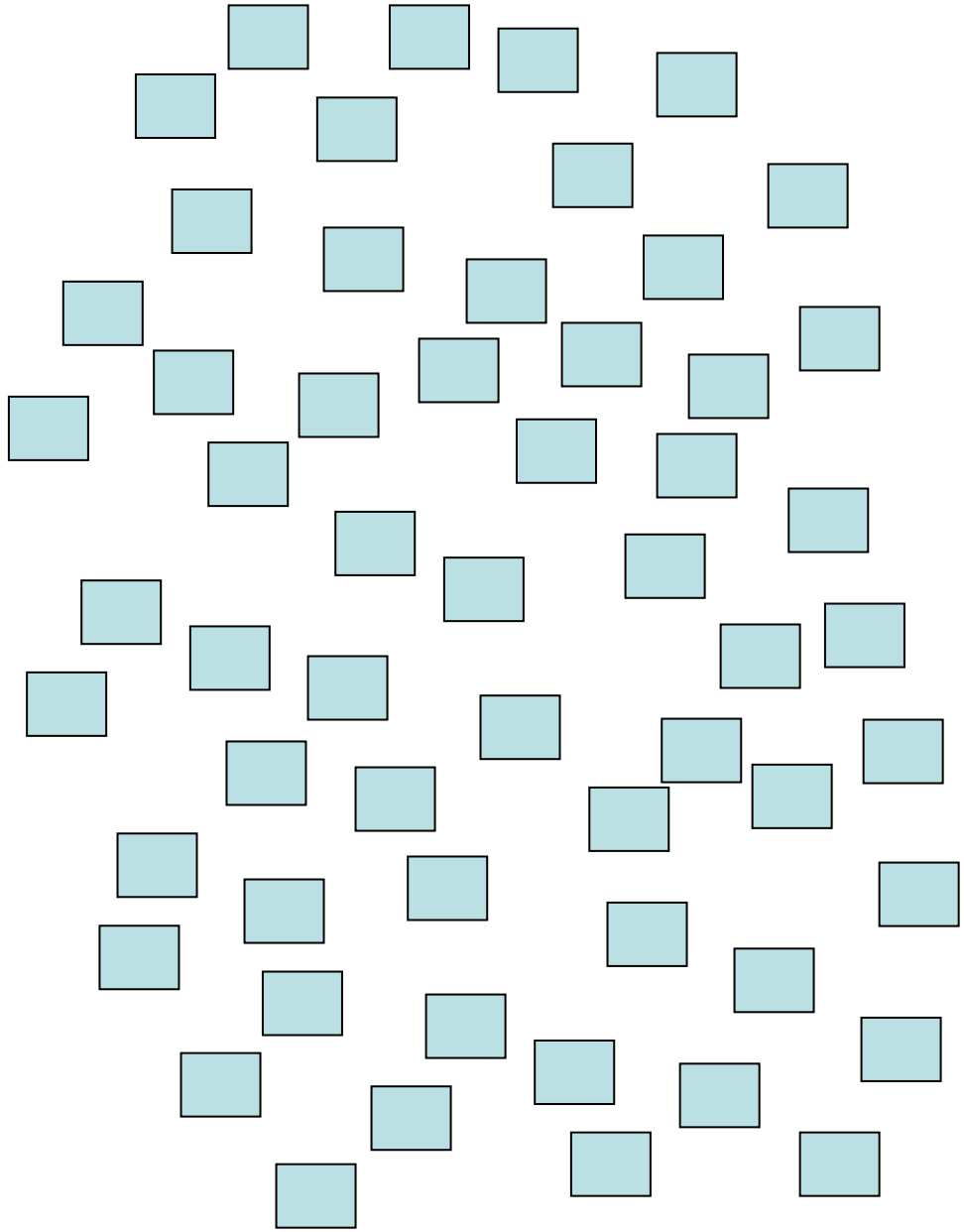
Amy Cannon is the first student enrolled in UMB's green chemistry Ph.D. program. She's working on constructing solar energy devices in a more environmentally benign manner. Currently, she explains, producing solar cells consumes so much energy that a solar panel has to operate for years before it generates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

How does all this relate to different Businesses?

