Green Chemistry: sustaining a high technology civilization

Terry Collins

Environmental Health Lecture Series, Seattle Town Hall, January 24, 2007

Our civilization is not sustainable as currently constituted

— flawed technologies are important components of the sustainability dilemma

— green chemists have to fix many of the flawed technologies as they are chemical in nature, meaning that green chemistry is an essential paradigm shift for chemistry

— there is no option – just think of the kids!

— all we have to work with is mere mortals

— which means considerable error and the need for open discourse across multiple disciplines to minimize it

"Altered Nature of Human Action"

"All previous ethics…[have been based upon the premises]…that the human condition, determined by the nature of man and the nature of things,was given once for all;
that the human good on that basis was readily determinable; and that the range of human action and therefore responsibility was narrowly circumscribed. … [But] with certain development of our powers the nature of human action has changed, and … [given rise to] …"

"***a whole new dimension of ethical relevance for which there is no precedent in the standards and canons of traditional ethics.***"

The Imperative of Responsibility: Finding an Ethics for the Technological Age, Hans Jonas, U. Chic. Press, 1984

What is Green Chemistry?

"Green Chemistry is the design of chemical products and processes that reduce or eliminate the use and generation of hazardous compounds."

Paul Anastas

The Fundamental Green Chemistry Concept Equation

$$\text{Risk} = f_1(\text{exposure}) \times f_2(\text{hazard})$$

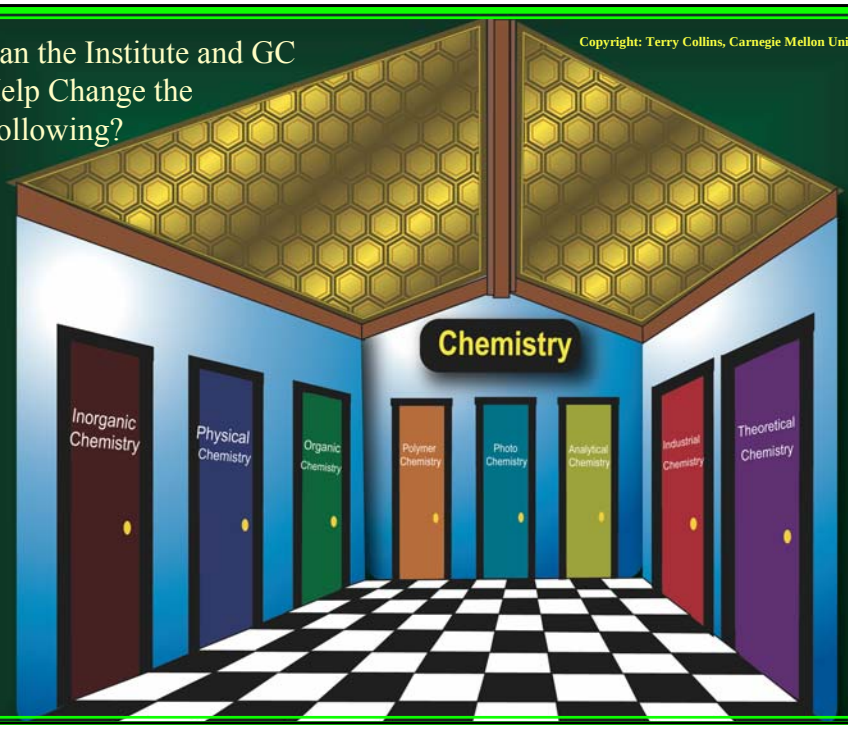
Paul Anastas and John Warner

What is the Institute for Green Oxidation Chemistry?

A research, education and development center in which a ***holistic approach to sustainability science*** is being developed.

Research	Education	Development
TAML® activators	GC curricula for the world	Pittsburgh TAML company

Can the Institute and GC Help Change the Following?



