



Green Chemistry: sustaining a high technology civilization

Terry Collins

*Oregon Environmental Council's
Healthy Environment Forum, Portland, Oregon, January 25, 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

TAML[®]
activators

Education

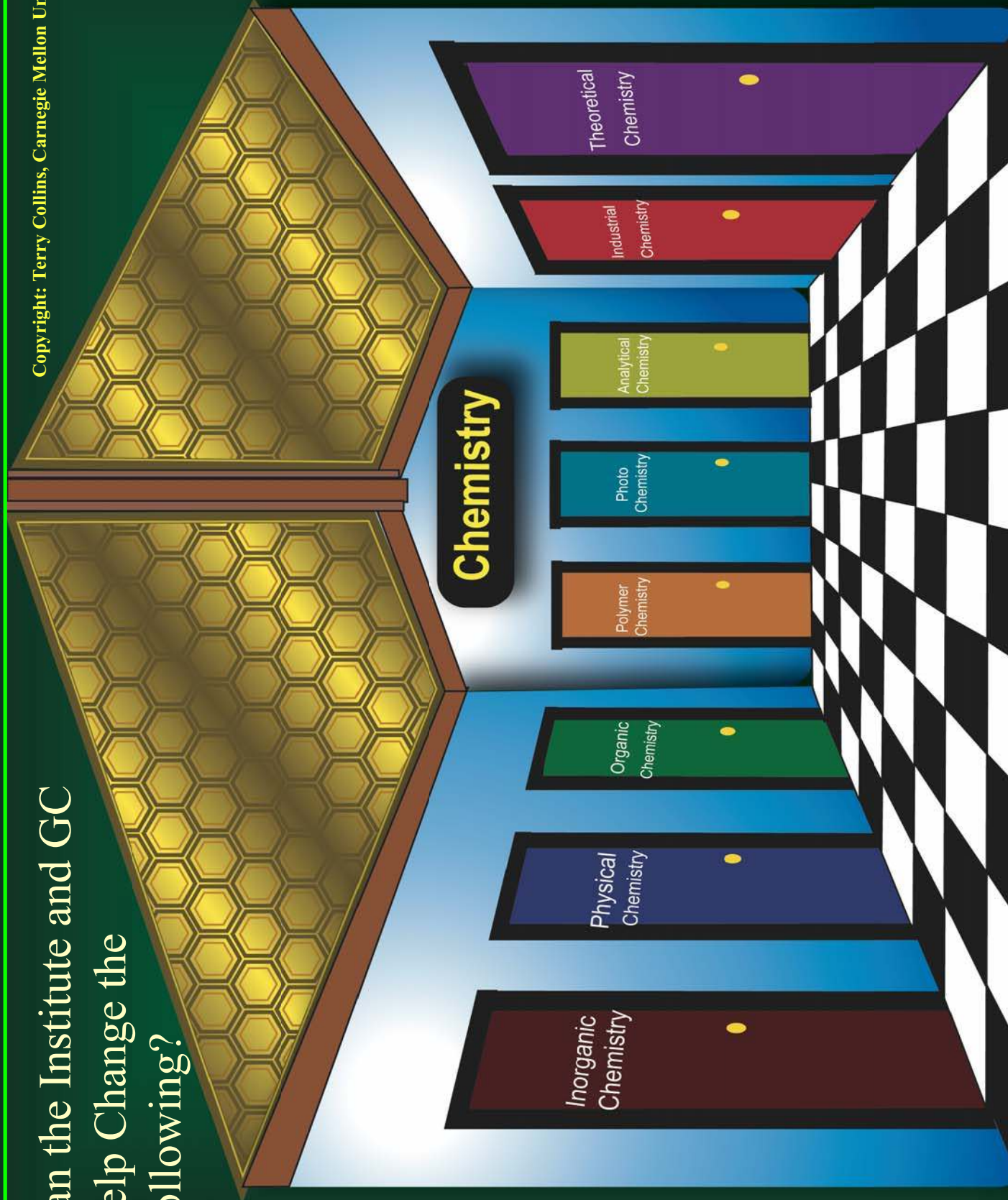
GC
curricula for
the world

Development

Pittsburgh
TAML
company

Can the Institute and GC
Help Change the
Following?

