Green Chemistry:
The Missing Element in Chemistry Education

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

warnerbabcock
institute for green chemistry

beyondbenign

Disclaimer

Do Chemistry

1988-1997 Worked in Industry (Polaroid) for 10 years.

Teach Chemistry

1996-2007 Worked in Academia (UMASS) for 11 years.

Invent Chemistry

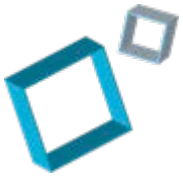
Over 250 Patents and Publications.

Invest in Chemistry

2007- Cofounded an Entrepreneurial For-Profit Company (WBI)

Manage Chemistry

1990 - Active in Green Chemistry (US EPA, CA DTSC, MA TURA)



Today's Talk:

- Doing Chemistry
- Teaching Chemistry
- Inventing Chemistry
- Investing in Chemistry
- Managing Chemistry

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For over 180 years of "Modern Chemistry"…

But Nature…

Heat things under high temperature

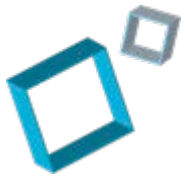
Runs reactions at "room" temperature

Apply high pressures

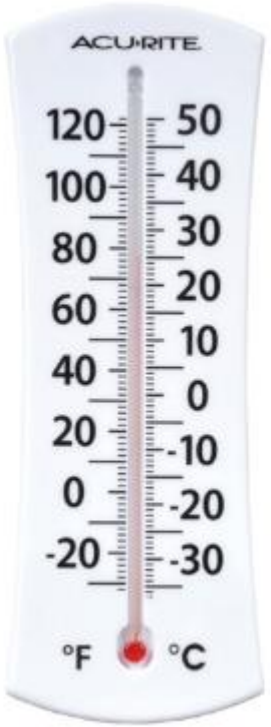
Runs reactions at ambient pressure

Use organic solvents

Uses water as a solvent



A thermometer is a molecular speedometer…



Molecular reactivity is based on specific geometries.

Most molecular collisions do not result in a chemical reaction.

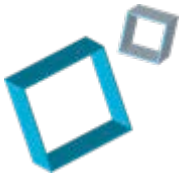
By heating up a reaction, or putting it under pressure,
we increase the velocity of the molecules,
and thus the frequency of the collisions.

This increases both the non-productive
and reaction producing collisions.

There is NEVER a REACTIVE COLLISION in Nature!

In nature, molecules for the most part first from some form
of complex or assembly, that orients the reactive orbitals.

I called this Non-Covalent Derivatization.



EPA Approval

Paul Anastas

Office of Pollution
Prevention and Toxics

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 .

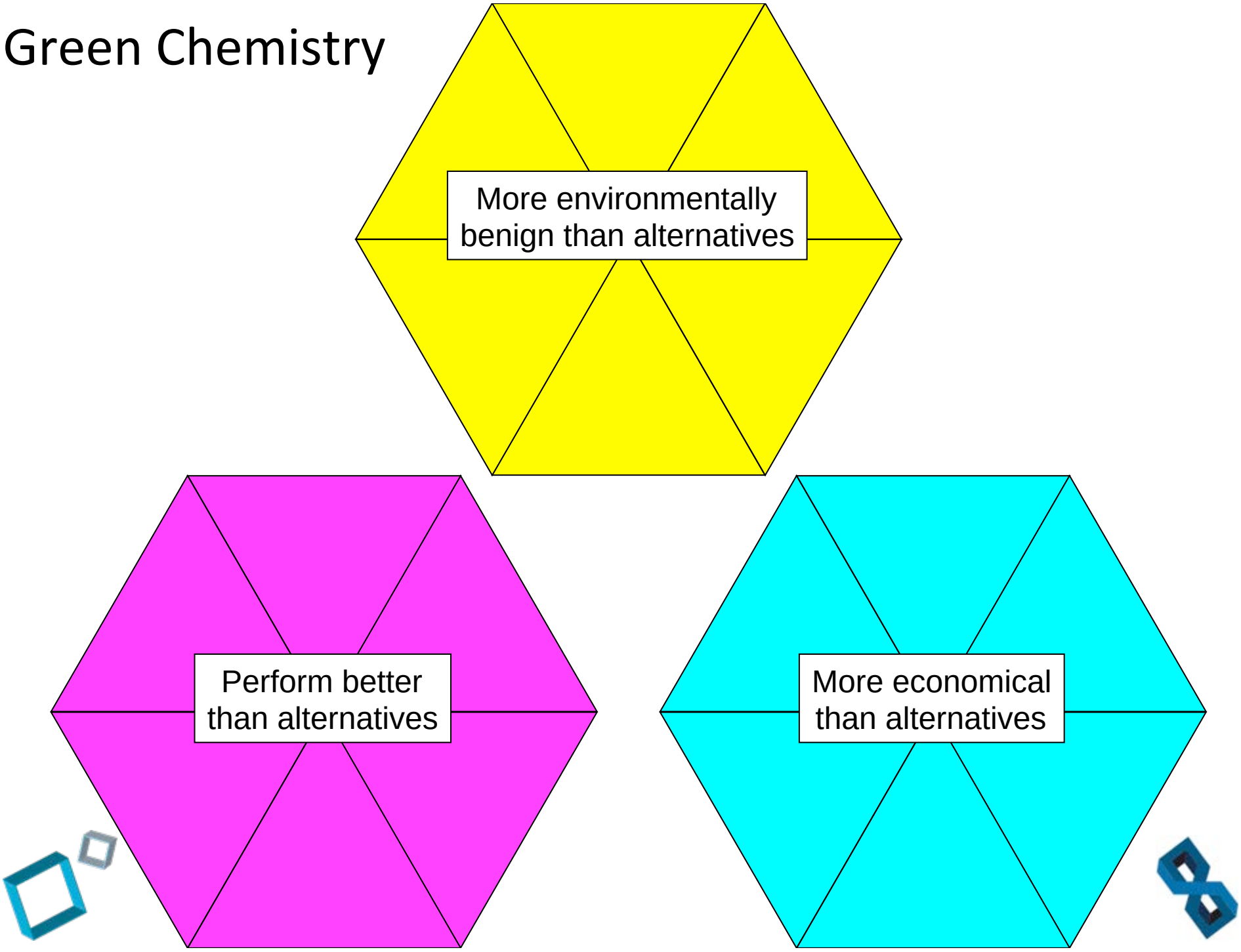
9. Catalysis. Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

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.

