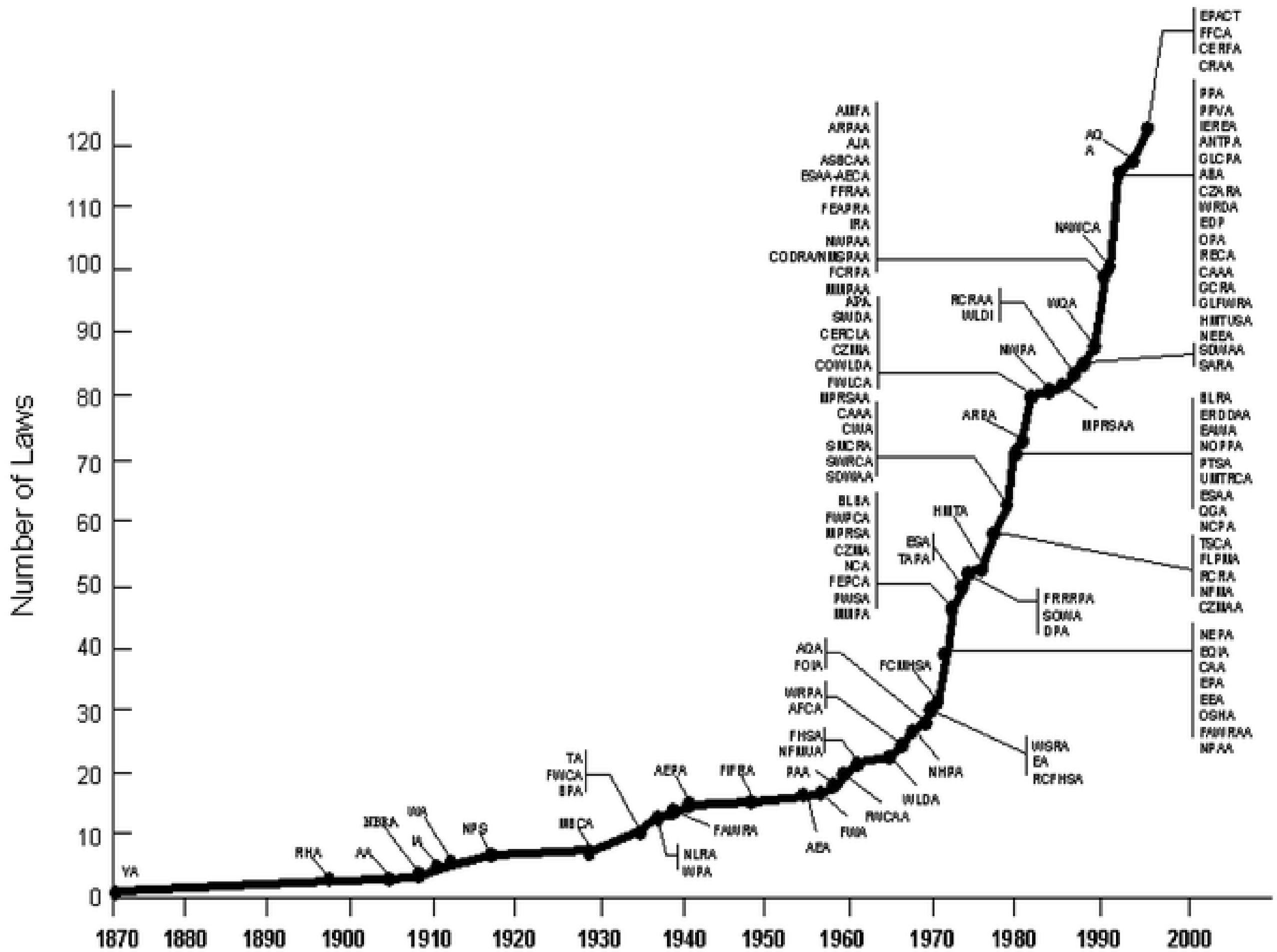
The How of Sustainability

Paul Anastas, Julie Zimmerman

Yale University

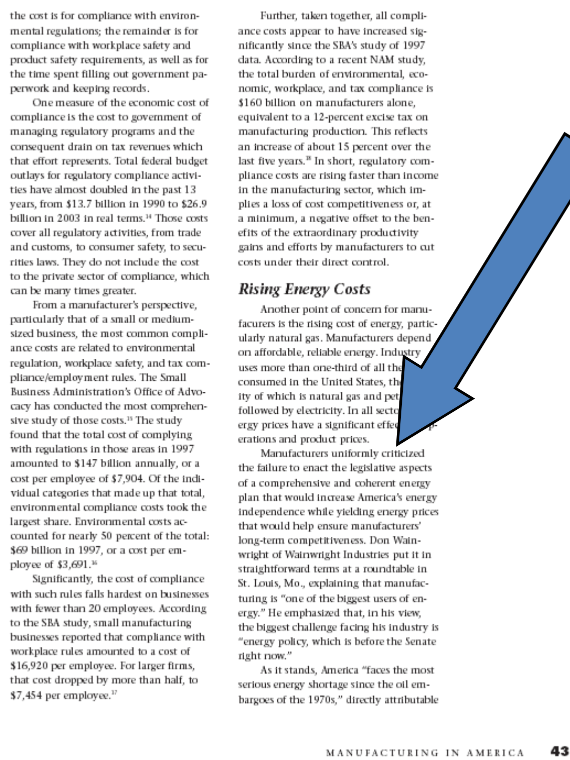
Environmental Regulation Growth



Source: J. A. Cusumano, New Technology for the Environment, Chemtech, 1992, 22(8), 482–489

P. T. Anastas, Meeting the Challenges of Sustainability through Green Chemistry, Journal of Green Chemistry, 2003, 5(2), G29-G34.

U.S. Dept. of Commerce Report on Manufacturing



the cost is for compliance with environmental regulations; the remainder is for compliance with workplace safety and product safety requirements, as well as for the time spent filling out government paperwork and keeping records.

One measure of the economic cost of compliance is the cost to government of managing regulatory programs and the consequent drain on tax revenues which that effort represents. Total federal budget outlays for regulatory compliance activities have almost doubled in the past 13 years, from $13.7 billion in 1990 to $26.9 billion in 2003 in real terms.[14] Those costs cover all regulatory activities, from trade and customs, to consumer safety, to securities laws. They do not include the cost to the private sector of compliance, which can be many times greater.

From a manufacturer's perspective, particularly that of a small or medium-sized business, the most common compliance costs are related to environmental regulation, workplace safety, and tax compliance/employment rules. The Small Business Administration's Office of Advocacy has conducted the most comprehensive study of those costs.[15] The study found that the total cost of complying with regulations in those areas in 1997 amounted to $147 billion annually, or a cost per employee of $7,904. Of the individual categories that made up that total, environmental compliance costs took the largest share. Environmental costs accounted for nearly 50 percent of the total: $69 billion in 1997, or a cost per employee of $3,691.[16]