Copyright: Terry Collins, Carnegie Mellon University



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*)

Toxicological Endpoints

Chemicals
that kill cells

Chemicals
that interact with
DNA causing
mutations that
may lead on
cancer

Chemicals
that disrupt cellular
development

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

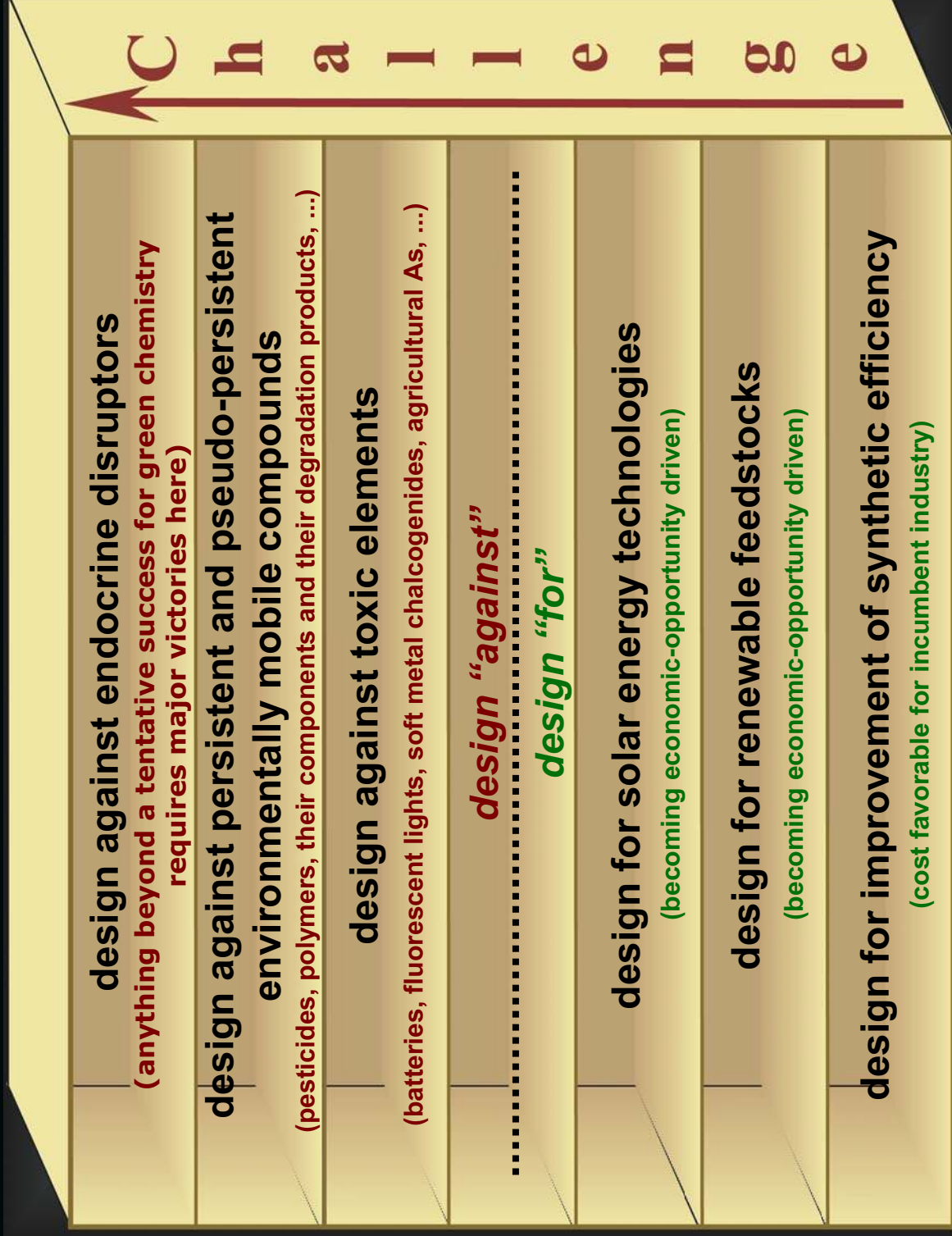
Tox/ecotox,
especially
endocrine
disruption!

Green
metrics

How to
design against
toxicity

Confront spin
on toxicity
and
ecotoxicity

Green Chemistry Research and Education Challenges

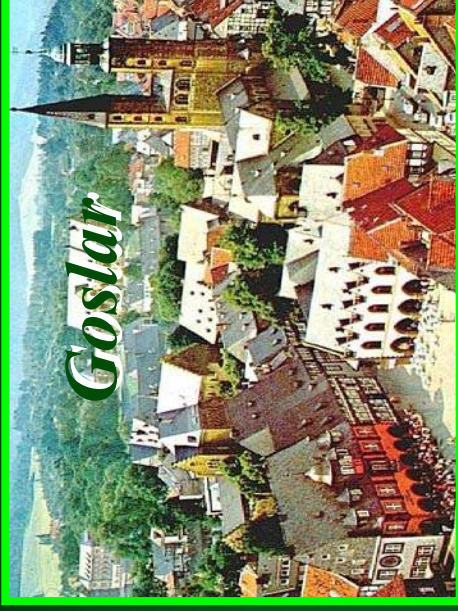
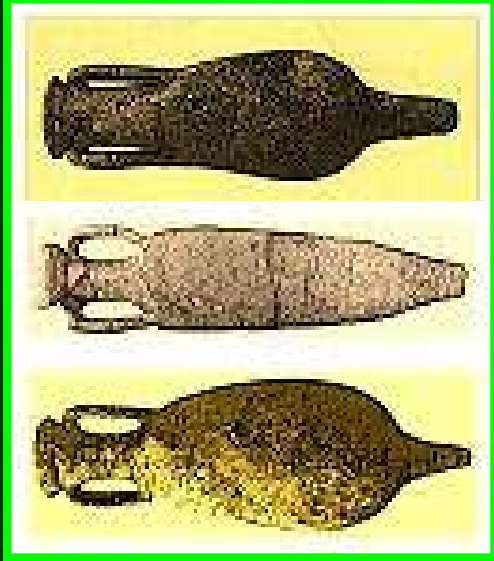