Of all the products and processes…

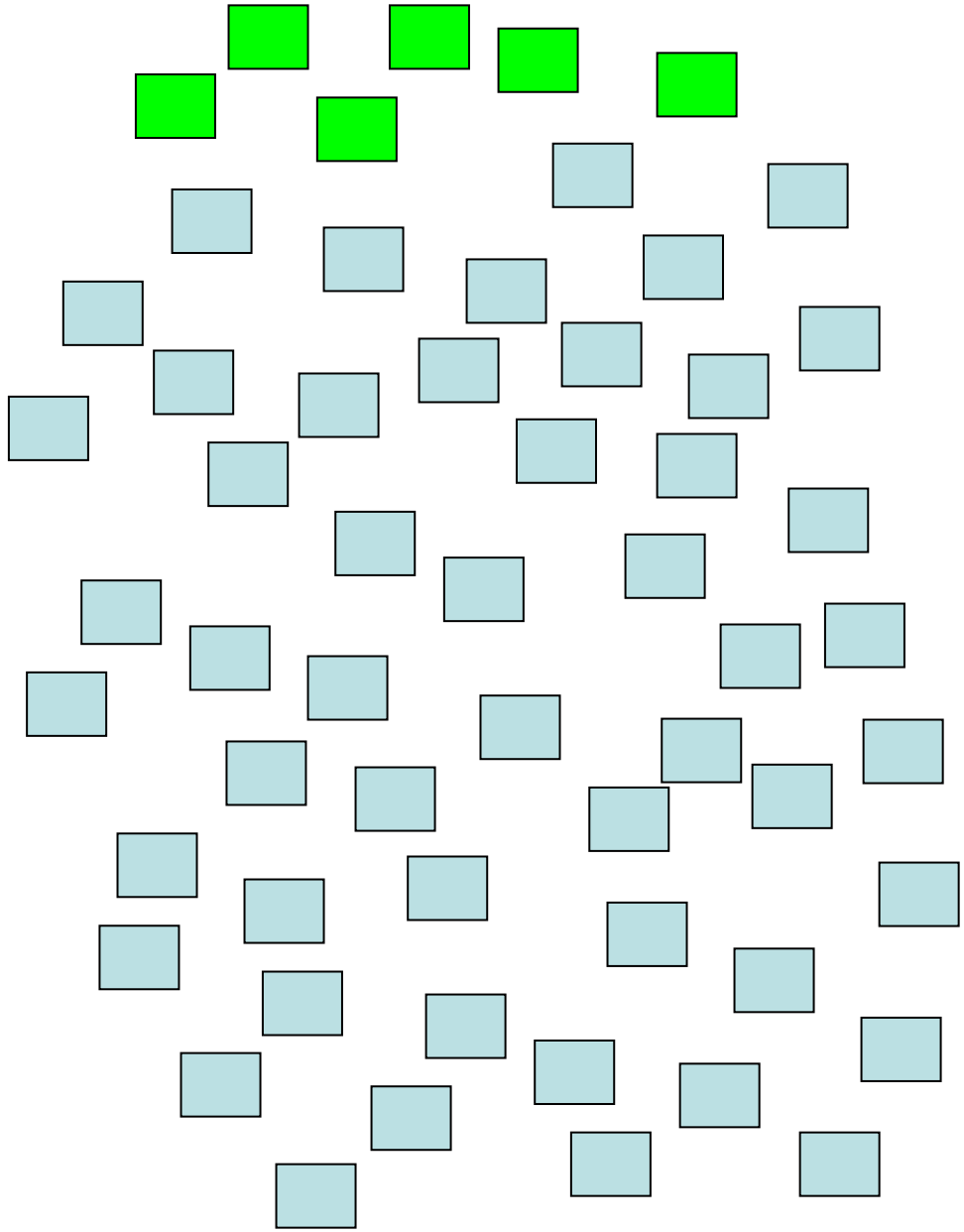
Maybe 10% are benign…



Of all the products and processes…

Maybe 10% are benign…

Maybe 25% more are relatively easy to do…

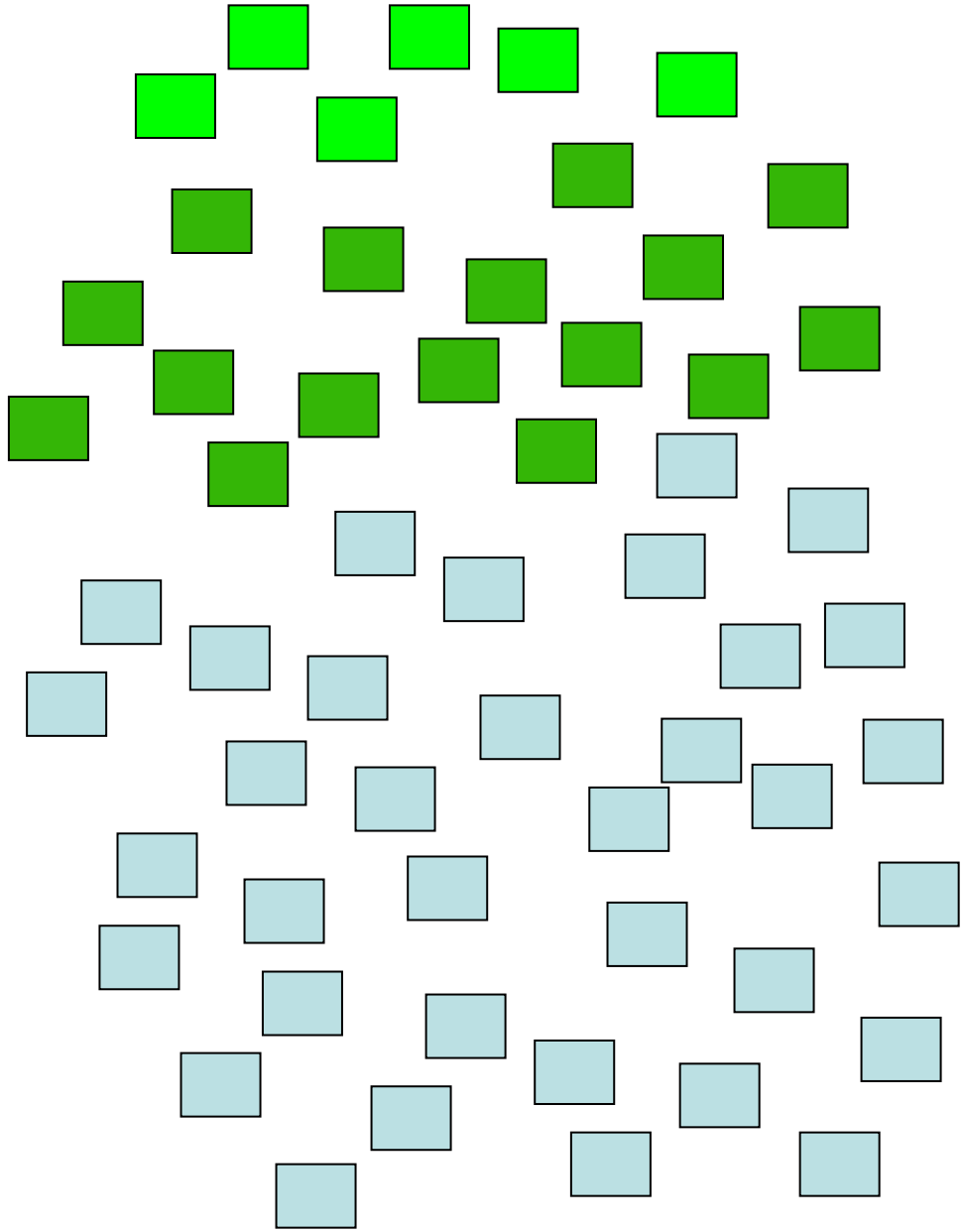


Of all the products and processes…

Maybe 10% are benign…

Maybe 25% more are relatively easy to do…

Who is going to invent the other 65%?



