CENTER FOR GREEN CHEMISTRY & GREEN ENGINEERING AT YALE

Green Chemistry: What Does "Green" Mean?

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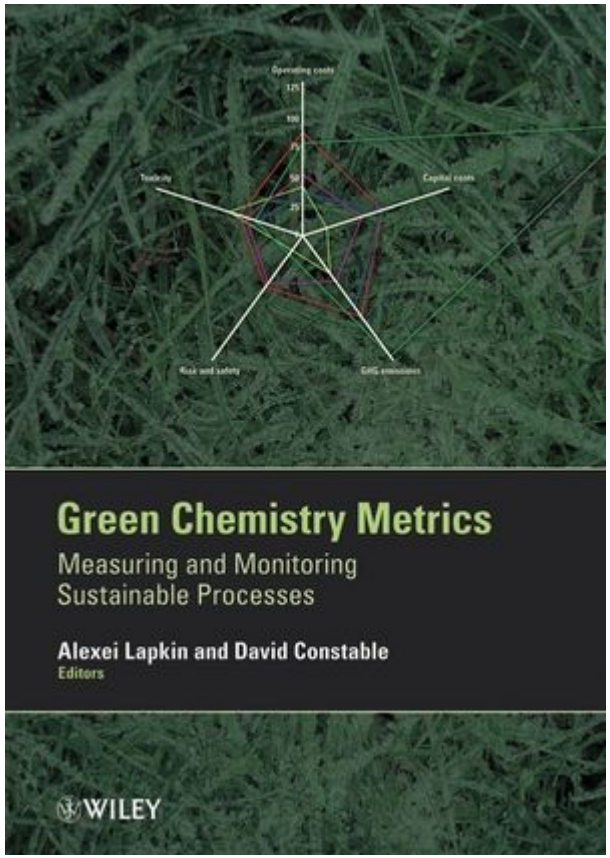


NSF/GCI/ANSI 355

iSUSTAIN™ Green Chemistry Index

Design for the Environment U.S. EPA

What green chemistry is *not*

- Banning/restricting chemicals
- Making political/value judgments
- Dogma

Green Chemistry: *Design*

Green chemistry is ***"the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances"***.

Green chemistry recognizes hazard as a molecular property that chemists can influence in the same way that we design molecules for color, solubility, melting point, reactivity, etc.

Hazard refers to the endangerment of humans or other life we depend on:

- Physical danger— fire and explosions
- Global deterioration — global warming, ozone depletion, exhaustion of natural resources, acid rain, and others
- Toxicological effects— acute and chronic, including emerging issues such as endocrine disruption and epigenetic phenomena