How might chemists learn how to avoid known toxicity/ecotoxicity in the design of new products and processes?

- 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

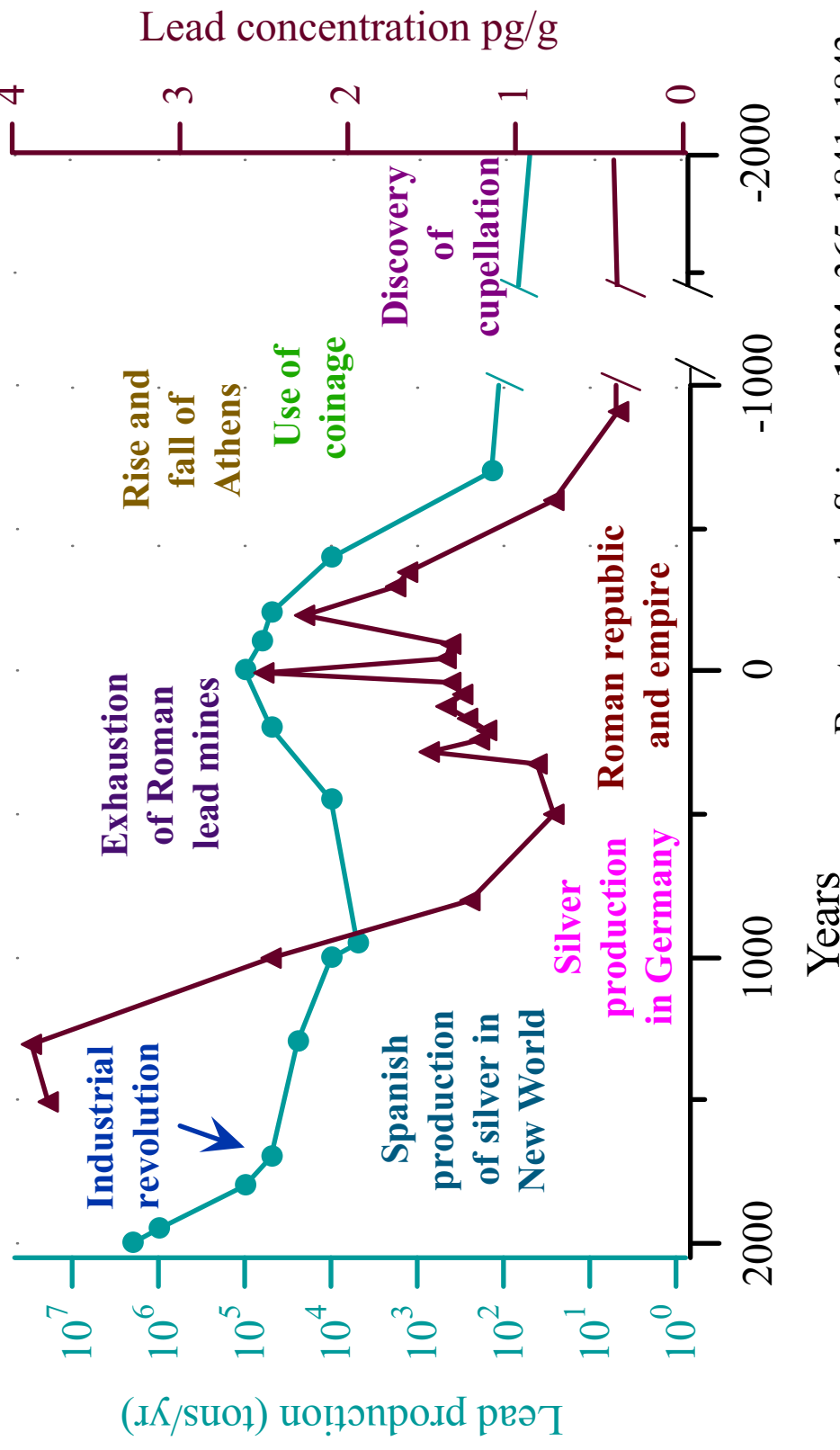
“Sweet Poison”
Josef Eisinger
Natural History, 7/96