The Human Products of Ph.D. Science Education

- Individuals who have spent ten key intellectually formative years focusing on technical skills, often while ignoring their implications (*we are missing toxicity and ecotoxicity understanding — this structural flaw will be fixed by green chemists*)
- Specialists devoted to technical performance as is essential for strong scientists (*this will not be lost as some appear to fear, but instead will be strengthened through GC*)
- People who don't control the destiny of their work given the corporate world structure (*can't easily be reoriented within the reigning business paradigm*)

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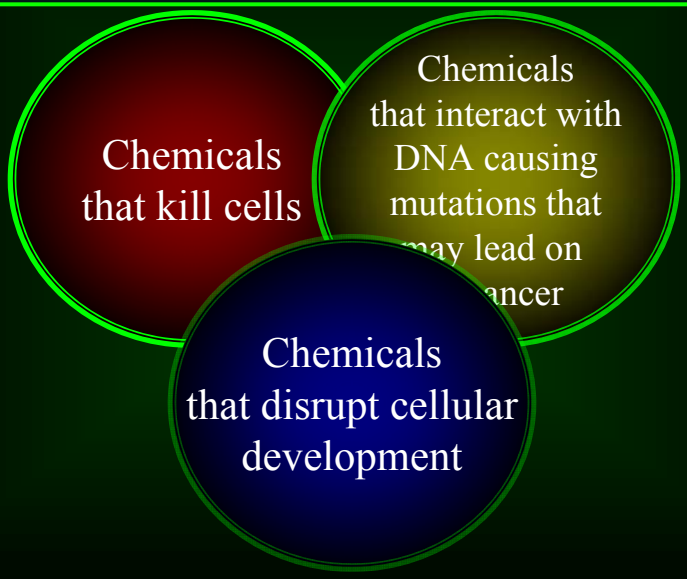
Toxicological Endpoints



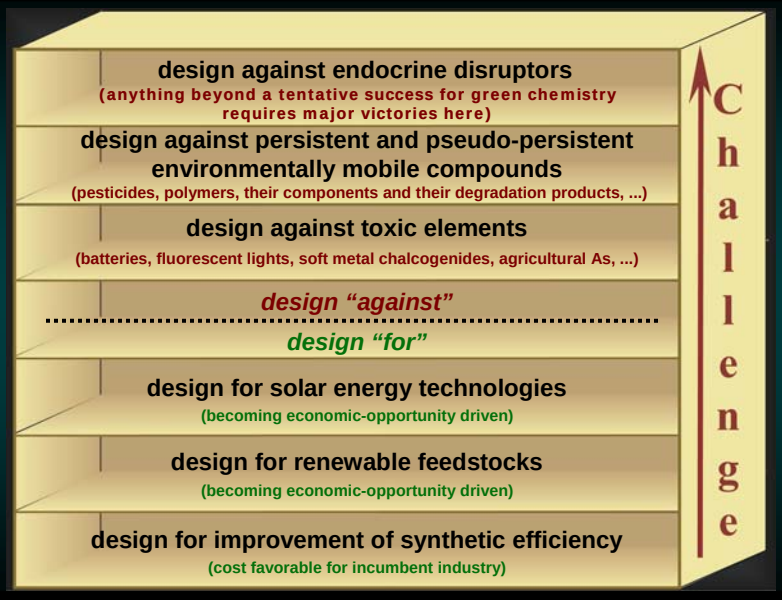
What is an endocrine disruptor?

"Decrease in anogenital distance among male infants with prenatal phthalate exposure", Shanna Swan et al., *Environmental Health Perspectives* on-line May 27, **2005**

One way to envision how our green chemistry will look in 20 years is to ponder essential curriculum elements

Sustainability ethics	Case studies of pollutants	Tox/ecotox, especially endocrine disruption!
Green metrics	How to design against toxicity	Confront spin on toxicity and ecotoxicity

Green Chemistry Research and Education Challenges



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How might chemists learn how to avoid known toxicity/ecotoxicity in the design of new products and processes?