Significantly, the cost of compliance with such rules falls hardest on businesses with fewer than 20 employees. According to the SBA study, small manufacturing businesses reported that compliance with workplace rules amounted to a cost of $16,920 per employee. For larger firms, that cost dropped by more than half, to $7,454 per employee.[17]

Further, taken together, all compliance costs appear to have increased significantly since the SBA's study of 1997 data. According to a recent NAM study, the total burden of environmental, economic, workplace, and tax compliance is $160 billion on manufacturers alone, equivalent to a 12-percent excise tax on manufacturing production. This reflects an increase of about 15 percent over the last five years.[18] In short, regulatory compliance costs are rising faster than income in the manufacturing sector, which implies a loss of cost competitiveness or, at a minimum, a negative offset to the benefits of the extraordinary productivity gains and efforts by manufacturers to cut costs under their direct control.

Rising Energy Costs

Another point of concern for manufacurers is the rising cost of energy, particularly natural gas. Manufacturers depend on affordable, reliable energy. Industry uses more than one-third of all the [illegible] consumed in the United States, th[illegible] ity of which is natural gas and pet[illegible] followed by electricity. In all secto[illegible] ergy prices have a significant effe[illegible]p-erations and product prices.

Manufacturers uniformly criticized the failure to enact the legislative aspects of a comprehensive and coherent energy plan that would increase America's energy independence while yielding energy prices that would help ensure manufacturers' long-term competitiveness. Don Wainwright of Wainwright Industries put it in straightforward terms at a roundtable in St. Louis, Mo., explaining that manufacturing is "one of the biggest users of energy." He emphasized that, in his view, the biggest challenge facing his industry is "energy policy, which is before the Senate right now."