The Bastion of Ulm

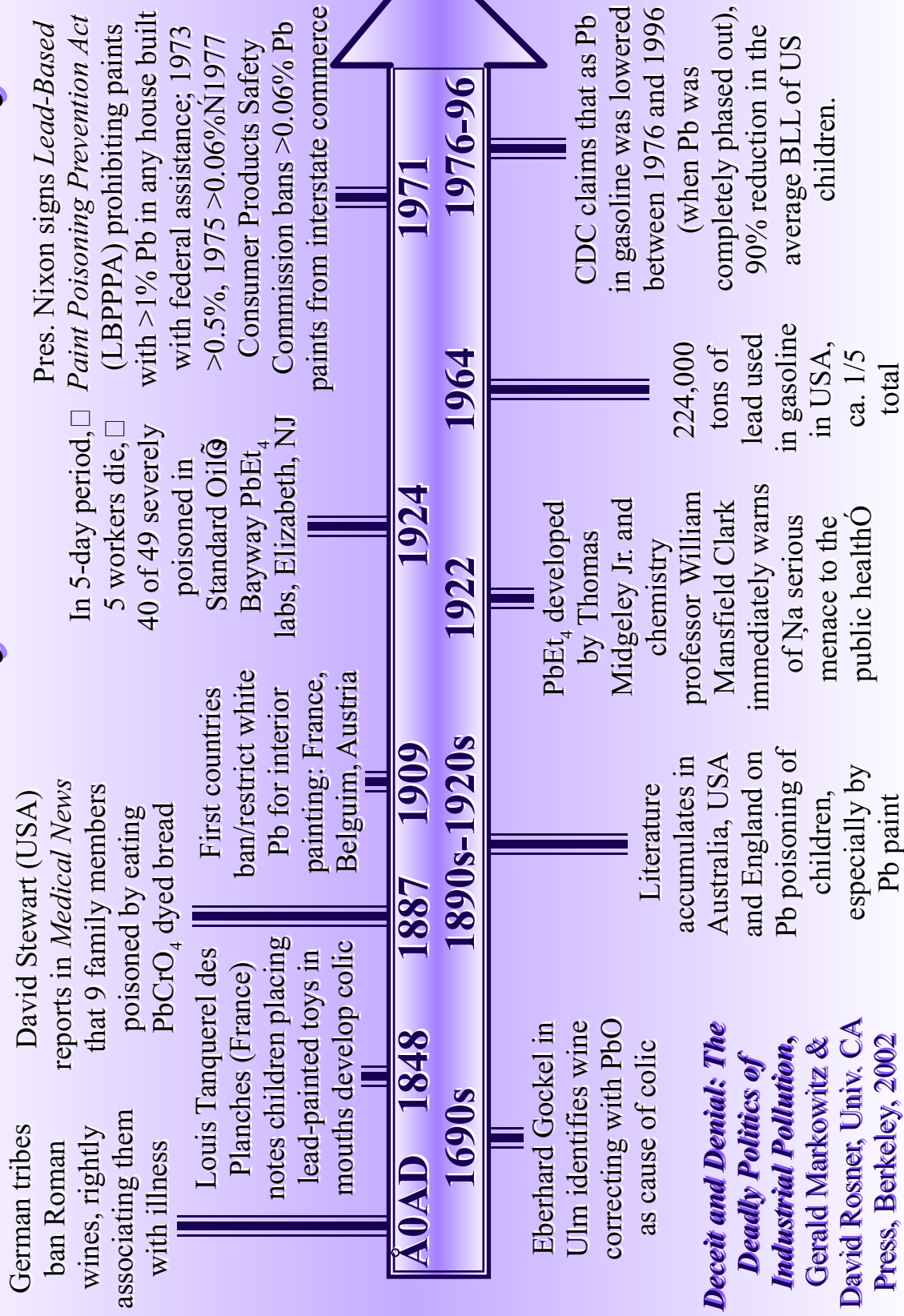
Hemispheric Lead Pollution: Greenland Ice Evidence