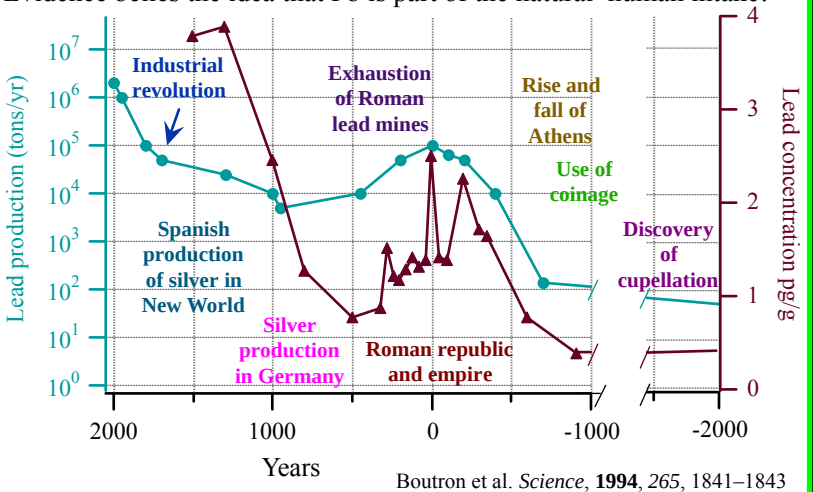
- Historical analyses building from the anecdotal, to the epidemiology, to the molecular level understanding — ***importance***.
- Toxicity testing as an integral component of chemical research — ***guidance***.
- More interdisciplinary research involving chemists and toxicologists — ***synergy***.
- An outright rejection of "spin" — ***obligation***.

Discovery of Lead Toxicity

"Sweet Poison"
Josef Eisinger
Natural History, 7/**96**

Hemisperic Lead Pollution: Greenland Ice Evidence

Evidence belies the idea that Pb is part of the natural human intake!



Boutron et al. *Science*, **1994**, *265*, 1841–1843

Selective History of Lead Toxicity

German tribes ban Roman wines, rightly associating them with illness

Louis Tanquerel des Planches (France) notes children placing lead-painted toys in mouths develop colic

David Stewart (USA) reports in *Medical News* that 9 family members poisoned by eating $PbCrO_4$ dyed bread

First countries ban/restrict white Pb for interior painting: France, Belguim, Austria

In 5-day period, 5 workers die, 40 of 49 severely poisoned in Standard Oil Bayway $PbEt_4$ labs, Elizabeth, NJ

Pres. Nixon signs *Lead-Based Paint Poisoning Prevention Act* (LBPPPA) prohibiting paints with >1% Pb in any house built with federal assistance; 1973 >0.5%, 1975 >0.06%; 1977 Consumer Products Safety Commission bans >0.06% Pb paints from interstate commerce

ÅAD 1848 1887 1909 1924 1971

1690s 1890s-1920s 1922 1964 1976-96

Eberhard Gockel in Ulm identifies wine correcting with PbO as cause of colic

Deceit and Denial: The Deadly Politics of Industrial Pollution, Gerald Markowitz & David Rosner, Univ. CA Press, Berkeley, 2002

Literature accumulates in Australia, USA and England on Pb poisoning of children, especially by Pb paint

$PbEt_4$ developed by Thomas Midgeley Jr. and chemistry professor William Mansfield Clark immediately warns of a serious menace to the public health

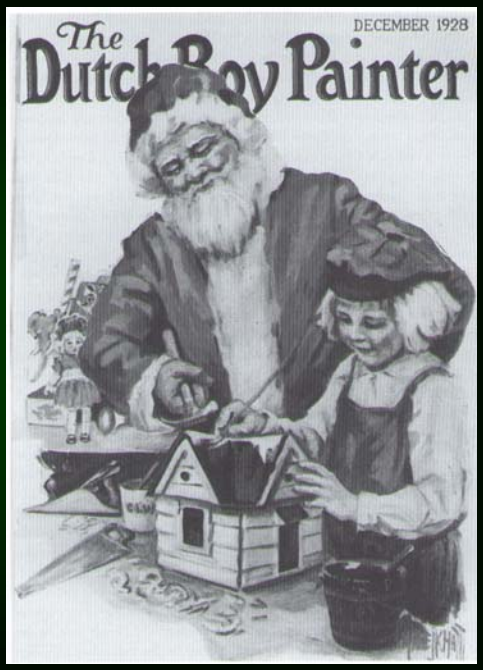
224,000 tons of lead used in gasoline in USA, ca. 1/5 total

CDC claims that as Pb in gasoline was lowered between 1976 and 1996 (when Pb was completely phased out), 90% reduction in the average BLL of US children.