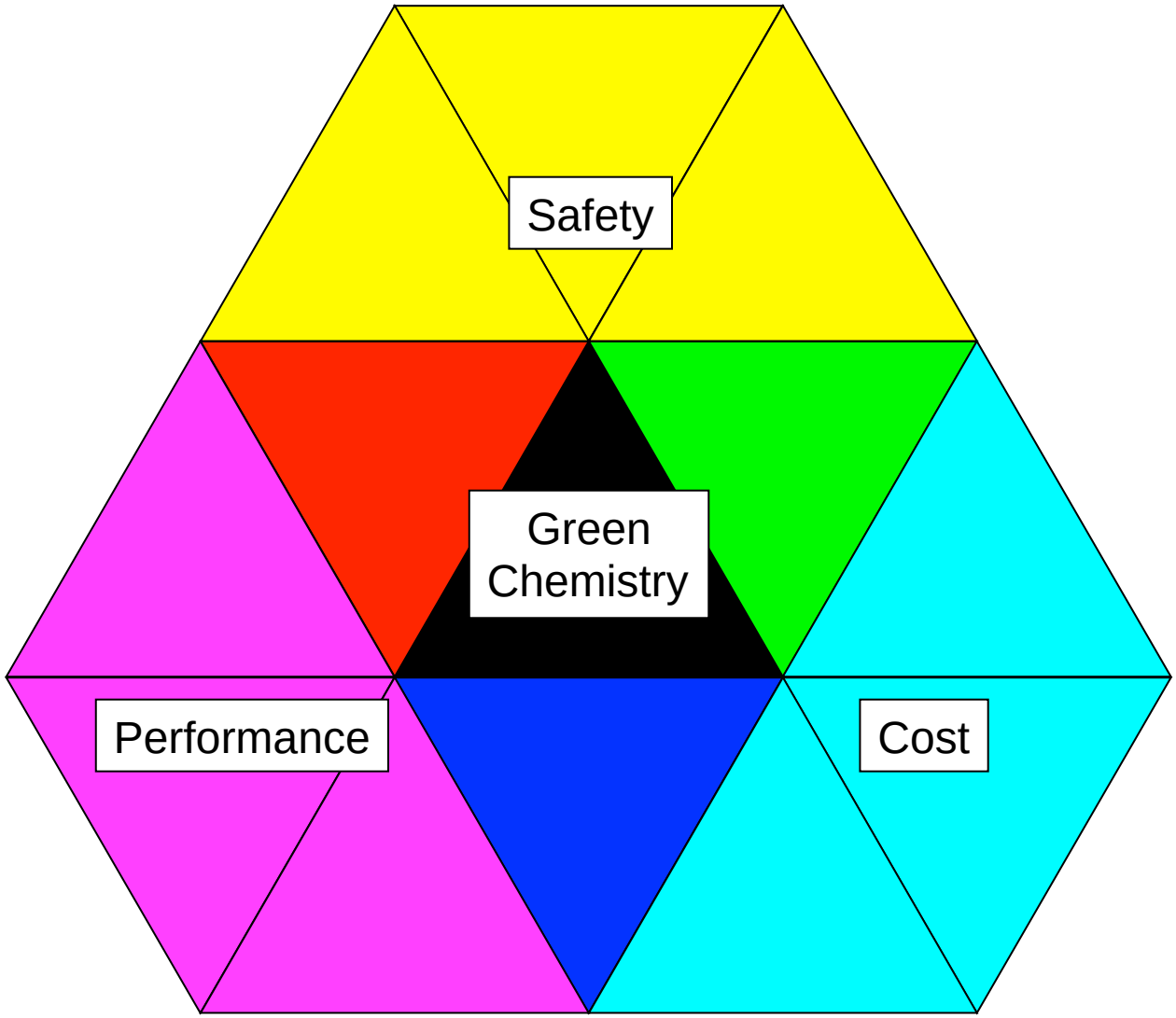
11. Real-time Analysis for Pollution Prevention. Analytical methodologies need to be further developed to allow for real-time in-process monitoring and control prior to the formation of hazardous substances.

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.

Green Chemistry



Green Chemistry



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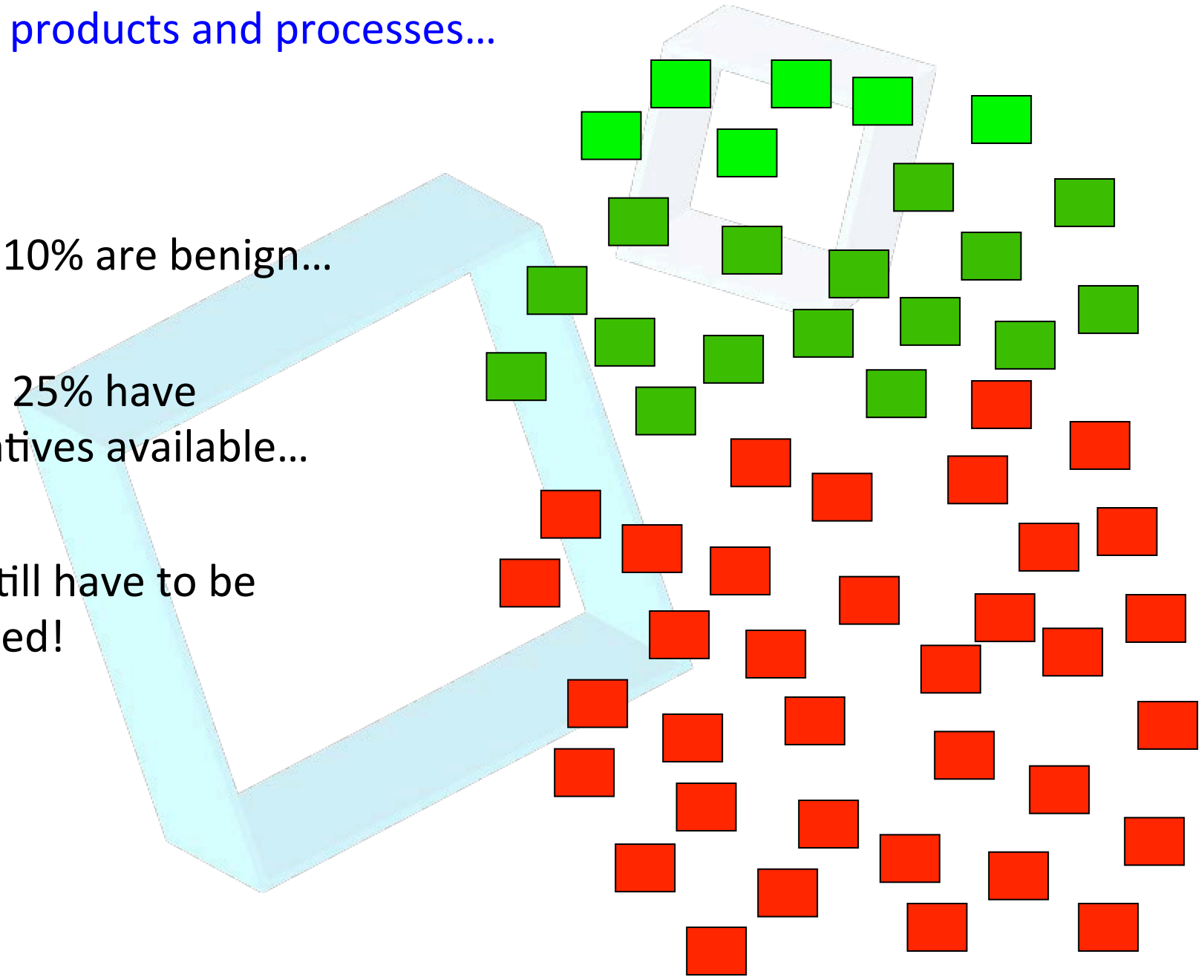
Of all the products and processes…