As it stands, America "faces the most serious energy shortage since the oil embargoes of the 1970s," directly attributable

MANUFACTURING IN AMERICA 43

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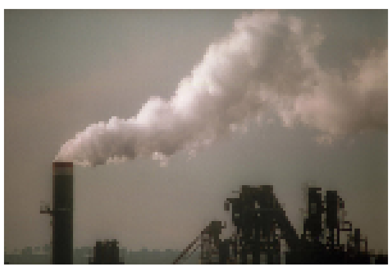
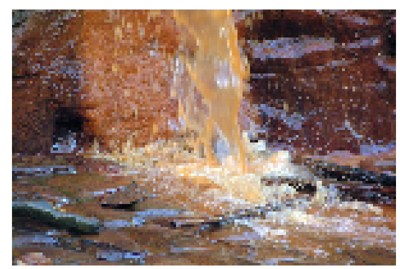
"The total burden…is $160 billion on manufacturers alone."

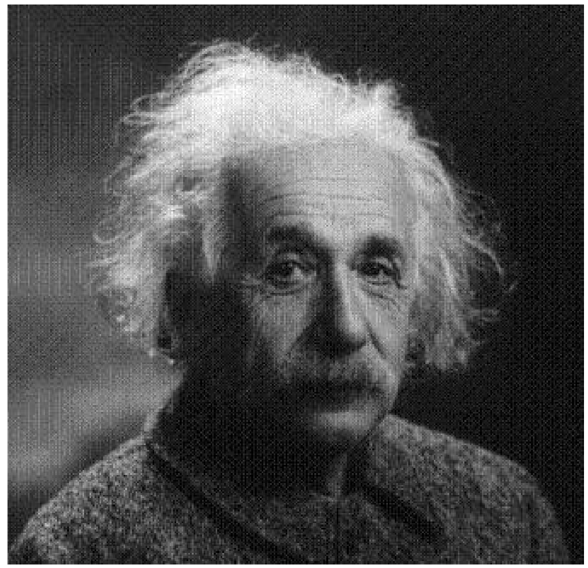
Environmental Impacts

- Toxics Release Inventory (TRI)
- 4.44 billion lbs. of toxic chemicals were released directly to air, land, and water in 2006 (latest year data released)





  – Only 650 of toxic chemicals and toxic chemical categories out of 78,000 in commerce are tracked by TRI



“Problems cannot be solved at the same level of awareness that created them.”

Green Chemistry Joins College Curriculum

By MARK PRATT
The Associated Press
Tuesday, October 9, 2007;

"When you think about chemistry, most people think about the hazards," said Paul Anastas, who coined the term green chemistry in 1991 while working at the U.S. Environmental Protection Agency. He is now director of Yale University's Center for Green Chemistry and Green Engineering.

The Washington Post

Green chemistry: Voluntary restraint is the target

FINANCIAL TIMES

By Sarah Murray
Published: September 18 2007
…Known as "green chemistry" the idea is to redesign materials and products in ways that cut or eliminate hazardous and toxic elements.

THE WALL STREET JOURNAL

"Green Chemistry Wins Converts"

October 9, 2007

Environmental awareness fuels green chemistry

- Story Highlights
- Green chemistry: The development of products that won't hurt the environment
- Only about a dozen colleges teach green chemistry
- Yale chemistry director: Green chemistry is useless unless it is profitable
- Businesses are seeking graduates with backgrounds in green chemistry