Lead Industry Advertises through Children

The cover of the National Lead Company's trade magazine conveys the message that children can be encouraged to use lead paint safely on toys. (*Dutch Boy Painter*, December **1928**)

"Deceit and Denial", Markowitz and Rosner



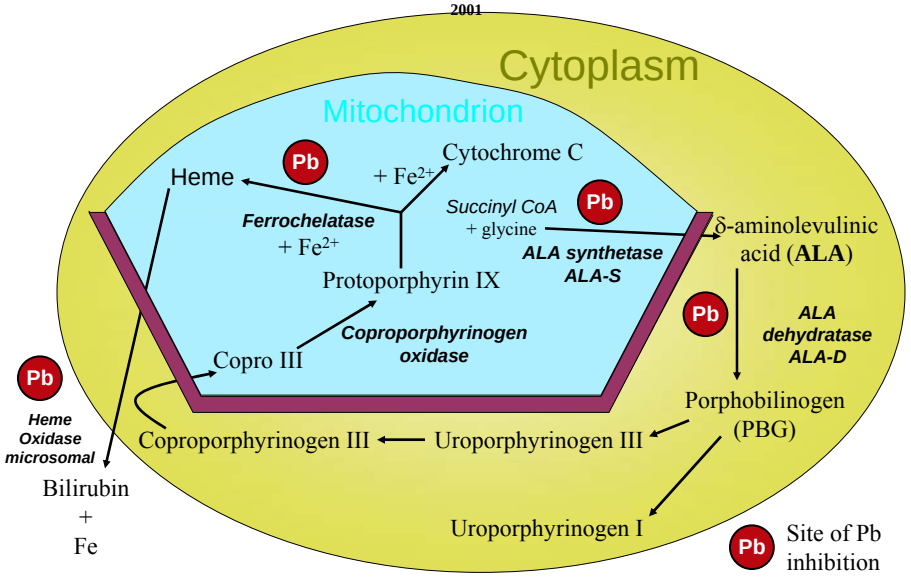
Some People of Lead History

"Deceit and Denial", Markowitz and Rosner

- **Felix Wormser**, General Secretary Lead Industries Association (LIA) from 1928 to 1947, led the industry's battle against negative publicity.
- **Joseph Aub**, Harvard University Lead Researcher supported by LIA, regularly underplayed lead paint toxicity.
- **Robert Kehoe**, University of Cincinnati Kettering Labs physiologist who helped formulate the lead industries position on toxicity of $PbEt_4$ — Aub and Kehoe dominated lead toxicity research for three decades from the 1920s.
- **Herbert Needleman**, academic pediatrician at Children's Hospital in Philadelphia, later psychiatrist at Harvard and then University of Pittsburgh, leader in showing toxic effects of low level lead in children.

Scheme of Heme Biosynthesis Showing Sites Where Pb Has an Effect

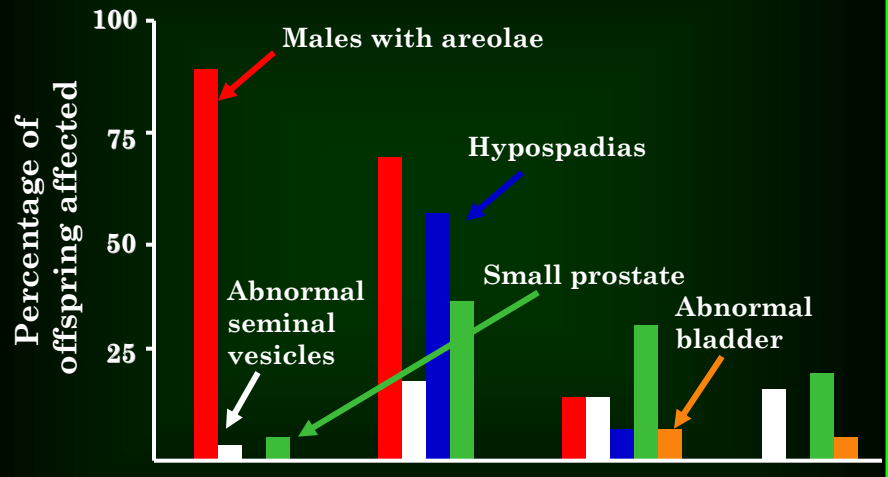
Developed from:Casarett and Doull's Toxicology: the basic science of poisons, 6th Edn. Curtis D. Klassen, McGraw-Hill, New York, 2001