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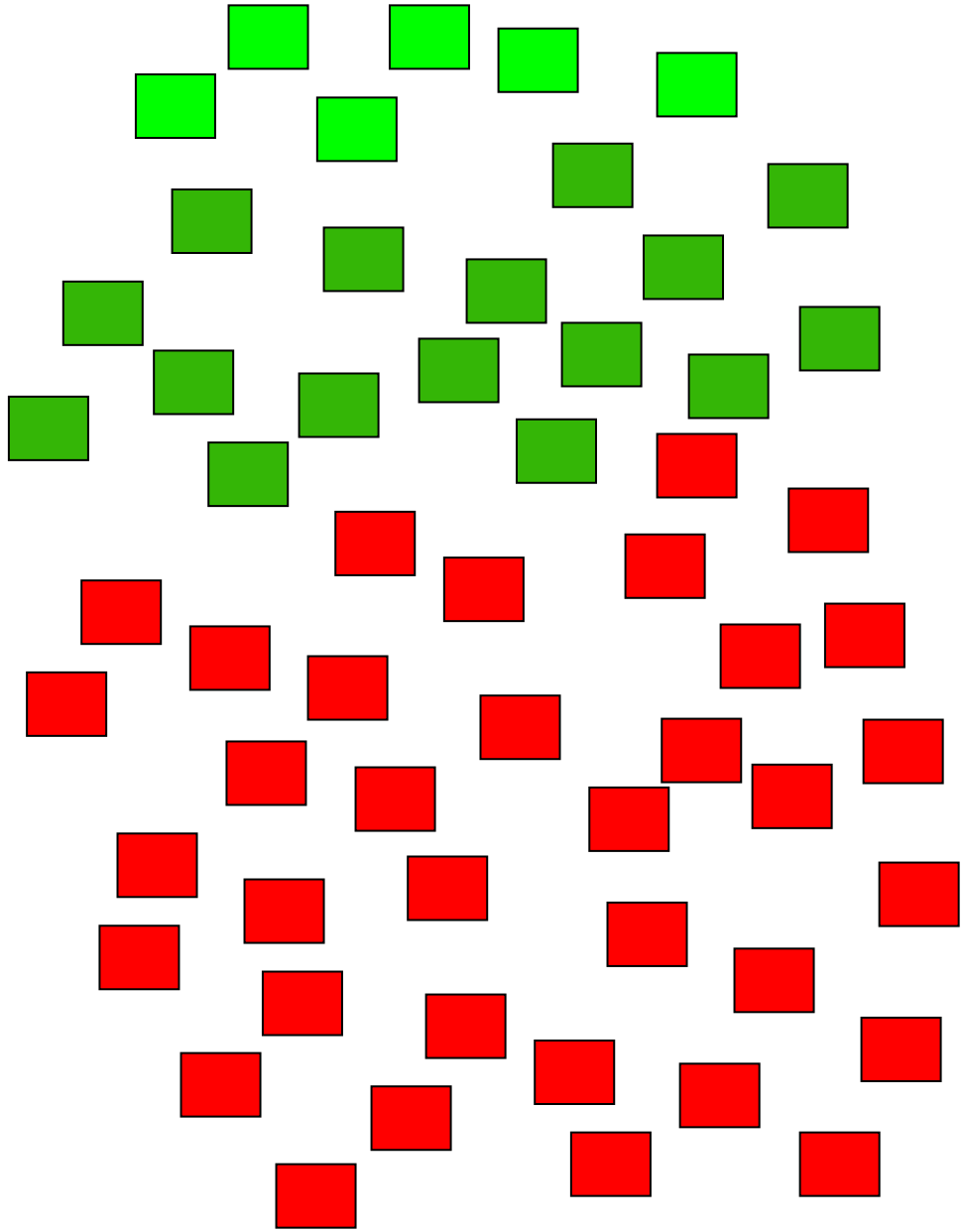
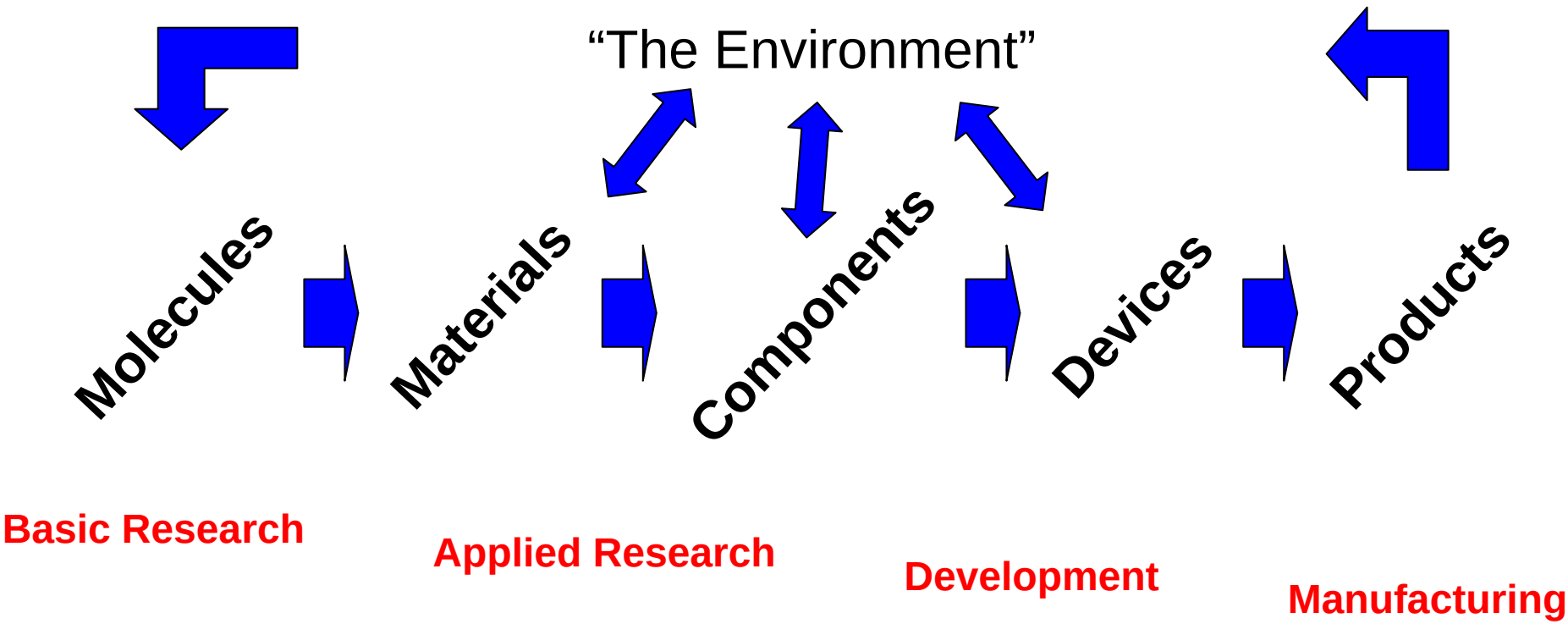


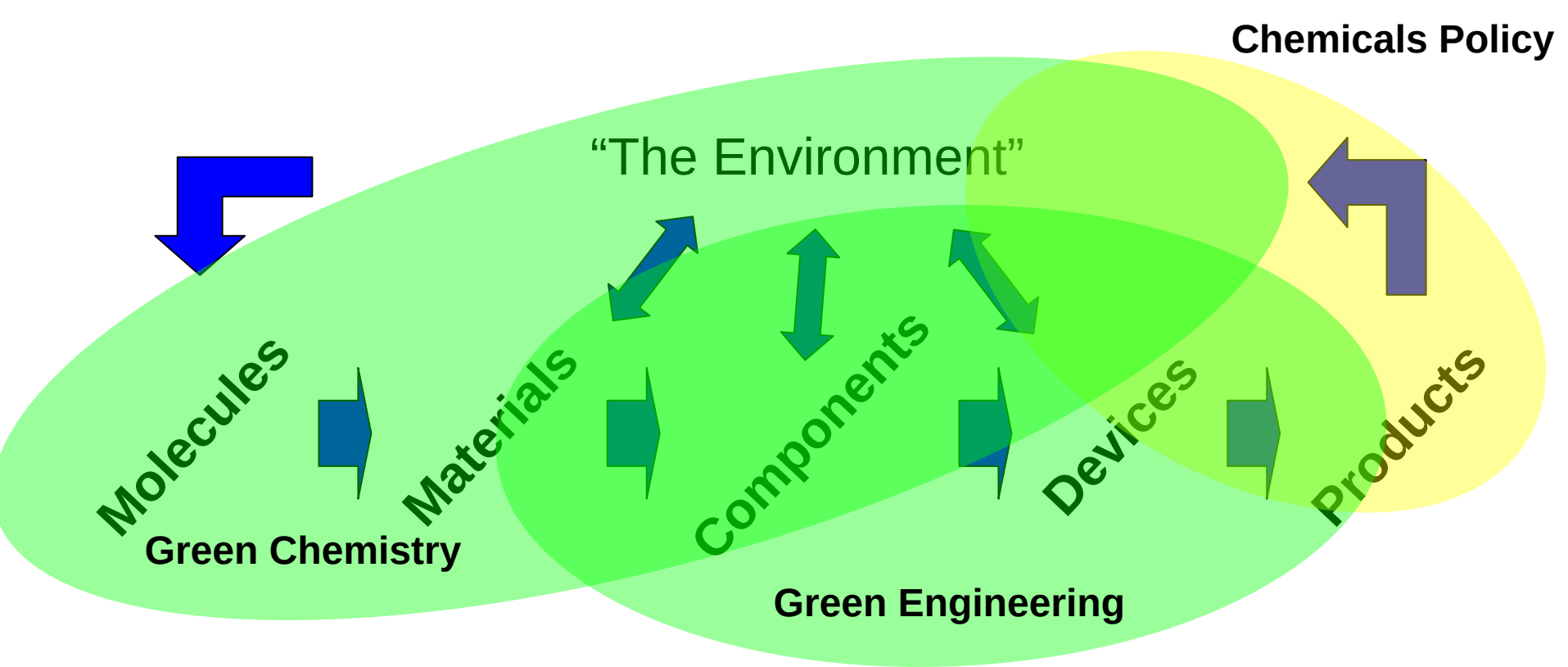
Where do products come from?