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



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

DECEMBER 1928

The Dutch Boy Painter



Some People of Lead History

“Deceit and Denial”,
Markowitz and Rosner

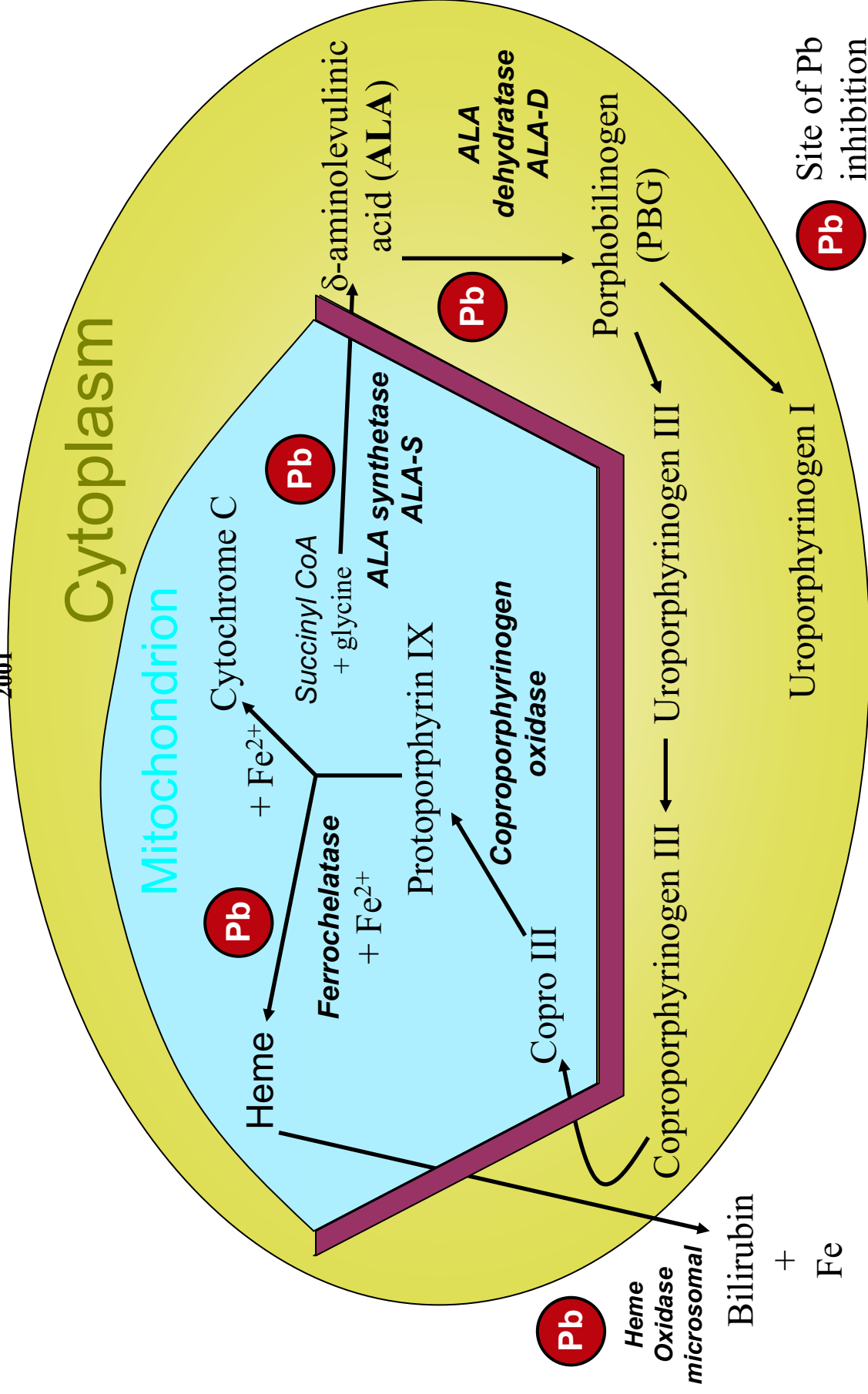
- **Felix Wormser**, General Secretary Lead Industries Association (LIA) from 1928 to 1947, led the industry’s battle against negative publicity.
- **Joseph Aub**, Harvard University Lead Researcher supported by LIA, regularly underplayed lead paint toxicity.
- **Robert Kehoe**, University of Cincinnati 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,