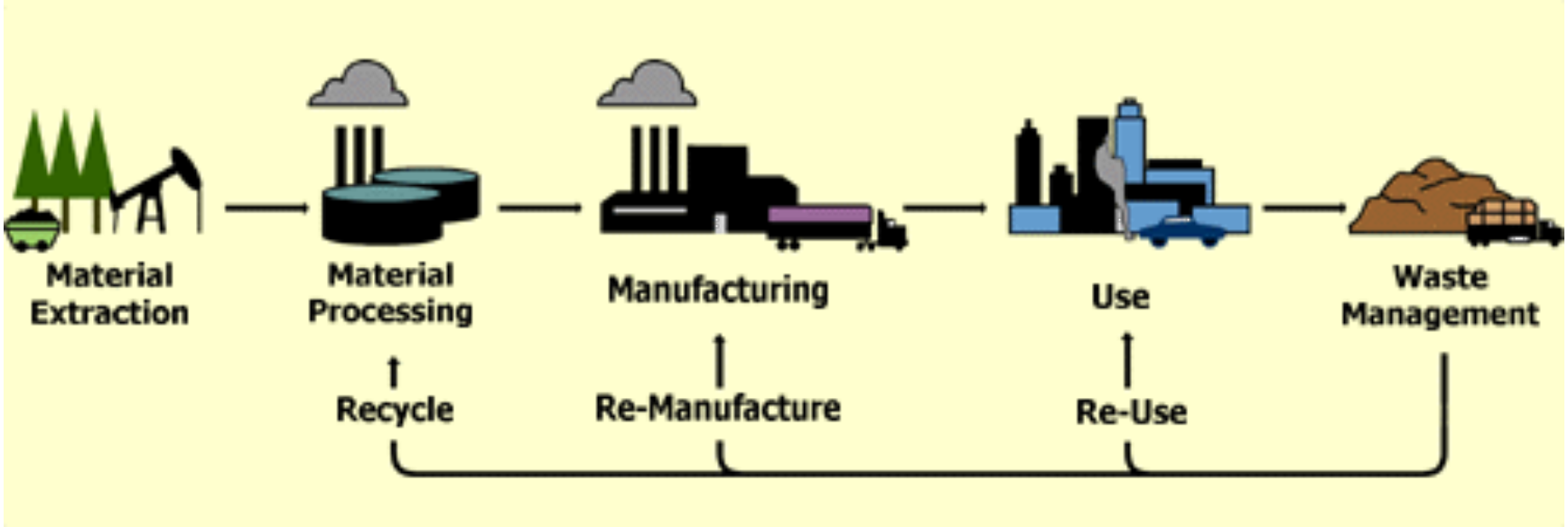
What green chemistry *is*

- Adding a layer of technical challenge
- Providing new tools
- Providing new choices
- A process of continuous improvement

Principles of green chemistry (1998)

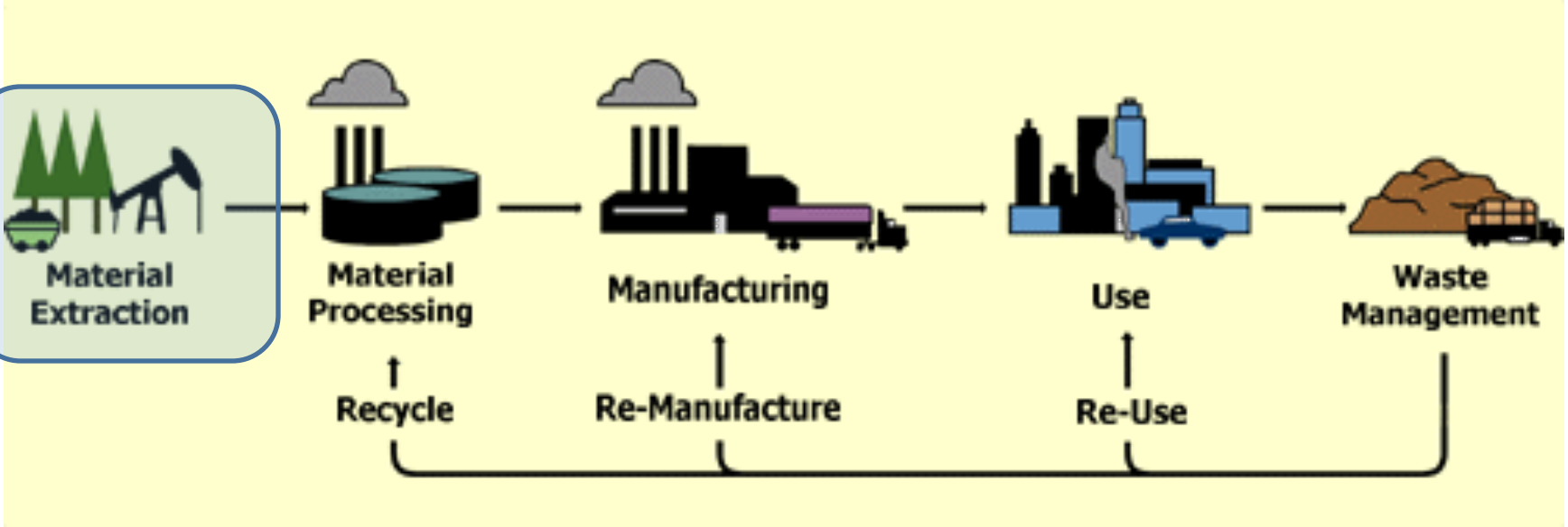
1. It is better to prevent waste that to treat or clean up waste after it is formed.
2. Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3. Wherever practicable, synthetic methodologies should be designed to use and generate 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 or 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.