Performance

Economics

Social Implications

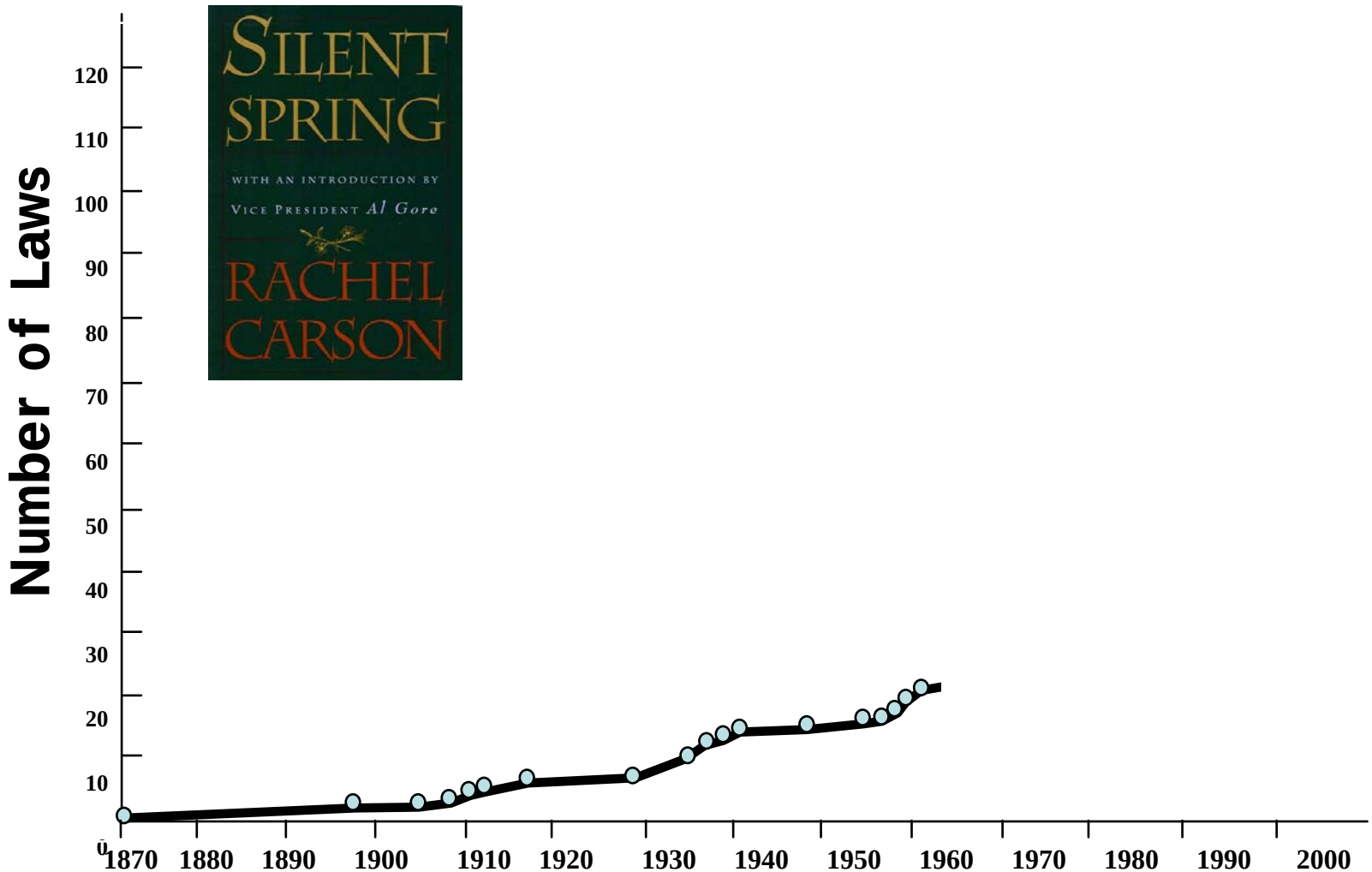

Chemicals Policy
"The Environment"
Molecules
Materials
Components
Devices
Products
Green Chemistry
Green Engineering