The stakes of the chemical enterprise continuing to fail to address endocrine disruptors are incredibly high.

- Decrease in anogenital distance among male infants with prenatal phthalate exposure, Shanna Swan et al., *Environmental Health Perspectives* on-line May 27, **2005**
- Use of di(2-diethylhexyl)phthalate-containing medical products and urinary levels of mono(2-diethylhexylphthalate) in neonatal intensive care units, Howard Hu et al., *Environmental Health Perspectives*, on-line, June 10, **2005**.
- A population-level decline in serum testosterone levels in American men, Travison, T.G., et al., *Journal of Clinical Endocrinology and Metabolism*, **2007**, 92, 196-202.
- Exposure to methoxychlor and vinclozolin produces male reproductive problems down 4 generations, Michael Skinner et al., *Science* **2005**, *308*, 1391-1392
- Induction of mammary gland ductal hyperplasias and carcinoma in situ following fetal bisphenol A exposure, Anna Soto and C Sonnenschein et al., *Reproductive Toxicology*, **2007**, in press

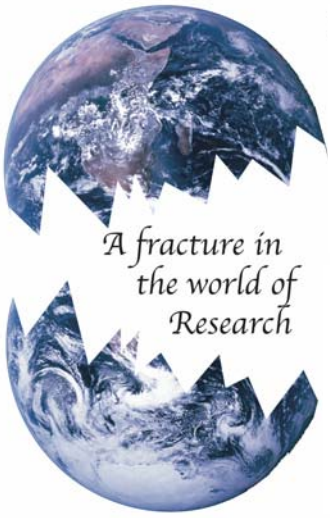
Exposure to anti-androgen, Flutamide



Courtesy of J. Peterson Myers

Paul Foster and Martha Harris, *Toxicol Sci*, **2005**, 1591

The Institute is "Sustainability" Focused



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Green Chemistry has to be, to some Extent, a Contact Sport

Chemistry and Engineering News
October 18, 2004 Volume 82, Number 42, pp. 40-45

TIFF (LZW) decompressor
are needed to see this picture.

THE MANY FACES OF CHLORINE

Howlett and Collins square off about one of the most evocative chemicals

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

PHOTO BY PETER CUTTS

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

PHOTO BY GARY F. THOMAS

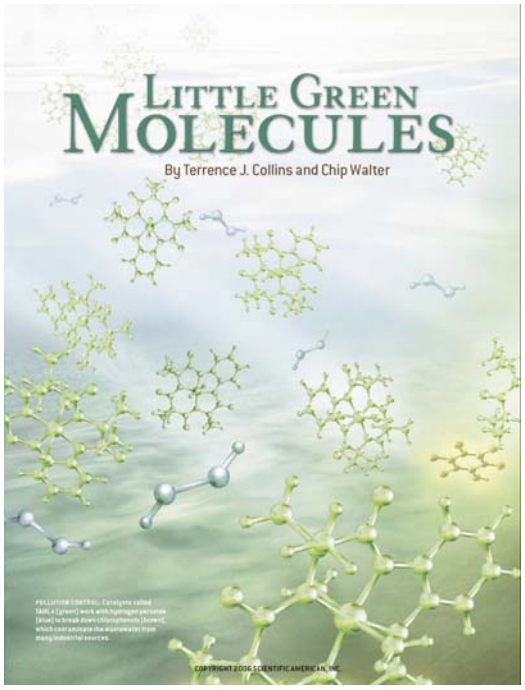
AT ODDS Chlorine Chemistry Council's Howlett (left) contends that chlorine is a chemical beneficial to humankind and on the path to sustainability despite the hazards from organochlorines enumerated by Carnegie Mellon's Collins.