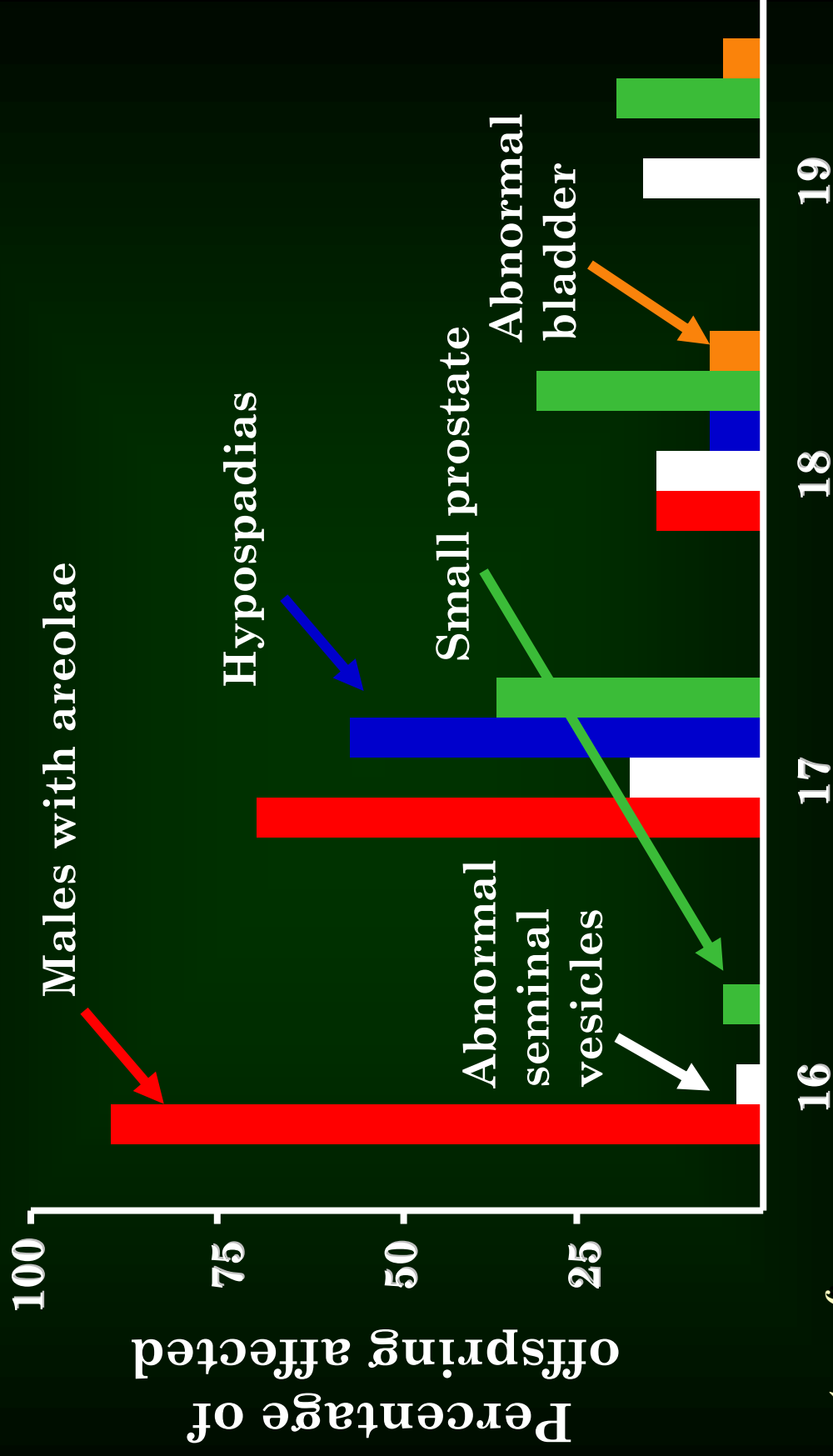
2001



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

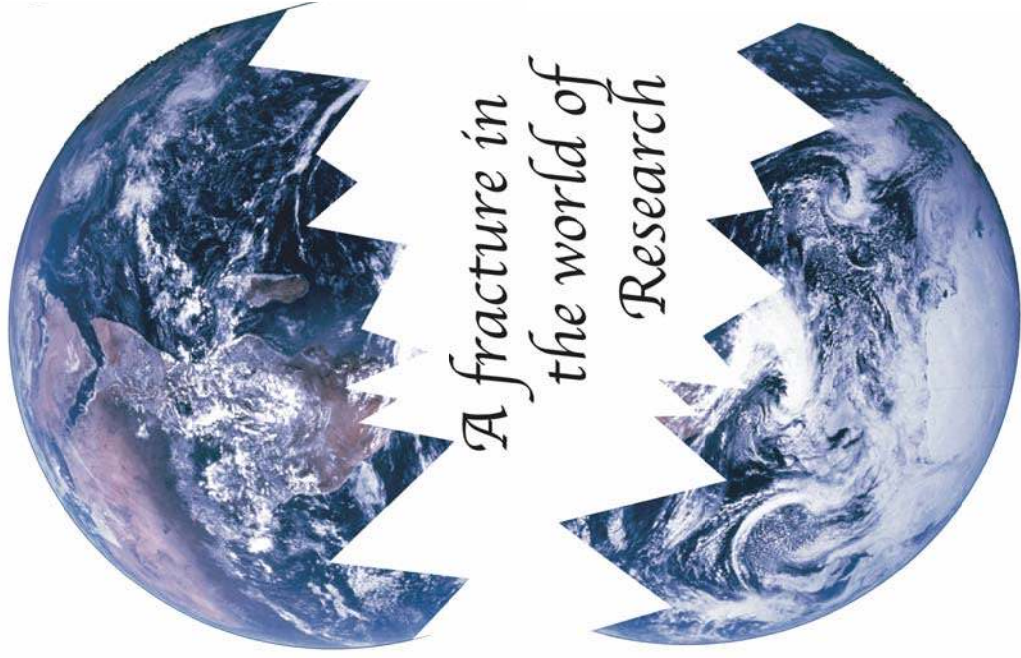


Courtesy of
J. Peterson Myers

Day of exposure after conception

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

The Institute is “Sustainability” Focused



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



PHOTO BY PETER CUTTS



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.