Risk = Exposure x Hazard

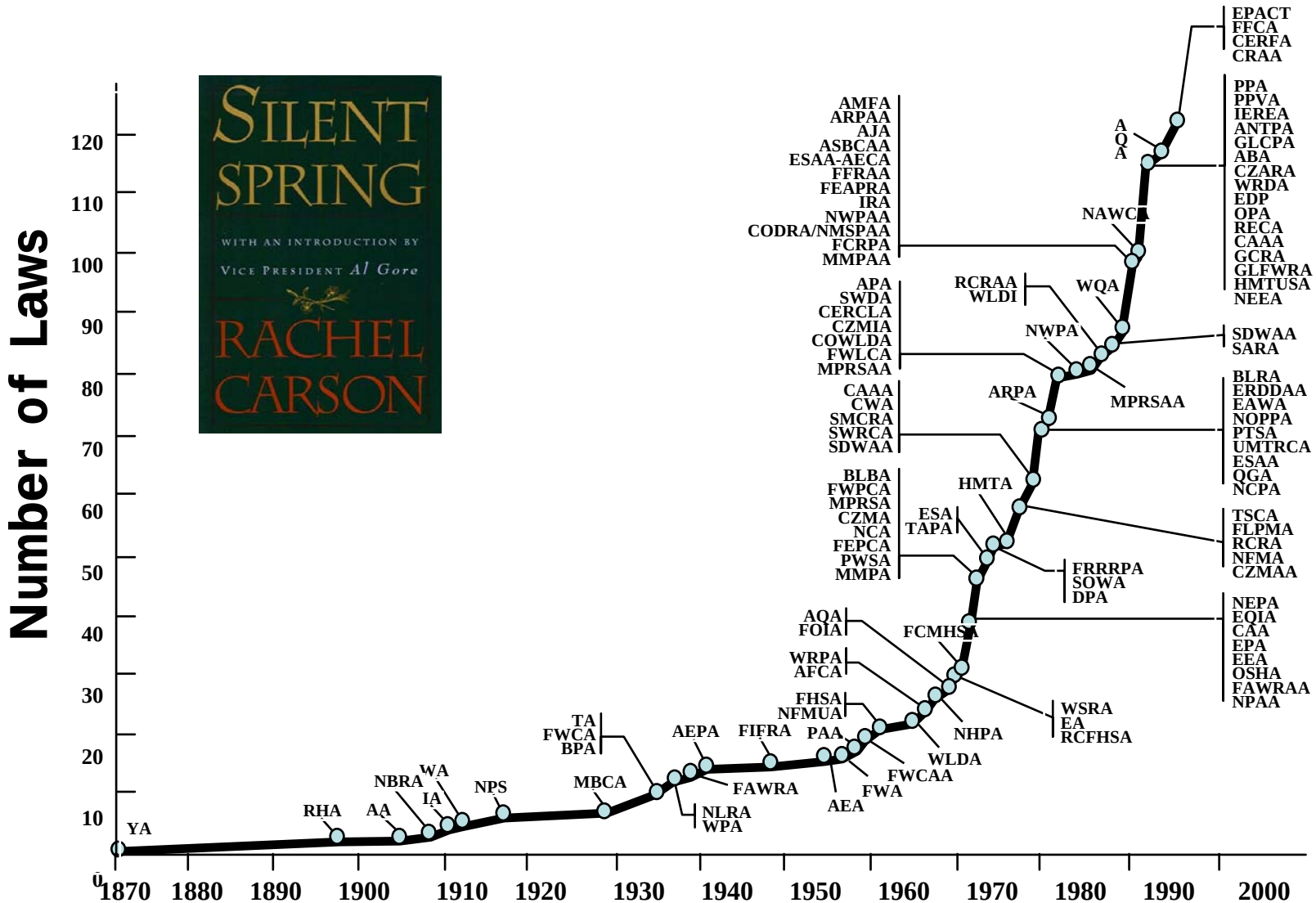
The cost of using hazardous materials:

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

Environmental Regulations



Environmental Regulations



Traditional Processes

- Carbon-Carbon Bonds
- Oxidations
- Reductions
- Hydroxylations
- Polymer Syntheses

Traditional Processes

Green Alternatives

Green Chemistry Research and Development Act of 2006

JENNIFER M. GRANHOLM
GOVERNOR

STATE OF MICHIGAN
OFFICE OF THE GOVERNOR
LANSING

JOHN D. CHERRY, JR.
LT. GOVERNOR

EXECUTIVE DIRECTIVE
No. 2006 – 6

PROMOTION OF GREEN CHEMISTRY FOR SUSTAINABLE ECONOMIC DEVELOPMENT AND PROTECTION OF PUBLIC HEALTH

WHEREAS, Section 1 of Article V of the Michigan Constitution of 1963 vests the executive power of the State of Michigan in the Governor;

WHEREAS, under Section 8 of Article V of the Michigan Constitution of 1963 each principal department of state government is under the supervision of the Governor unless otherwise provided by the Constitution;

WHEREAS, Section 52 of Article IV of the Michigan Constitution of 1963

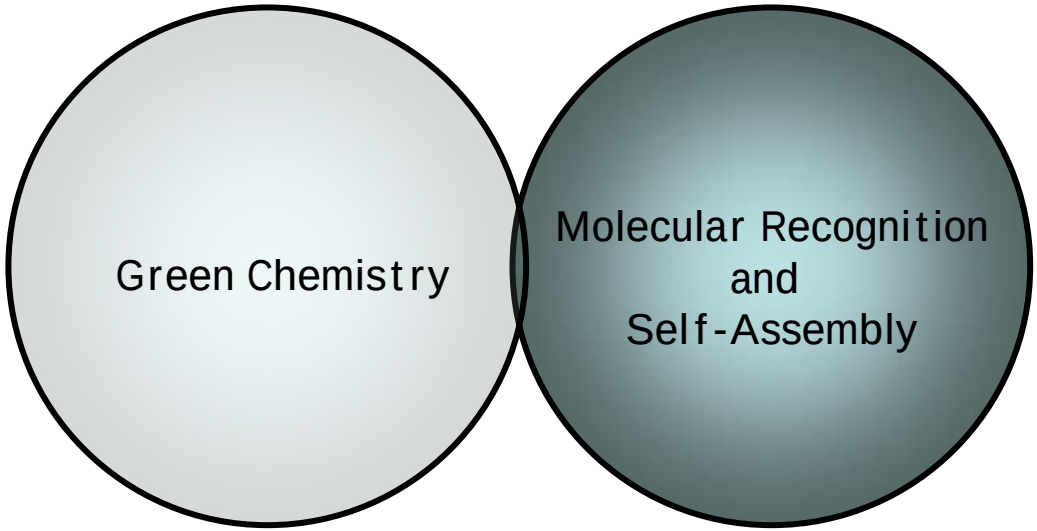
I don’t get it, this seems obvious, why haven’t we always done this?

Everyday Hazards

Unrelated Hazards

Center for Green Chemistry

Bioinspiration



NonCovalent Derivatization

Bioinspired Polymers

Ambient Metal Oxide Semiconductors

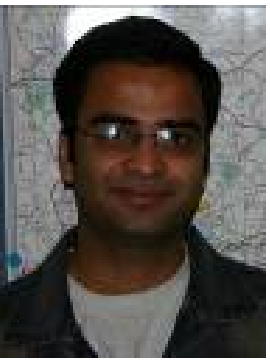
Educational Research

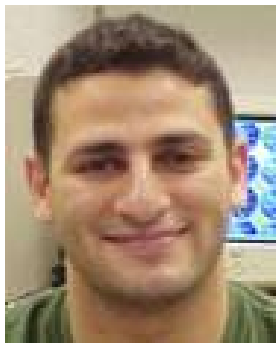
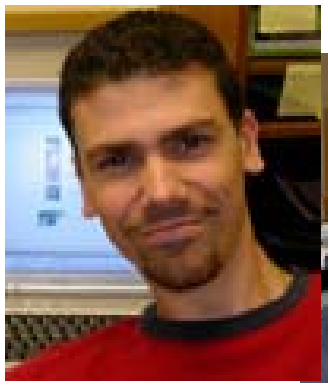
Medicinal Chemistry

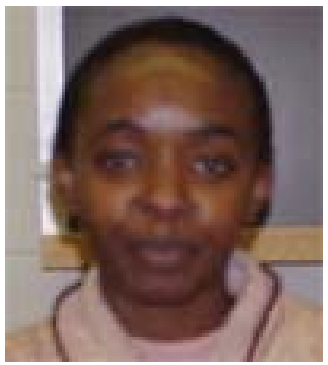
Reaction Design

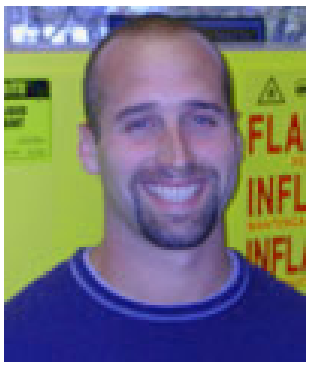
Center for Green Chemistry

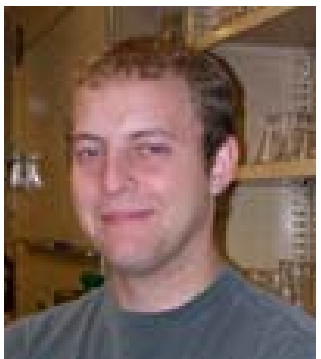
John_warner@uml.edu
www.greenchemistry.uml.edu