Maybe 10% are benign…

Maybe 25% have alternatives available…

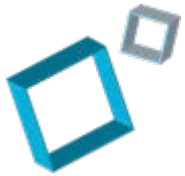
65% Still have to be invented!

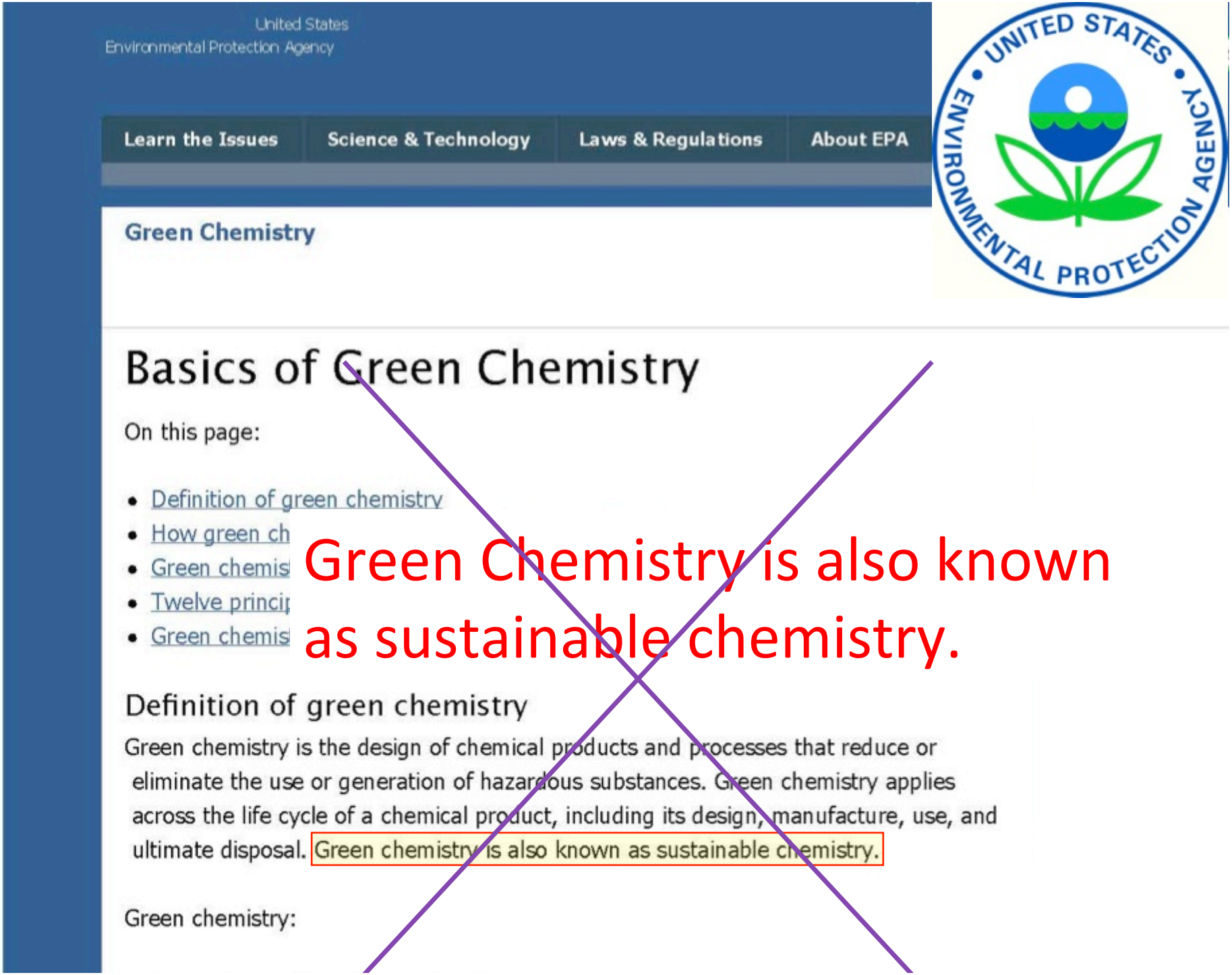


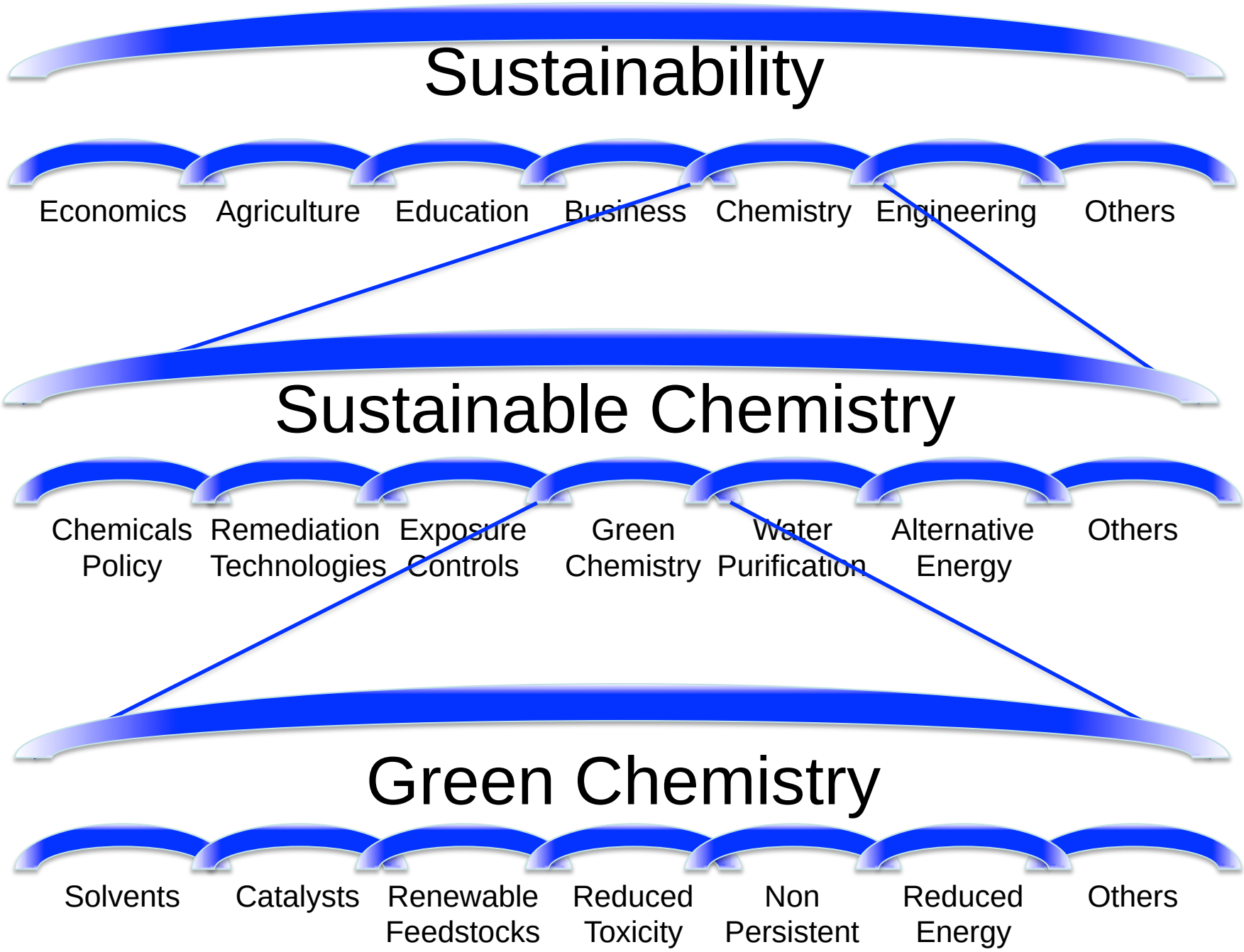
Traditional Processes

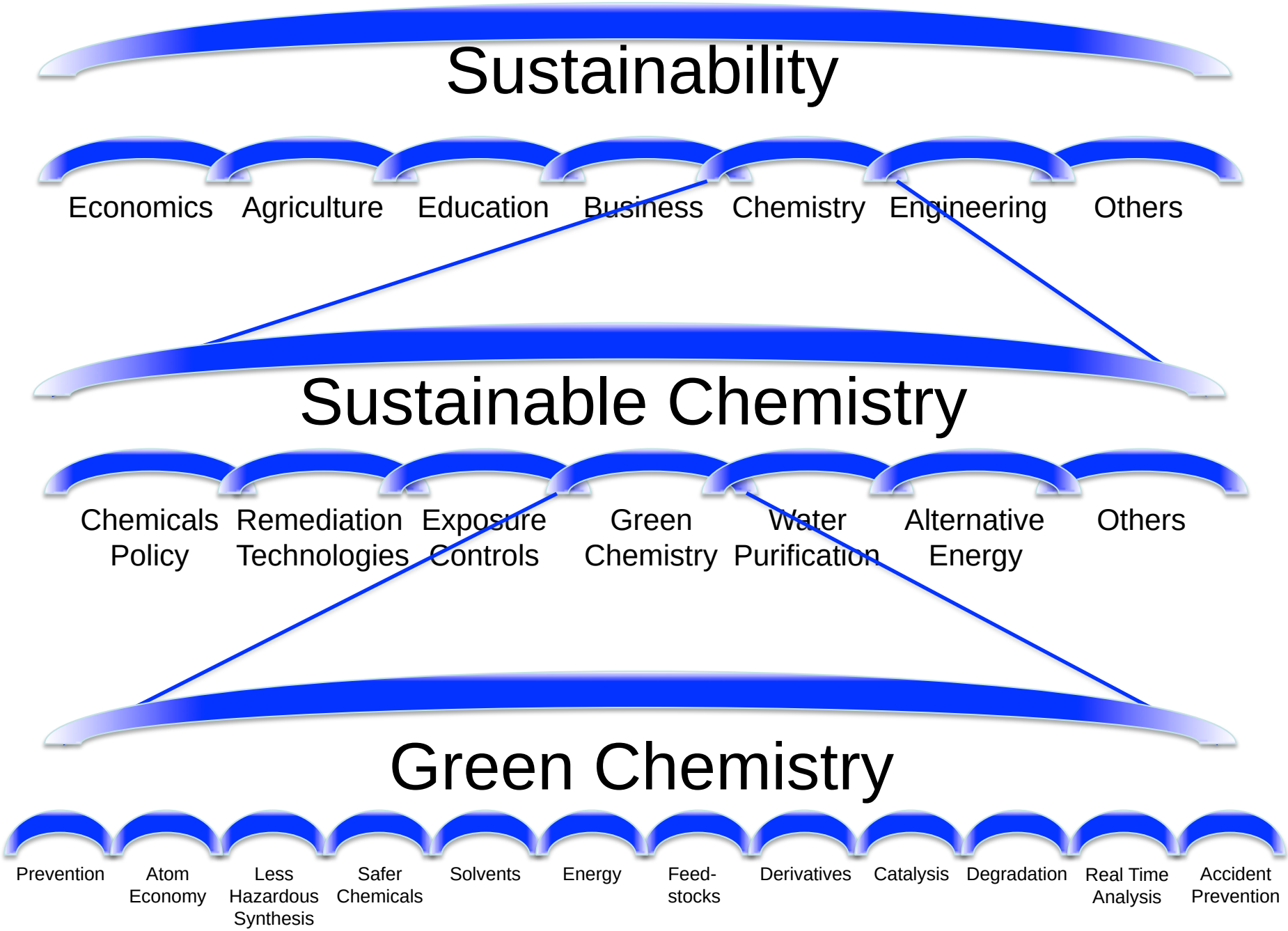
Green Alternatives

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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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

Lets talk about nothing:

There are two issues with the use of “free” and “zero”:

(1) What does “chemical free” mean?