LITTLE GREEN MOLECULES

By Terrence J. Collins and Chip Walter

POLLUTION CONTROL. Catalysts called TAMs (green) work with hydrogen peroxide (blue) to break down chlorophenols (brown), which contaminate the wastewater from many industrial sources.

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Extensive Scientific Characterization of TAML[®] Activators and Their Chemistry
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.

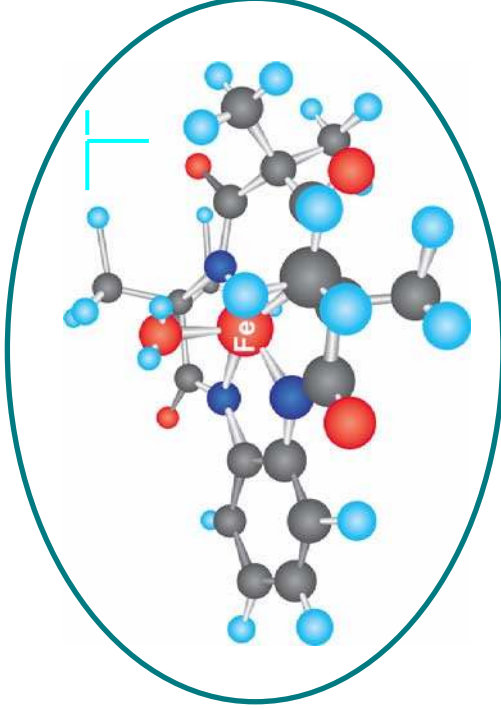
Water Cleaning
chlorinated pollutants, EDCs,
phenols, BPA, ...

Biological Warfare
Rapid destruction of
anthrax-like spores

Pesticides Decon
major class (thiophosphates)
rapidly/completely destroyed

Laundry
dye transfer inhibition,
stain removal

Drinking Water Disinfection
safer drinking water free of
chlorinated disinfection byproducts



Textiles
dye bleaching,
effluent decolorization

Possible Site Cleaning
all the problem compounds
of the TNT explosives

Military Chemical
rapid destruction of toxic
residuals & CWAs

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

Agricultural
removal of estrogens from water,
renewable feedstocks

Pharmaceuticals Decon
trace pharmaceuticals removed
from water

Others
metal refining, carpet
recycling, hospital disinfection

Petroleum Refining
removal of sulfur
from diesel & gasoline



Safe Energy

New chemistry for
solar-to-electrical
or solar-to-
chemical energy
conversions



Renewable Feedstocks

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

www.stirlingenergy.com

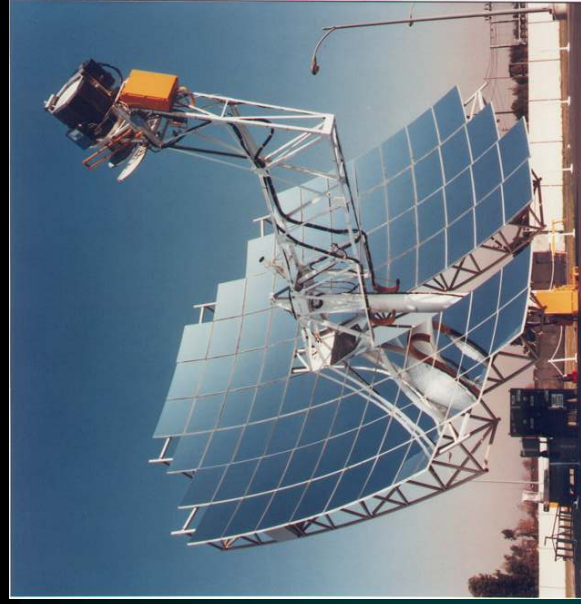
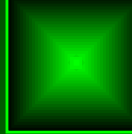


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Escaping
Urgency
Addition:
How should
universities
confront
sustainability?



I m p o r t a n t

N o t i m p o r t a n t

U r g e n t

Necessity
Here we do
what we
genuinely must.

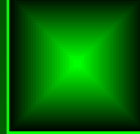
Deception
Here we let
systems steal
our chances to
be authentic.

N o t u r g e n t

Originality
Here we define
our authenticity
and frame the
original work we
are capable of.