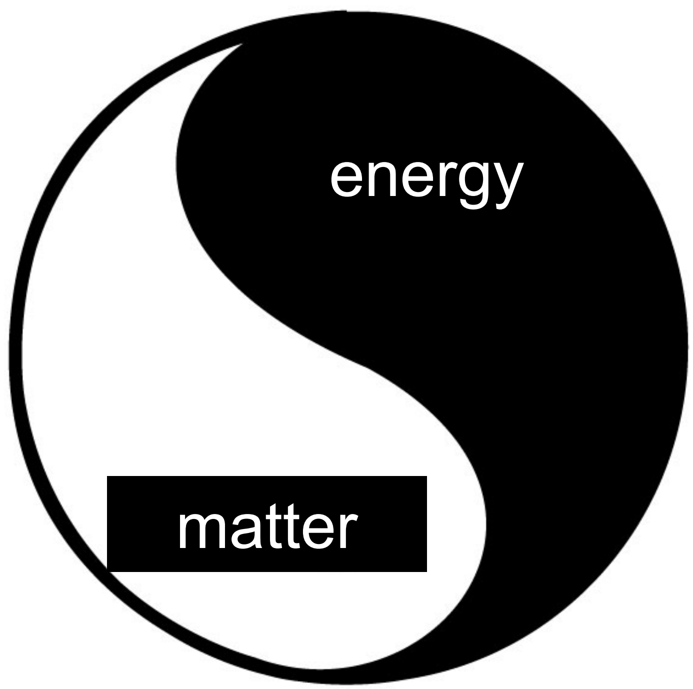
CNN

The bottom line on green design

"People who originally thought green chemistry was just about environmental concerns are now seeing that it also increases process efficiencies," says Paul Anastas, professor of green chemistry at the Center for Green Chemistry and Green Engineering at Yale University in the US, who is seen by many as the father of green chemistry. "This is an engine for the innovation side of the business and an ability to distinguish yourself in the market with new products with new capabilities."

The Economist

All we have is…



Green Chemistry and Engineering

- Green Chemistry and Engineering develop products and processes that enhance performance and profitability while minimizing impacts on human health and the environment.
- , aerospace, and defense.

Demonstrated achievements of GC&E across industrial sectors

- Defense and aerospace
  - *Adhesives, coatings, corrosion inhibitors*
- Automotive
  - *Solvents, polymers, fuels*
- Household cleaners
  - *Surfactants, fragrances, dyes*
- Cosmetics
  - *Builders, chelating agents, dyes*
- Agriculture
  - *Pesticides, fungicides, fertilizers*
- Electronics
  - *Solder, housings, displays*
- Pharmaceuticals

Definition

GREEN CHEMISTRY

The design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances

Principles of Green Chemistry

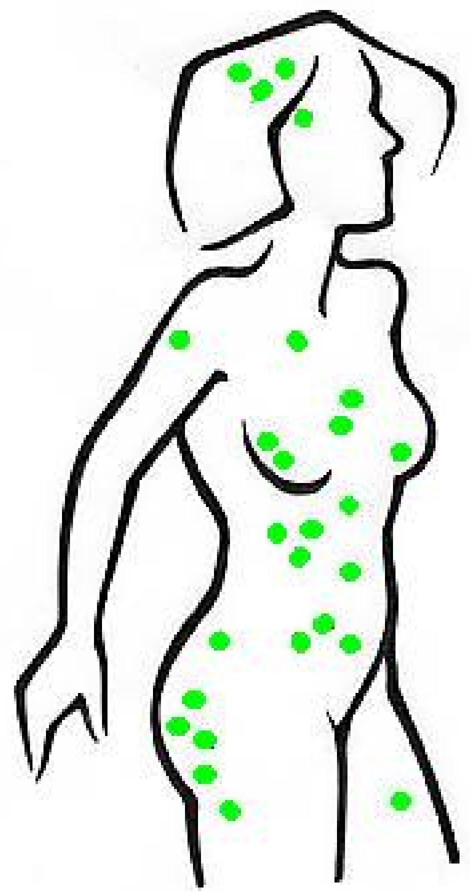
1. It is better to prevent waste that to treat or clean up waste after it is formed.
2. Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3. Wherever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
4. Chemical products should be designed to preserve efficacy of function while reducing toxicity.
5. The use of auxiliary substances (e.g. solvents, separation agents, etc.) Should be made unnecessary wherever possible and, innocuous when used.
6. 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. A raw material of feedstock should be renewable rather than depleting wherever technically and economically practicable.
8. Reduce derivatives - Unnecessary derivatization (blocking group, protection/ deprotection, temporary modification) should be avoided whenever possible.
9. Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. Chemical products should be designed so that at the end of their function they do not persist in the environment and break down into innocuous degradation products.
11. 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. Substances and the form of a substance used in a chemical process should be chosen to minimize potential for chemical accidents, including releases, explosions, and fires.

Twelve Principles…Isn’t that how it is done now?

- Entire industries are geared toward cleaning up after wasteful chemical syntheses.
- Today’s scientific literature is filled with synthetic pathways that are inefficient by design.
- Reagents are seldom selected with regard to hazard.
- Industrial chemicals do not have minimal hazard as a performance criterion
- Persistence of chemicals in the biosphere and in our bodies is a major global health issue. (CDC 250 chemicals since 1945)
- The vast majority of organic chemicals are made by depleting (non-renewable) feedstocks
- Our chemical industry deals with security through guns, guards and gates.