“BPA Free”:

(2) Can we ever have an “anything” free product?

● Handling receipts with care

Surprise: The thermal paper receipts from many ATMs and cash registers are coated with high levels of BPA, which can be absorbed through the skin or transferred from fingers to food, reveals research by John C. Warner, Ph.D., author of *Green Chemistry: Theory and Practice.*

BPA in cash register receipts….

No BPA added in the coating…

Unavoidable trace amounts of BPA in the paper!!!!

So what does “BPA-Free” mean?

Is it achievable?

“Nothing” and Big Numbers:

55 Gal Drum water

6.97×10^{27} Molecules of water

6 9 7 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Teaspoon of sugar

7.93×10^{21} Molecules of sugar 1.14 ppm

7 9 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Grain of sugar

5.22×10^{17} Molecules of sugar 50.6 ppt

3 5 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Nanogram of sugar

1.76×10^{12} Molecules of sugar

176 Billion molecules of sugar

1 7 6 0 0 0 0 0 0 0 0 0

Amedeo Avogadro

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John Warner's 5 Elements of Innovation

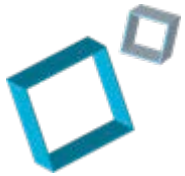
1. All innovation begins with science fiction

2. Innovation happens not within the field of focus but in the periphery.

3. Encyclopedic knowledge inhibits innovation in the absence of intuitive knowledge.

4. The ability to innovate is simultaneously proportional to wisdom and the tolerance of intellectual risk.

5. Innovation is orthogonal to complexity.



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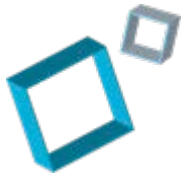

Renovation

The 2011 World Science Fiction Convention
August 17-21, 2011, Reno, Nevada

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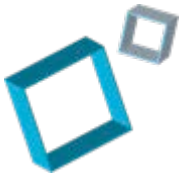

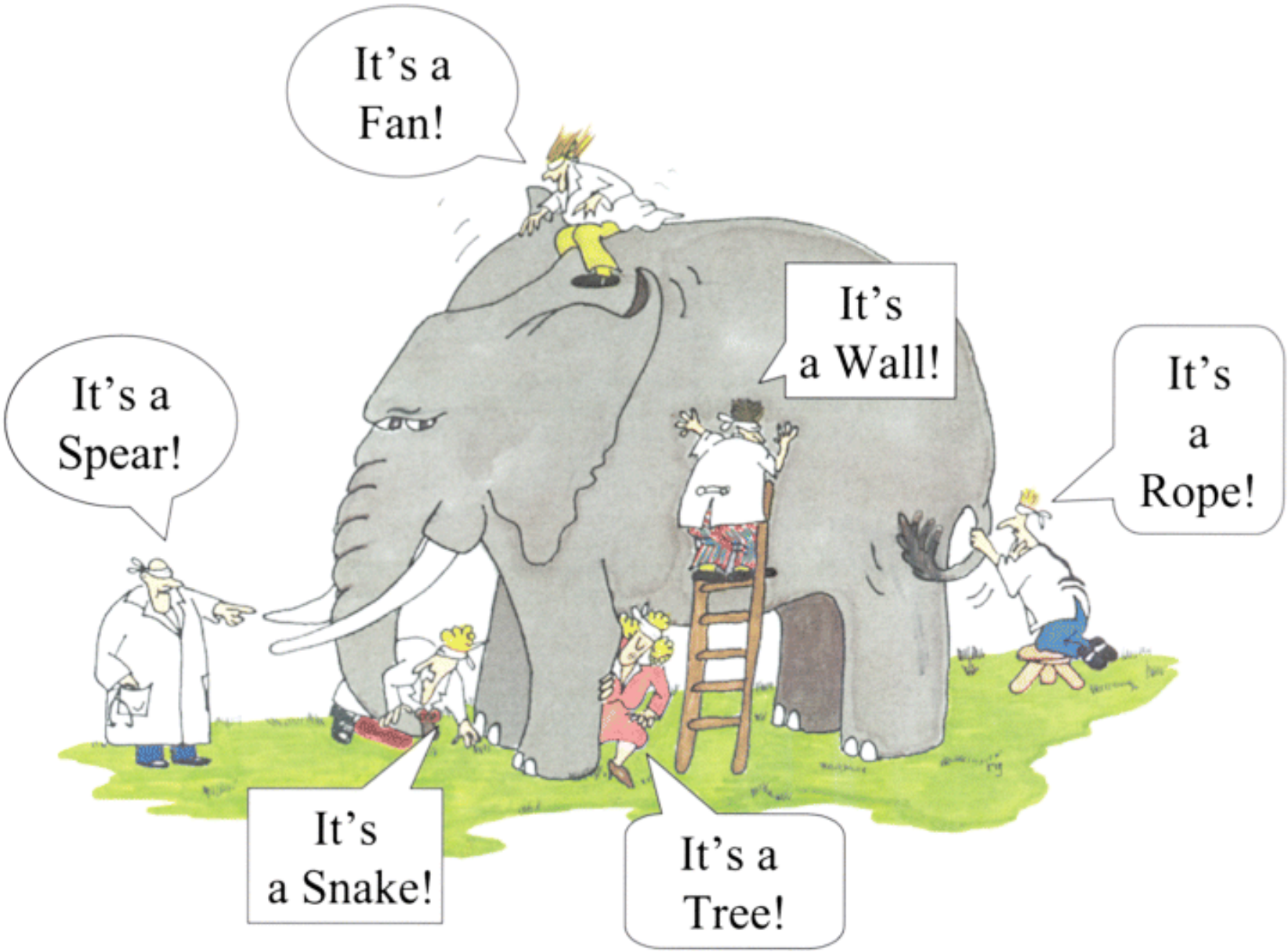
It's a Fan!
It's a Spear!
It's a Wall!
It's a Rope!
It's a Snake!
It's a Tree!