Waste
Here we
squander our
chances to be
authentic.

How should universities change to deal with sustainability?



Important

Not important

Urgent

Necessity

- secure your dominion (tenure)
- collect adequate resources
- recruit great coworkers
- publish adequately

Deception

- “publish or perish” in place of “do important work”
- turn green chemistry into purely a resource collection exercise

Not urgent

Originality

- focus research energy on great sustainability problems
- integrate sustainability ethics, toxicity and ecotoxicity into research and education

Waste

???

Sustainability Determinant Timescales

KINETIC DETERMINANTS

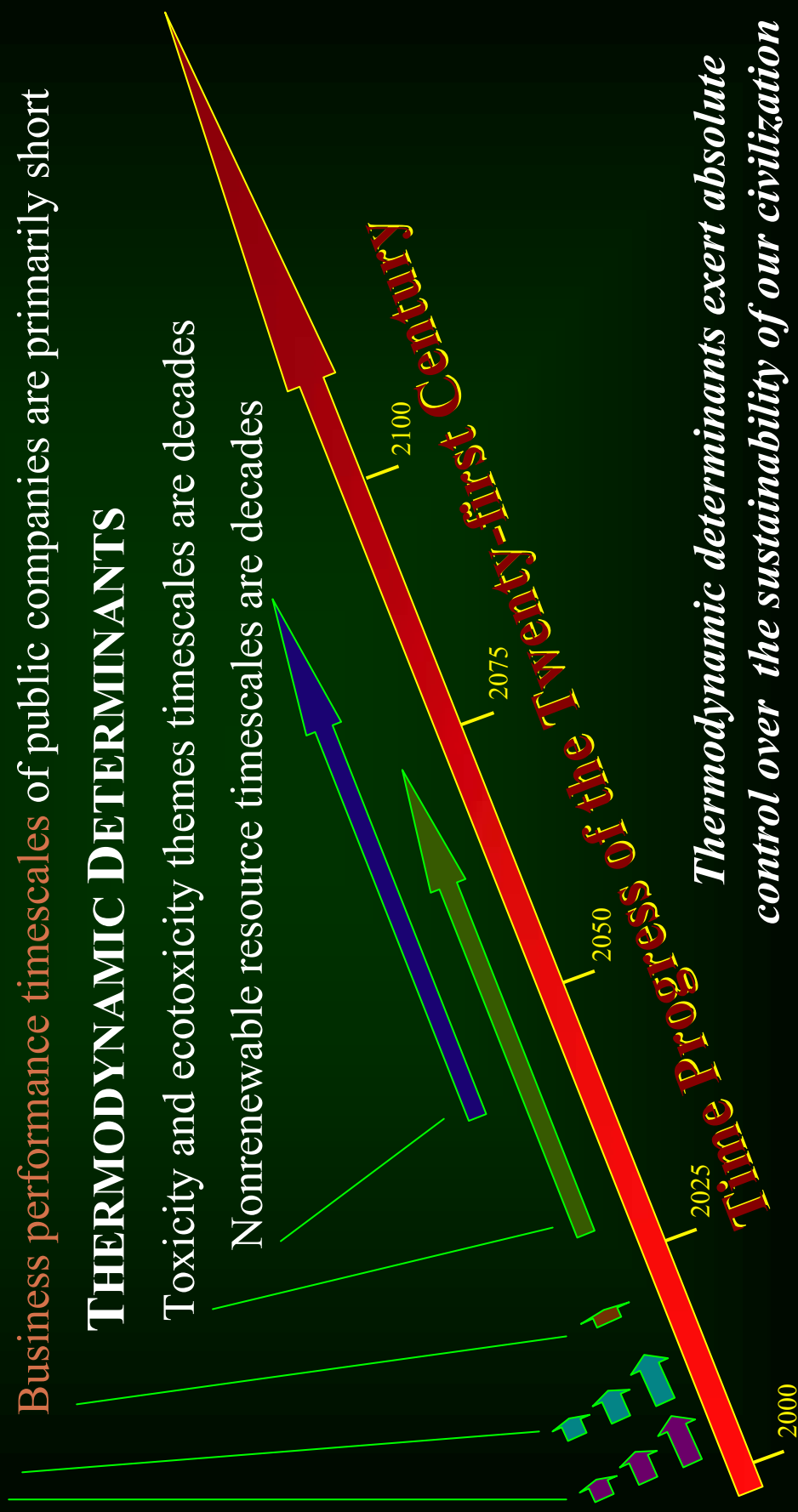
Political timescales are 2, 4 and 6 years; similarly, research grants

Business performance timescales of public companies are primarily short

THERMODYNAMIC DETERMINANTS

Toxicity and ecotoxicity themes timescales are decades

Nonrenewable resource timescales are decades



Thank you!