Body Burden

- 148 chemicals in the body as determined by CDC study
- Of the chemicals found:
  - 76 cause cancer in humans or animals,
  - 94 are toxic to the brain and nervous system, and
  - 79 cause birth defects or abnor development.
- The dangers of exposure to these chemicals in combinati has never been studied.



Chemical Site Security

- Over $2B in security enhancements since 2001. (American Chemistry Council testimony to Senate,)

Focus on Use and Generation

Risk = Hazard x Exposure

Green chemistry and engineering focus on reducing risk by reducing hazard.

The Change in Thinking

- Green chemistry and engineering moves our consideration of how to deal with environmental problems from the ***circumstantial*** to the ***intrinsic*****.**
- Hazard must be recognized as a ***design flaw***

Distinguishing the Circumstantial vs. Intrinsic

Circumstantial

- Use
- Exposure
- Handling
- Treatment
- Protection
- Recycling
- Costly

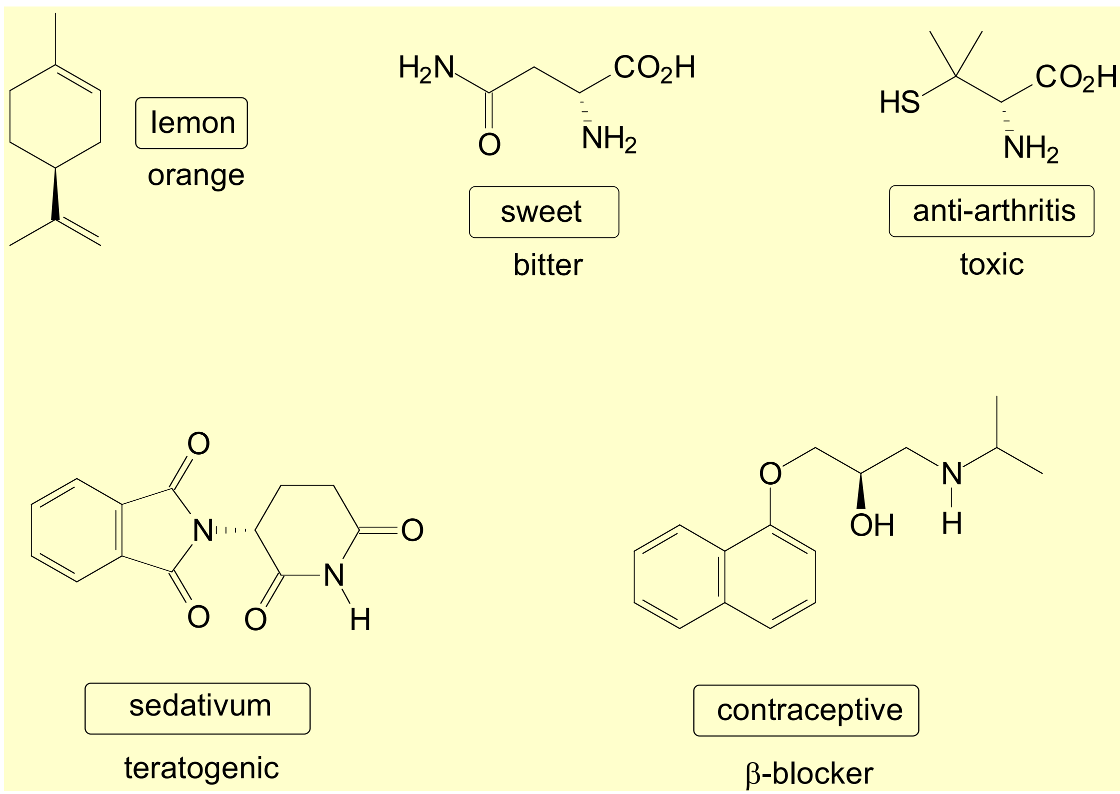
Intrinsic

- Molecular design for reduced toxicity
- Reduced ability to manifest hazard
- Inherent safety from accidents or terrorism
- Increased potential profitability

Molecular Formulas: Function and Toxicity

Molecular formula (C_3H_6O)			
Name	Acetone	Methyl vinyl ether	Allyl alcohol
Toxicity LD-50	9.0 g/kg (oral-rat)	4.9 g/kg (oral-rat)	0.06 g/kg (oral-rat)