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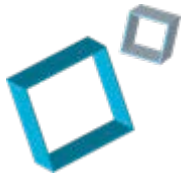
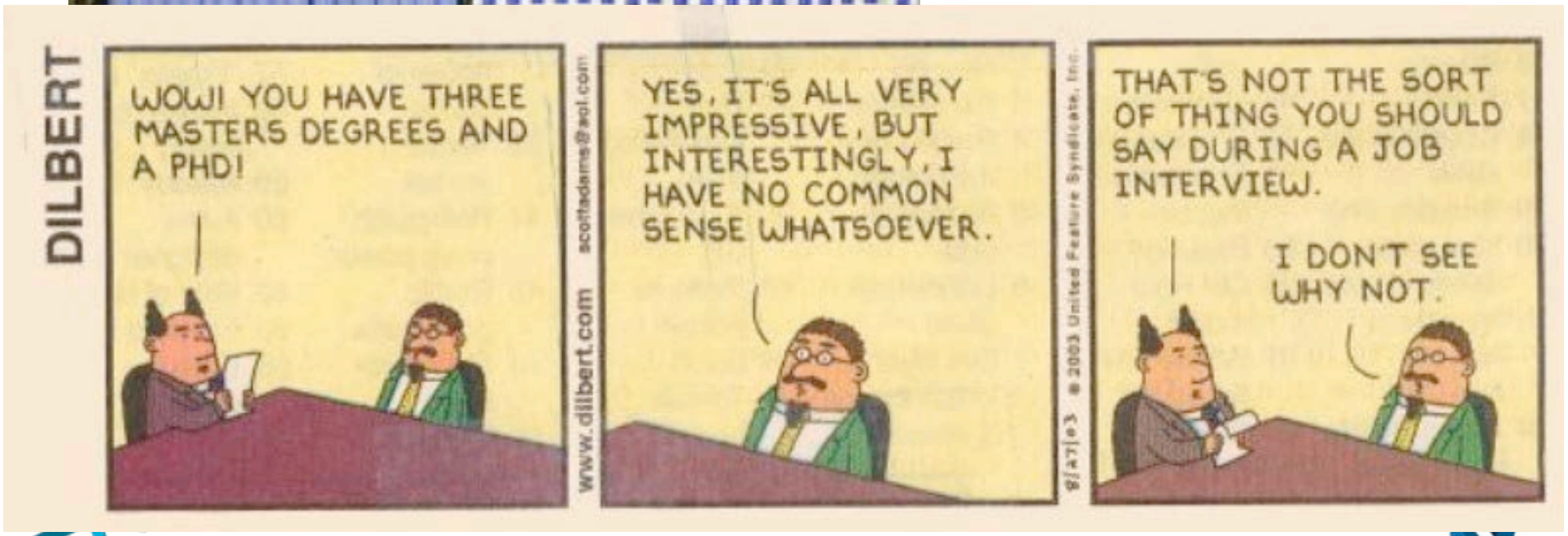


Encyclopedic Knowledge



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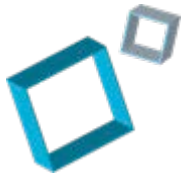

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Sort and list Nobel Prizes and Nobel Laureates | Prize category: Chemistry

The Nobel Prize in Chemistry 2011
Dan Shechtman

The Nobel Prize in Chemistry 2011

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Dan Shechtman

KUNGL. VETENSKAPS AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

English
English (pdf)
Swedish
Swedish (pdf)

Press Release

5 October 2011

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Chemistry for 2011 to

Dan Shechtman
Technion - Israel Institute of Technology, Haifa, Israel

"for the discovery of quasicrystals"

A remarkable mosaic of atoms

In quasicrystals, we find the fascinating mosaics of the Arabic world reproduced at the level of atoms: regular patterns that never repeat themselves. However, the configuration found in quasicrystals was considered impossible, and Dan Shechtman had to fight a fierce battle against established science. The Nobel Prize in Chemistry 2011 has fundamentally altered how chemists conceive of solid matter.

On the morning of 8 April 1982, an image counter to the laws of nature appeared in Dan Shechtman's electron microscope. In all solid matter, atoms were believed to be packed inside crystals in symmetrical patterns that were repeated periodically over and over again. For scientists, this repetition was required in order to obtain a crystal.

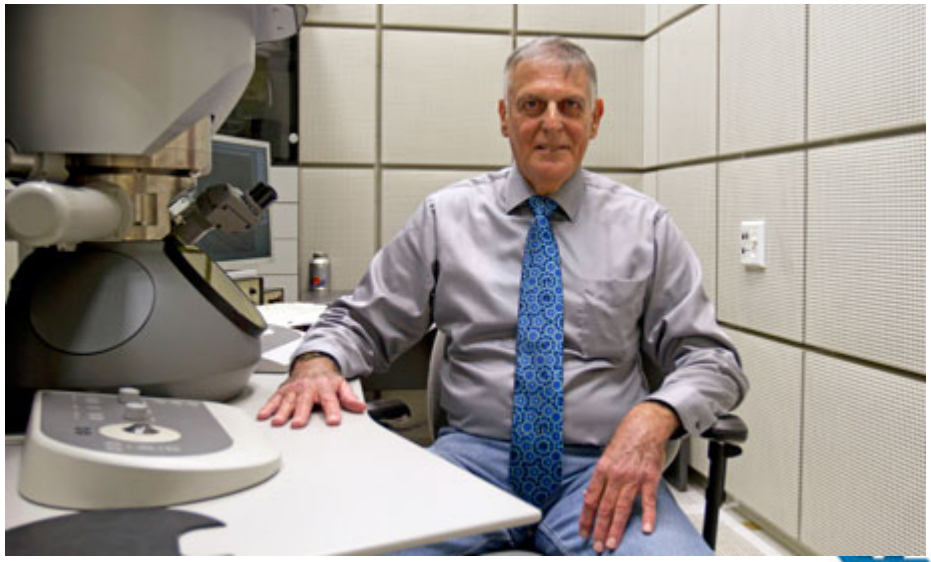
Shechtman's image, however, showed that the atoms in his crystal were packed in a pattern that could not be repeated. Such a pattern was considered just as impossible as creating a football using only six-cornered polygons, when a sphere needs both five- and six-cornered polygons. His discovery was extremely controversial. In the course of defending his findings, he was asked to leave his research group. However, his battle eventually forced scientists to reconsider their conception of the very nature of matter.