Green Chemistry has to be, to some Extent, a Contact Sport

- PVC provides the principal market for EDC phthalates (ca. 75%); we make over 10 B lbs per year
- Burning PVC produces dioxins: as we put more and more PVC into the built environment, more and more adventitious fires will be PVC fires
- PVC fires release hydrochloric acid making them even more dangerous than a non-PVC fire
- PVC contains heavy metal stabilizers — lead and cadmium — disposing of PVC disposes of these also
- The vinyl chloride monomer is a carcinogen

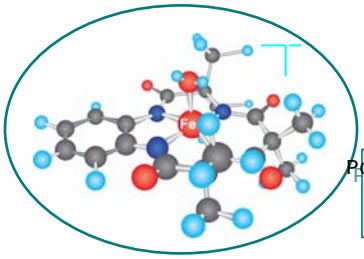
What are the scientific achievements of the Institute for Green Oxidation Chemistry?

This *Scientific American* article explains the motivational and design history of our 25-year search for nontoxic small molecule activators of hydrogen peroxide and oxygen.



Extensive Scientific Characterization of TAML® Activators and Their Chemistr

TAML activators solve a multi-decade standing chemistry problem. They work "as well as" nature's major oxidizing enzymes. We understand how they function in deep detail.



Water Cleaning
chlorinated pollutants, EDCs, phenols, BPA, …

Textiles
dye bleaching, effluent decolorization

Biological Warfare
Rapid destruction of anthrax-like spores

Possible Site Cleaning
all the problem compounds of the TNT explosives

Pesticides Decon
major class (thiophosphates) rapidly/completely destroyed

Pulp and Paper
pulp bleaching, effluent smell, organochlorine and color removal

Military Chemical
rapid destruction of toxic residuals & CWAs

Laundry
dye transfer inhibition, stain removal

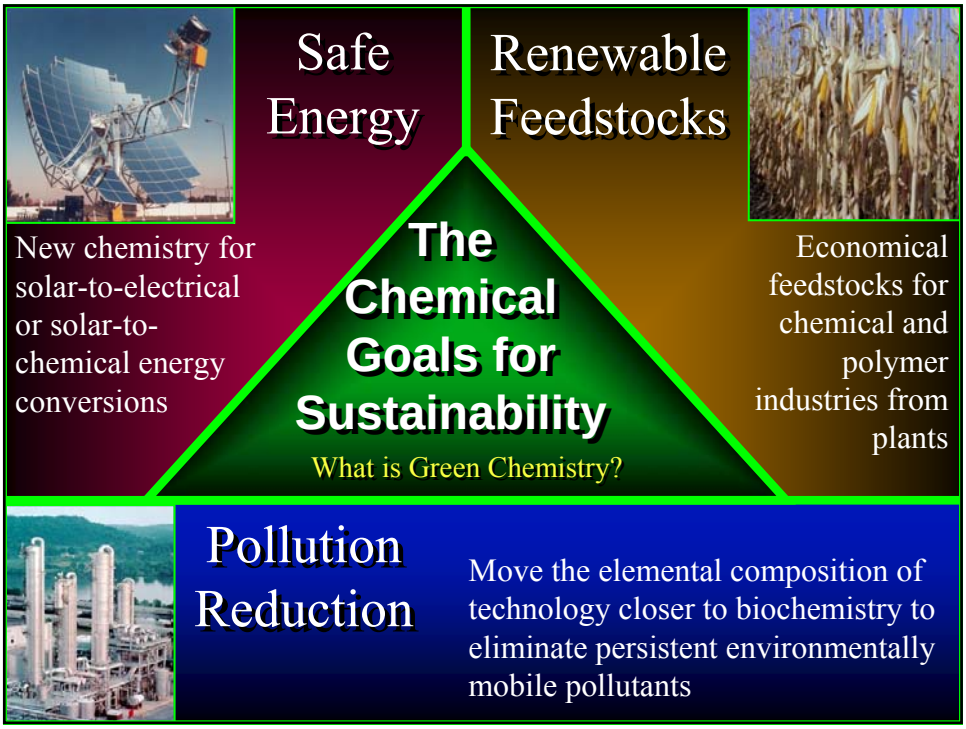
Pharmaceuticals Decon
trace pharmaceuticals removed from water