Isomers:
Function and Toxicity



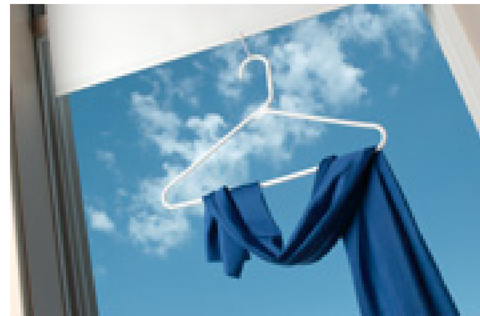
The great enemy of the truth is very often not the lie, deliberate, contrived and dishonest, but the myth, persistent, persuasive and realistic.

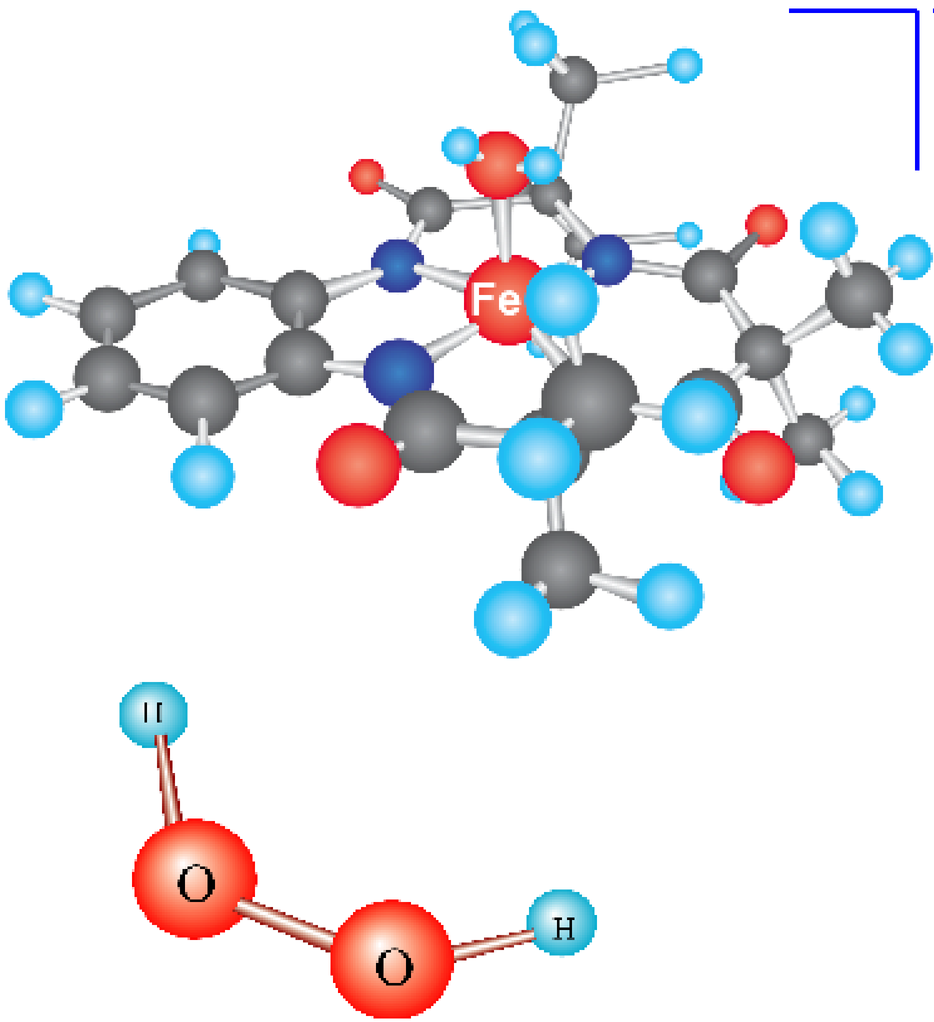
--John F. Kennedy

EXAMPLES OF
GREEN CHEMISTRY

Biobased Plastics

- Polylactic acid has multiple applications:
  - Fabric
  - Fibers
  - Bottles
  - CDs, DVDs





TEXTILES
dye bleaching,
effluent decolorization

PULP AND PAPER
pulp bleaching,
effluent AOX and color removal

WATER CLEANING
halogenated aromatics and
organics destruction

LAUNDRY
Dye transfer inhibition,
stain removal

PETROLEUM REFINING
rapid oxidation of sulfur
contaminants, other uses

HOMELAND DEFENSE
Rapid destruction of chem-bio
warfare/terrorism agents

Serenade®: An Effective, Environmentally Friendly Pesticide

- Applicable in both organic farming
- Produced without solvents or nonrenewable resources
- Feedstock includes agricultural materials (soybeans, starches, sugars) from plant-based sources
- No synthetic chemical residues
- Non-toxic to humans, beneficial insects and organisms.
- Does not cause insect or disease resistance.