Aperiodic mosaics, such as those found in the medieval Islamic mosaics of the Alhambra Palace in Spain and the Darb-i Imam Shrine in Iran, have helped scientists understand what quasicrystals look like at the atomic level. In those mosaics, as in quasicrystals, the patterns are regular - they follow mathematical rules - but they never repeat themselves.

When scientists describe Shechtman's quasicrystals, they use a concept that comes from mathematics and art: the golden ratio. This number had already caught the interest of mathematicians in Ancient Greece, as it often appeared in geometry. In quasicrystals, for instance, the ratio of various distances between atoms is related to the golden mean.

Daniel Shechtman, who has won the chemistry Nobel for discovering quasicrystals, was initially lambasted for 'bringing disgrace' on his research group

"His discovery was extremely controversial. In the course of defending his findings, he was asked to leave his research group," the Nobel committee at the Royal Swedish Academy of Sciences said in a statement.



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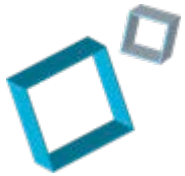

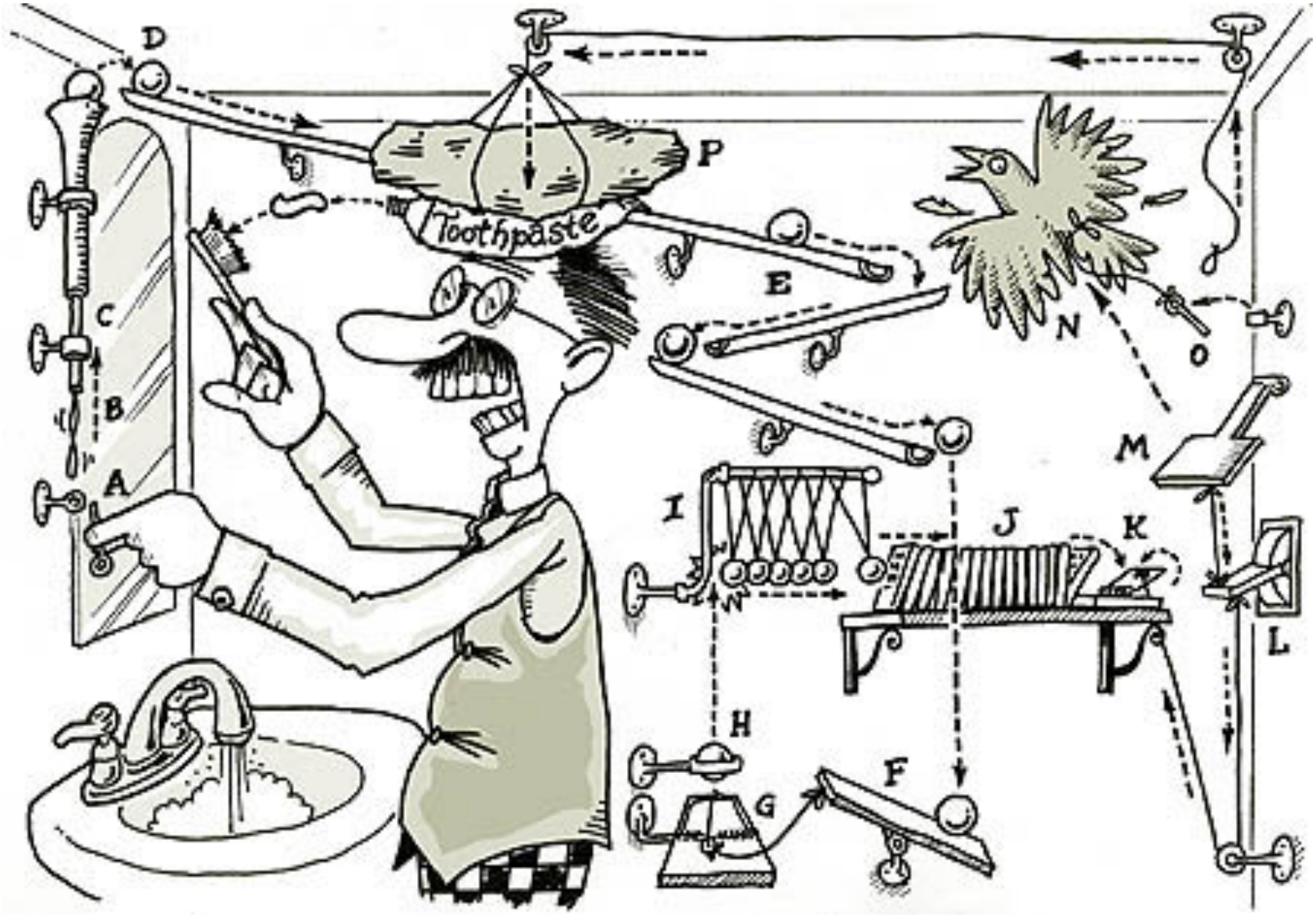
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Science

Business

Explore

Observe and define structure and dynamics.

Basic Research

Understand

Identify and characterize impact of changes of structure on dynamics and dynamics on structure.

Parameterize

Design alterations in structure and/or dynamics to purposefully control response.

Market Analysis

Explore

Observe and define a product and market.

Understand

Identify and characterize market history and likely future trends

Parameterize

Design potential products and assess potential markets and parameters for success.

Technology Greenhouse

Create

Create a potentially useful prototype.

Develop

Develop a potentially successful product.

Commercialize

Commercialize a successful product.