Agricultural
removal of estrogens from water, renewable feedstocks

Drinking Water Disinfection
safer drinking water free of chlorinated disinfection byproducts

Others
metal refining, carpet recycling, hospital disinfection

Petroleum Refining
removal of sulfur from diesel & gasoline


Safe Energy
Renewable Feedstocks
New chemistry for solar-to-electrical or solar-to-chemical energy conversions
Economical feedstocks for chemical and polymer industries from plants
The Chemical Goals for Sustainability
What is Green Chemistry?
Pollution Reduction
Move the elemental composition of technology closer to biochemistry to eliminate persistent environmentally mobile pollutants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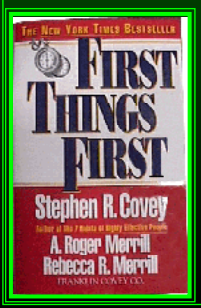
QuickTime™ and a
decompressor
are needed to see this picture.

Escaping Urgency Addition:

How should universities confront sustainability?

	Urgent	Not urgent
Important	**Necessity** Here we do what we genuinely must.	**Originality** Here we define our authenticity and frame the original work we are capable of.
Not important	**Deception** Here we let systems steal our chances to be authentic.	**Waste** Here we squander our chances to be authentic.

How should universities change to deal with sustainability?



	Urgent	Not urgent
Important	**Necessity** • secure your dominion (tenure) • collect adequate resources • recruit great coworkers • publish adequately	**Originality** • focus research energy on great sustainability problems • integrate sustainability ethics, toxicity and ecotoxicity into research and education
Not important	**Deception** • "publish or perish" in place of "do important work" • turn green chemistry into purely a resource collection exercise	**Waste** ???

Sustainability Determinant Timescales

KINETIC DETERMINANTS

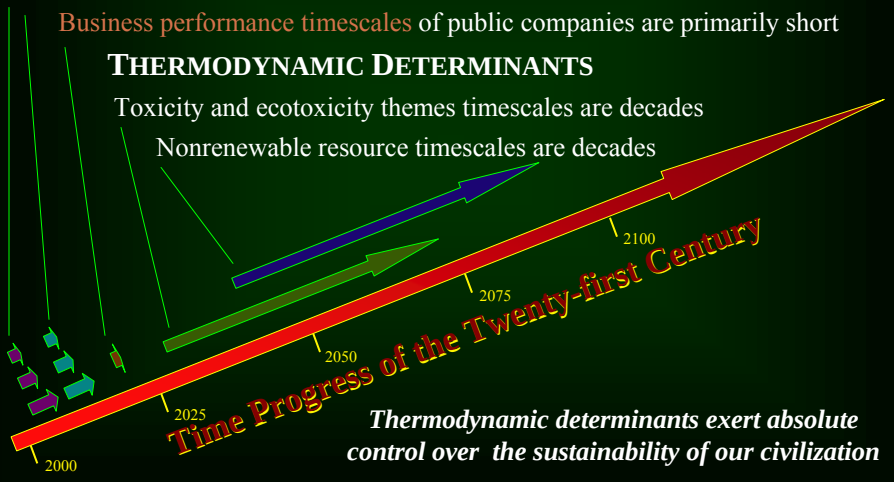
Political timescales are 2, 4 and 6 years; similarly, research grants

Business performance timescales of public companies are primarily short

THERMODYNAMIC DETERMINANTS

Toxicity and ecotoxicity themes timescales are decades

Nonrenewable resource timescales are decades



Thermodynamic determinants exert absolute control over the sustainability of our civilization

Thank you!