COSMETICS / PERSONAL CARE

Hair Curling

Fingernail Polish

Alternative Colorants

Formulation Design

PHOTONICS/ELECTRONICS

Solar Cell Semiconductors

Fuel Cell Membranes

Conductive Polymers

Photoresists

Water Purification

Chemical Sensors

FINE CHEMICALS and POLYMERS

Cellulose Based Technologies

Novel Synthetic Methodologies

Enzymatically Processed Polymers

Textile and Fiber Shape Control

Biodegradable Plastics and Packaging

Low VOC Expanded Polystyrene

PHARMACEUTICALS

Drug Delivery

Focused Bioavailability

Antibacterial Coatings

Anticancer Drugs

Used Pharmaceuticals Destruction

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Green chemistry

John C. Warner*, Amy S. Cannon, Kevin M. Dye

Center for Green Chemistry, University of Massachusetts-Boston, 100 Morrissey Boulevard, Boston, MA 02125-3393, USA

Abstract

A grand challenge facing government, industry, and academia in the relationship of our technological society to the environment is reinventing the use of materials. To address this challenge, collaboration from an interdisciplinary group of stakeholders will be necessary. Traditionally, the approach to risk management of materials and chemicals has been through interventions intended to reduce exposure to materials that are hazardous to health and the environment. In 1990, the Pollution Prevention Act encouraged a new fact-elimination of hazards at the source. An emerging approach to this grand challenge seeks to embed the diverse set of environmental perspectives and interests in the everyday practice of the people most responsible for using and creating new materials—chemists. The approach, which has come to be known as Green Chemistry, intends to eliminate intrinsic hazard itself, rather than focusing on reducing risk by minimizing exposure. This chapter addresses the representation of downstream environmental stakeholder interests in the upstream everyday practice that is reinventing chemistry and its material inputs, products, and waste as described in the "12 Principles of Green Chemistry".
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Keywords: Green chemistry; Pollution prevention; Benign by design; Reducing intrinsic hazard

1. A grand challenge

There is a grand challenge facing government, industry, and academia in the relationship of our technological society to the environment—Reinventing the

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doi:10.1016/j.eiar.2004.06.006

FEATURE

The incorporation of hazard reduction as a chemical design criterion in green chemistry

By Nicholas D. Anastas, John C. Warner

INTRODUCTION

Molecular designers use their knowledge of chemical properties and behavior to alter the structure of existing molecules or introduce new compounds into the world that have never before existed. Thousands of new compounds are discovered or synthesized every day–each with an unknown hazard profile. These compounds come from the fertile minds and skilled hands of scientists in academic research laboratories, pharmaceutical companies and industrial manufacturing enterprises. As part of the design process of modifying the structure of existing chemicals or *de novo* synthesis, decisions are made on what structural and physical characteristics are necessary to achieve the intended function of the target molecule.

In any of the chemical manufacturing sectors, chemical products are intended to achieve some beneficial use. The intended function of most molecules synthesized in the pharmaceutical industry is to beneficially influence human health and to improve quality of life. It is important to realize that it is often the intent that final-product molecules exhibit certain properties and reactivity. Throughout the chemical industry, compounds have been intentionally created to be reactive–in order to achieve a variety of functions. Unfortunately, this reactivity can lead to adverse consequences. Industrial chemicals encompass an extremely wide range of individual and classes of compounds, for example, solvents, adhesives, plastics, polymers, fine and bulk chemicals. These chemicals are used in myriad ways. To be commercially successful, industrial chemicals need to be economical to synthesize, relatively easy to distribute and ultimately able to achieve their intended function. Historically, of all of the considerations that are part of the design process, designing for reduced hazard has not been routinely included. It is useful to review what progress has been made toward changing the current methods of molecular design and what work yet needs to be done in order to ensure that hazard reduction is a criterion for future chemical design.

Green chemistry seeks to incorporate hazard reduction ab initio, in other words, as an integral part of the design process.

Green chemistry[1] seeks to incorporate hazard reduction *ab initio*, in other words, as an integral part of the design process. Just as preventive medicine uses the advances and tools that are available to physicians and allied health professionals to prevent untoward events, green chemistry's goal is to prevent adverse consequences of the design of chemicals by making informed design choices that minimize hazard. As a design criterion, hazard reduction would occupy equal status with the other physicochemical attributes associated with chemical structure and function. *Hazard should be considered a design flaw and efforts need to be made in the designing phase to minimize or eliminate it.* Development of a framework to design safer chemicals will significantly improve the likelihood of reducing the generation of hazardous chemicals.

WHAT IS HAZARD?

Designing safer chemicals requires an understanding of what makes a chemical dangerous. Hazard is an overarching term that encompasses several categories including toxicity, physical hazards and global hazards. Each of these categories has subcategories and overlap among them is unavoidable given the complex nature of the interactions among living things and the biosphere. Defining and using the terms hazard, toxicity and risk is not as straightforward an assignment as it should be–due to a number of factors, among them overlapping conceptual material, inconsistent historical use and professional judgment on where to draw categorical lines.

Table 1 presents the definitions used throughout this paper selected from some major reference documents used in toxicology and risk assessment. The five terms have common attributes and often times encompass overlapping and similar scopes. For the purposes