AgraQuest, Inc.

Fire Extinguishing Foam

- Traditional products are ozone depleting and sources of toxic emissions
- Biodegradable surfactants used in very small quantities
- Results in an 87-93% reduction in product usage
- Extinguished a large oil tanker fire at sea in 12.5 minutes (estimated to require 10 days)

PYROCOOL Technologies, Inc.

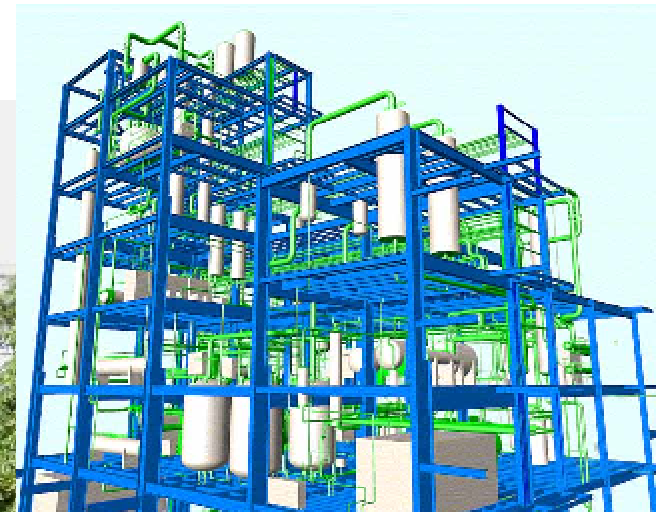
Eli Lilly (Talampanol)

- Presidential Green Chemistry Challenge Award
- Drug for treating epilepsy and neuro degenerative diseases
- New process
  - 7 steps with 3 product isolations
  - Eliminated 34000 l and 300 kg chromium waste per 100 kg API
  - Yield increased from 16 to 55%
  - Bioreduction of a ketone to a chiral alcohol with *Zygosaccaromyces rouxii* in 96% yield.

Strategies for transformative sustainable design

Sustainability, & chemical product design

Coffee decaffeination using methylene chloride

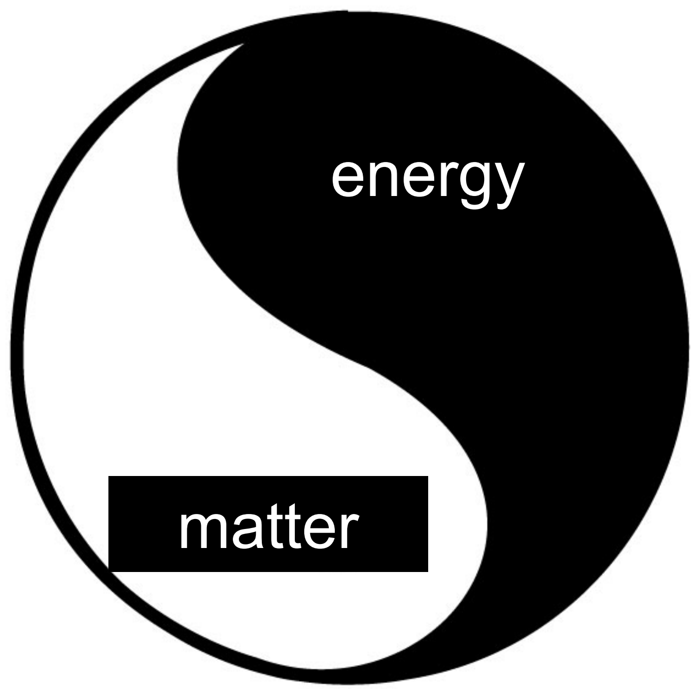


Coffee decaffeination using CO_2 (not a “solvent

The task is the cleaning of clothes; current product is detergent.

Fabric dying

Is this really all we have?



Center for
Green Chemistry
&
Green Engineering
at
Yale

www.greenchemistry.yale.edu