Technology Incubator

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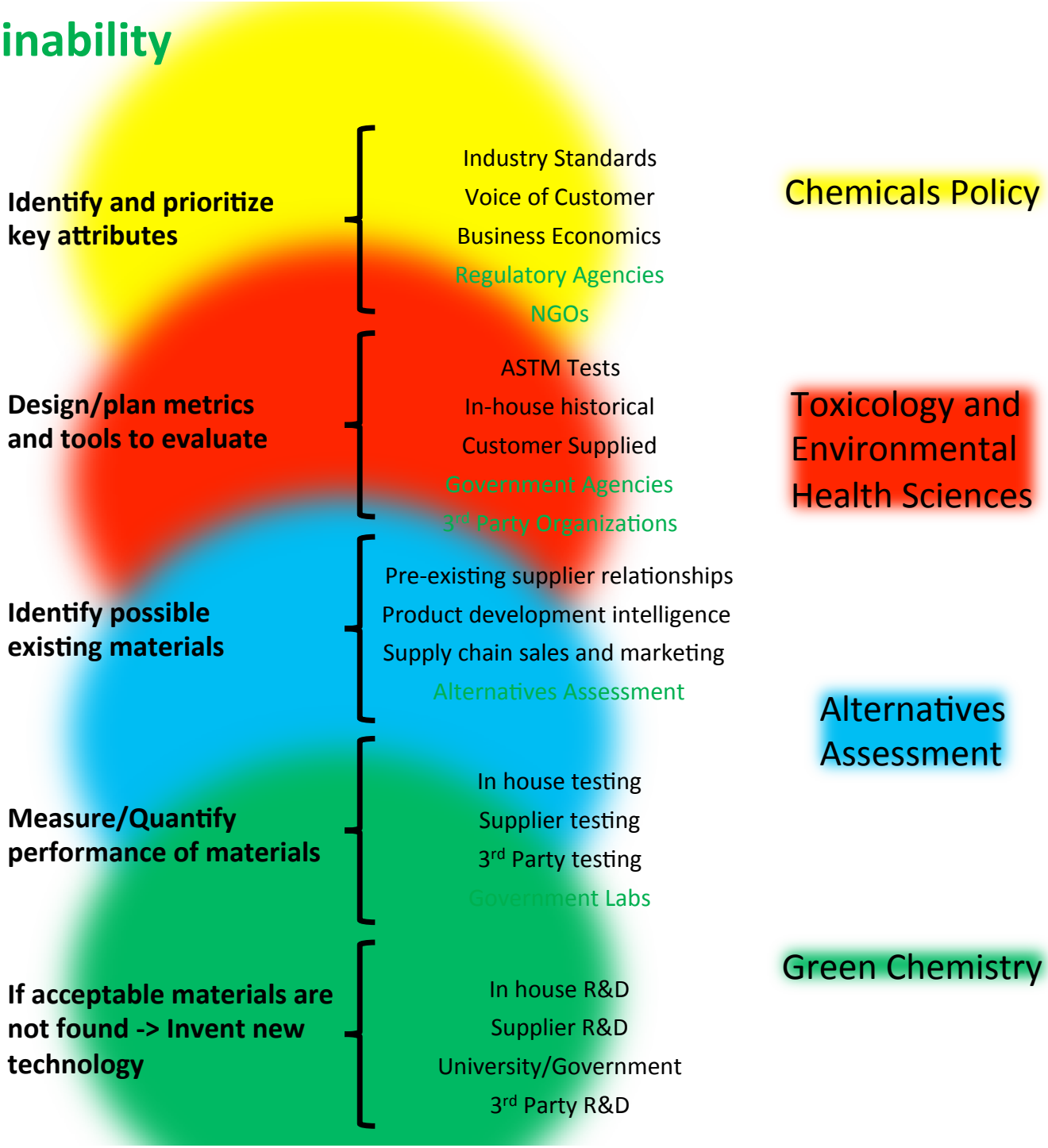
Safety and Sustainability



Elements of Safer Chemicals Policy

Element 1. **Move from a list based system to an assay based system.**

Focusing on assays avoids unfortunate substitutions.

Identifying criteria of success allows companies to invest strategically.

Element 2. **Move from a molecule based system to a product based system.**

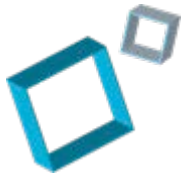
Some “ingredients” disappear and some molecules appear during manufacturing.

Avoids disclosing trade secrets.

Element 3. **Identify and disclose results of assays.**

Allows consumers quantitative assessments to base decisions.

Provides a framework for advocacy groups to communicate effectively.



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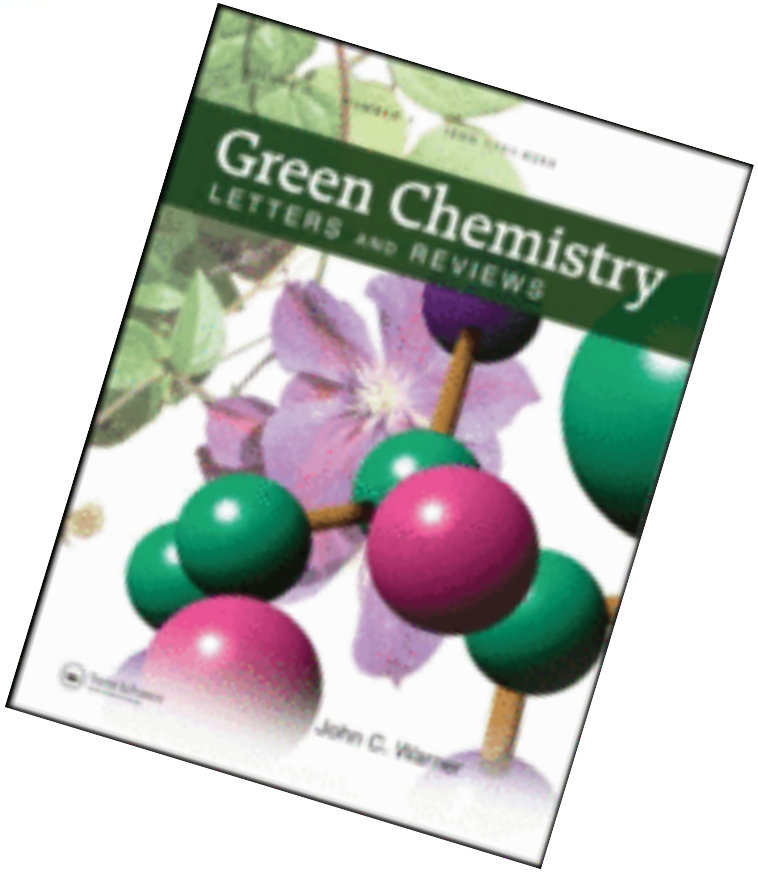

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