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1074-9098/04/$30.00
doi:10.1016/j.chs.2004.10.001
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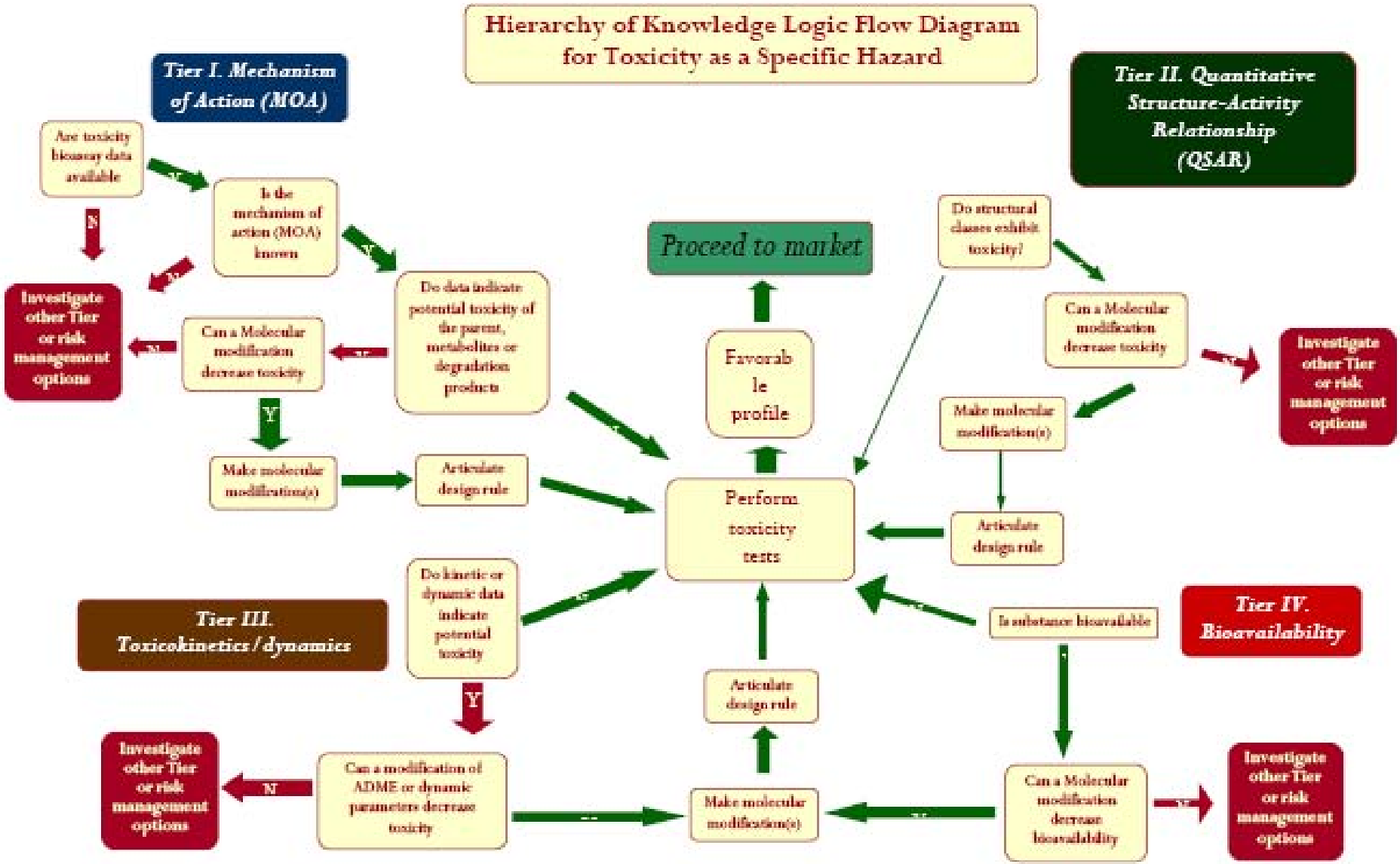
J. Environmental Impact Assessment, **2004** *24* 775-799.

J. Chem. Health and Safety **2005**, *12(2)*, 9-13.

J. Chem. Health and Safety **2005**, *12(2)*, 9-13.



The bigger picture.

Physical properties of a material

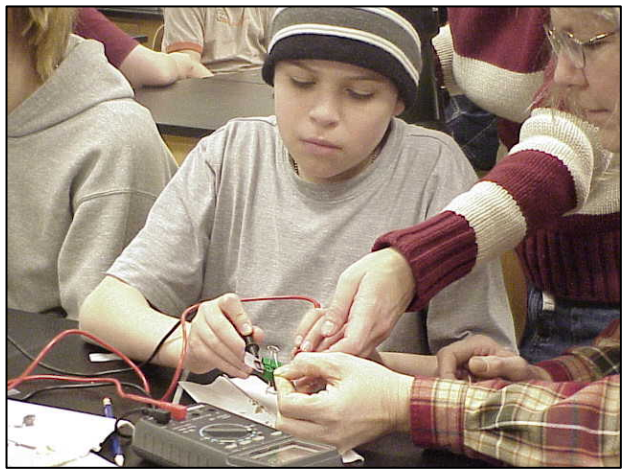
- State of Matter
- Color
- Melting Point
- Boiling Point
- Solubility
- Electrical Conductivity

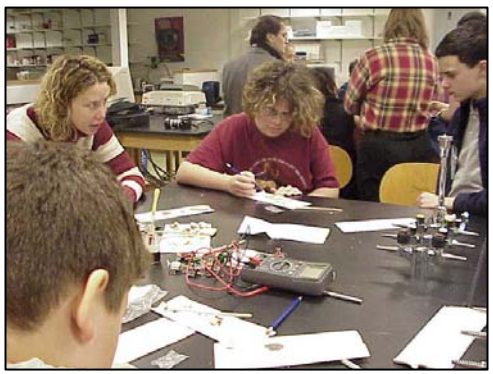
Physical properties of a material

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

Outreach and Community Education

K-12 Education:





Welcome to
Green Chemistry Day
with UMass Lowell
Please join us!
Blue Wing, Lower Level
Science
Exhibit Halls
are open today
9:00 am – 5:00 pm
Science

Community Outreach:

Green Chemistry

Carole LeBlanc, Editor, Toxics Use Reduction Institute, UMass Lowell, Lowell, MA 01854

Lowell's Industrial Evolution
Earth Day, April 22, 2006
The UML Center for Green Chemistry and the Revolving Museum

UML Center for Green Chemistry[1]
John_Warner@uml.edu[2]

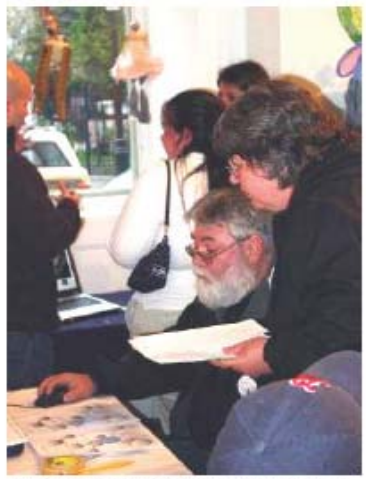
What does the typical chemistry research group do on the weekend? It is more likely than not, business as usual: conducting experiments using a variety of instrumentation – chromatography, spectroscopy, scanning reactions, refluxing, or writing up reports. On a normal weekend, graduate students and staff at the Center for Green Chemistry are routinely doing these things. However, Saturday, April 22 was special. The Center for Green Chemistry hosted an event in honor of Earth Day 2006 - not the typical activity of a chemistry research group.

On Earth Day, downtown Lowell's Revolving Museum was the scene of a public outreach event, the Center for Green Chemistry's presentation of "Lowell's Industrial Evolution". People from all backgrounds and disciplines were invited to this free event that housed over twenty original exhibits designed to disseminate the group's research and its green chemistry focus to anyone willing to learn.

At the 6 PM opening, visitors were welcomed to four hours of multimedia presentations from posters to video to interactive computer applications. Hands-on experiments were performed with interested children, as well as inquiring adults and elders, on the methods of creating environmentally benign solar cells using ingredients such as black berries and powdered donuts. In addition to refreshments, the music of the local vocal group Aksara added to the comfortable and relaxed atmosphere of this atypical, intergenerational learning environment.

Two dozen graduate students and staff of the Center for Green Chemistry, their spouses, and friends developed artistic renderings of their scientific research in a fashion accessible to the public. This event alloys the spirit of UMASS Lowell's mission in Sustainable Development with the Revolving Museum's emergence as a public art space that fosters interdisciplinary collaboration in its mission of education and urban redevelopment.

Professor John Warner, Director of the Center of Green Chemistry, led the effort to make the research technology accessible to local citizens. The first industrial revolution a



couple of centuries ago served to separate society from technology. This revolution sees them coming back together again. What he wanted was a cultural happening in the downtown arts district, next to the headquarters of Lowell's National Park, a poem to the Industrial Revolution. Consequently, he decided to have the Center offer the city a celebration of technology in the service of the environment –

"Lowell's Industrial Evolution" in synchrony with the Revolving Museum's "evolve" campaign.

The Center's full participation in the earth day event culminated in 23 creative portrayals of research in the development of sustainable materials. Earth Day exhibits covered research in: bio-inspired photopolymers, crystal engineering, biodegradation of plastics, plastics based on biomass, antimicrobial surfaces without resistance-causing antibiotics, the life cycle of electronic wastes, photopolymer functionalized papers and textiles, work on toxics reduction in nail salons, the use of catalysts enabling hydrogen peroxide to clean up paper and textile mill wastewater, opportunities for greening chromatography, and improving bioavailability of pharmaceuticals through Green Chemistry.

Hands-on stations engaged walk-ins from the general public in making their own solar cells, creating images using photopolymers and ultraviolet light, and painting with photochromic coatings - materials that change color in different light. Another interactive station previewed the release of a new website called "Clickable Principles" which provide both the layman and the bench chemist a guided tour through the Principles of Green Chemistry, with applications in the home and in the lab.

The human side of technology was highlighted through maps, video, and interactive flipcharts. A map presented during the event highlighted the Center's outreach activities in schools, communities, museums, professional associations, industry, and academia in the New England area. A video production of the international faces of Green Chemistry presented translations of each principle of Green Chemistry into a dozen different languages spoken by members of the Center. This video calls attention to Dr. Warner's seminal book, *Green Chemistry: Theory and Practice*, now translated into a dozen languages. A collection of chap books on each member of the Center was developed by the wife of a post-doctoral researcher from the Waseda University in Tokyo. Each book started with, "What was your dream as a child?", moved on to other biographical questions along with "Why did you decide to become a chemist?", "What is your deepest environmental concern?", and "What message would you like to offer the reader?". Attendees of the event turned this into a game of guessing which students and staffers were linked to which dreams.

Visitors from downtown, families, and elders, included many faces familiar to the burgeoning downtown cultural scene. The event also provided an opportunity for visits by Center member families, other faculty and their families, and a contingent of students and faculty from a number of local colleges and universities. Feedback from the droves of visitors from the time the doors opened until closing time at 10 pm was overwhelmingly positive which made the night that much more special to the already enthusiastic presenters. Visitors stayed engaged with exhibits in one-on-one conversations with the researchers and students for extended periods. The night fostered an interesting combination of public education and communication training for the students. The event marked the beginning of an annual tradition the Center for Green Chemistry hopes to continue with the Revolving Museum.

1. Parts of this article have appeared in the May 10th issue of the *UMass Lowell Shuttle* and appear here with the permission of Mary Lou Hobble, the *Shuttle's* Editor. It is a collaborative effort of a group of authors.
2. Questions and comments on this article may be directed to Dr. John Warner: John_Warner@uml.edu.

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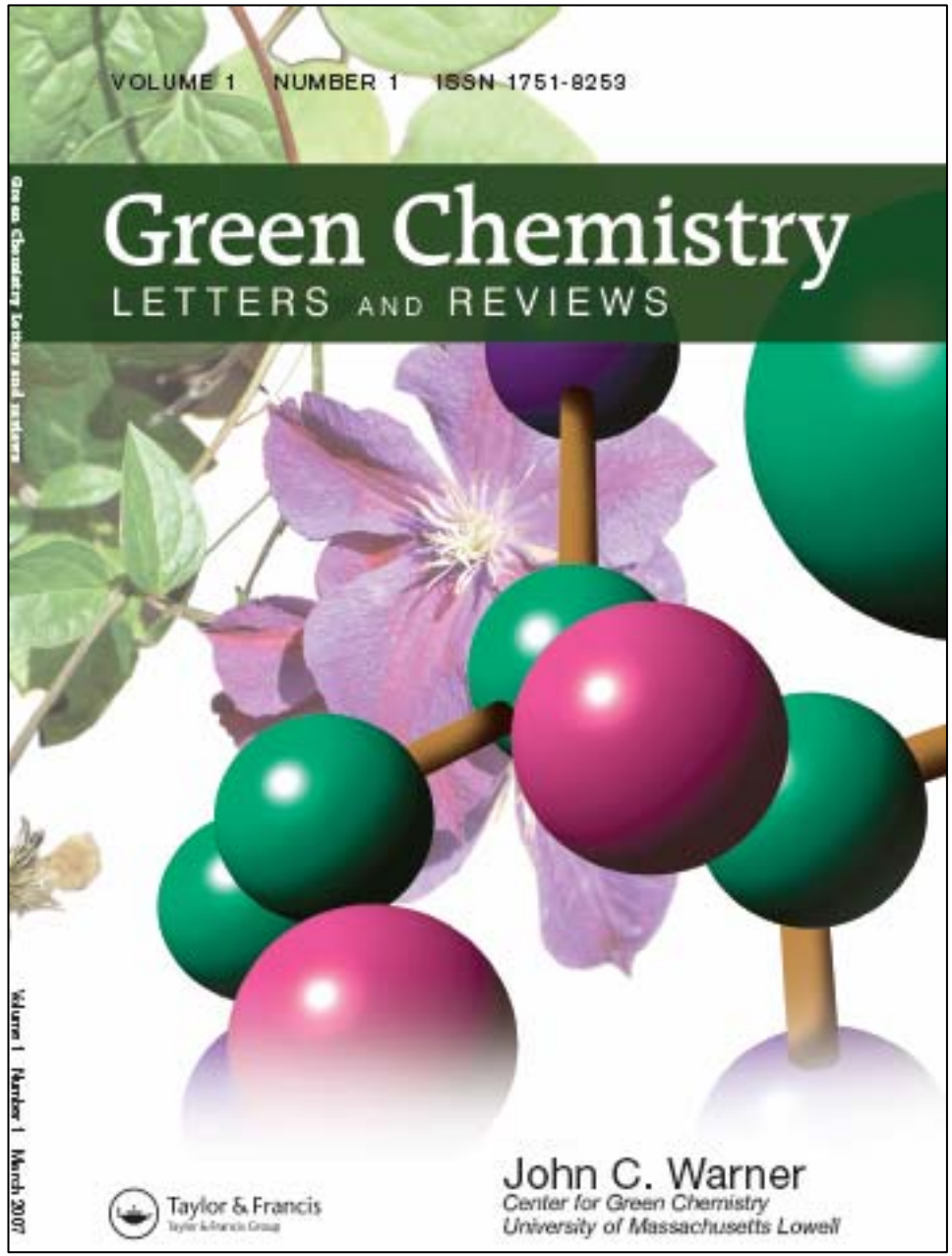

Center for Green Chemistry

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