12 Principles / Chemical Life Cycle



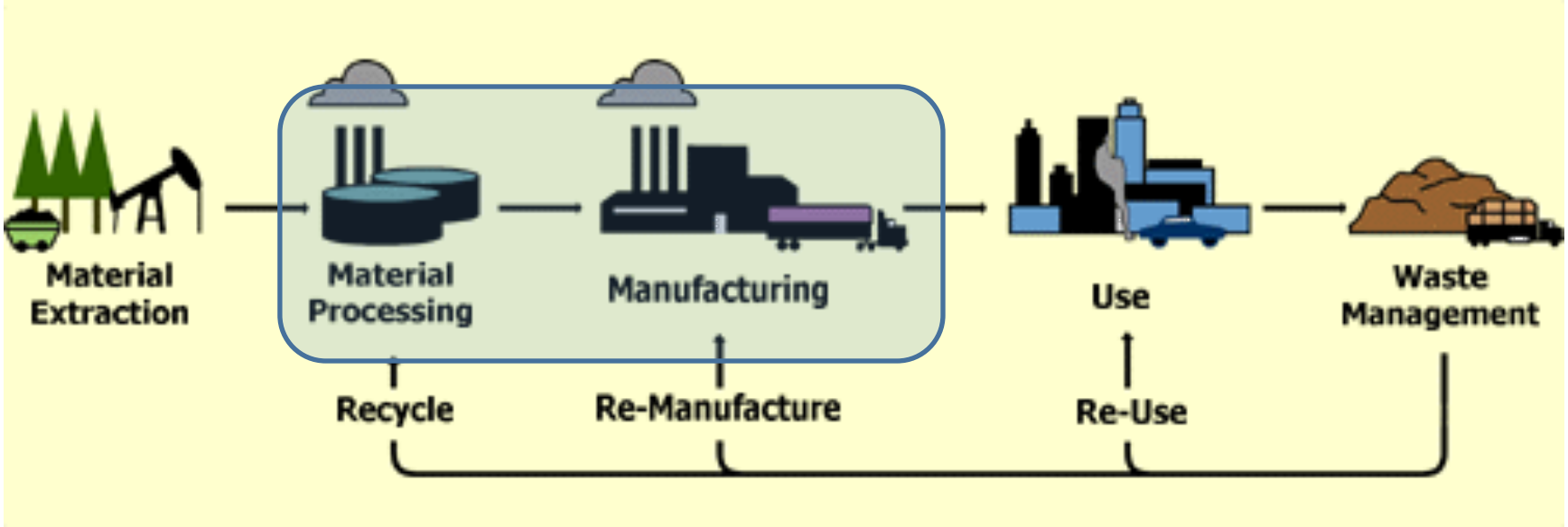
- Across the lifecycle: prevent waste, minimize energy and toxicity impacts

12 Principles / Chemical Life Cycle



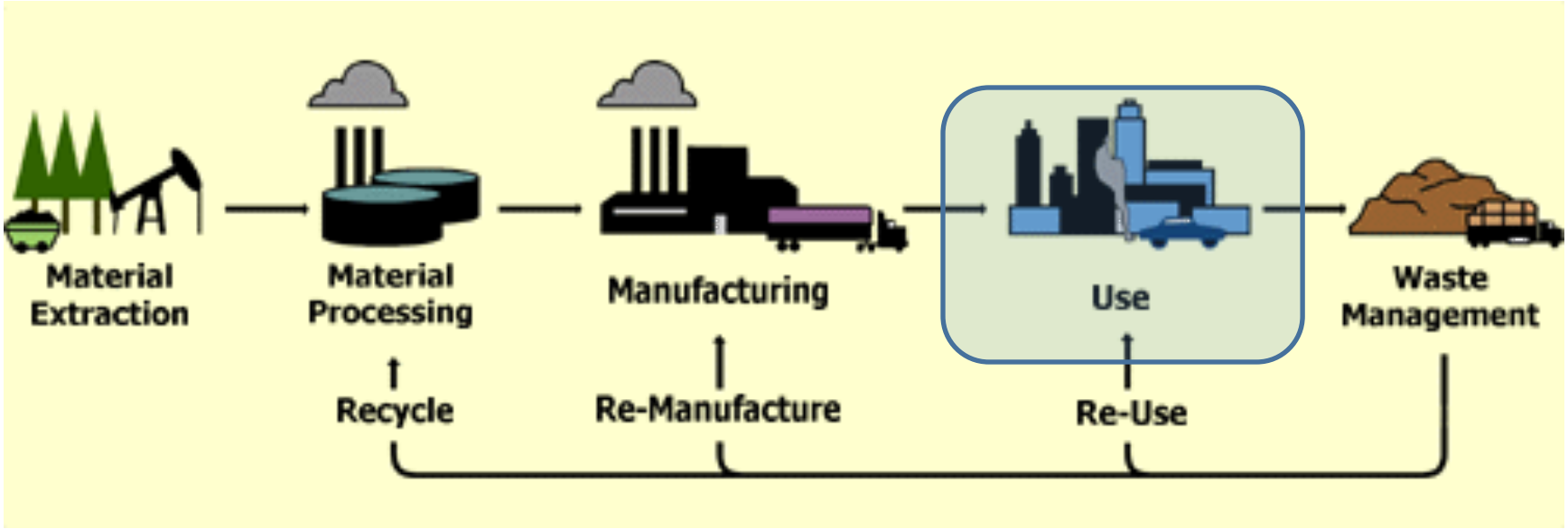
- Renewable resources

12 Principles / Chemical Life Cycle



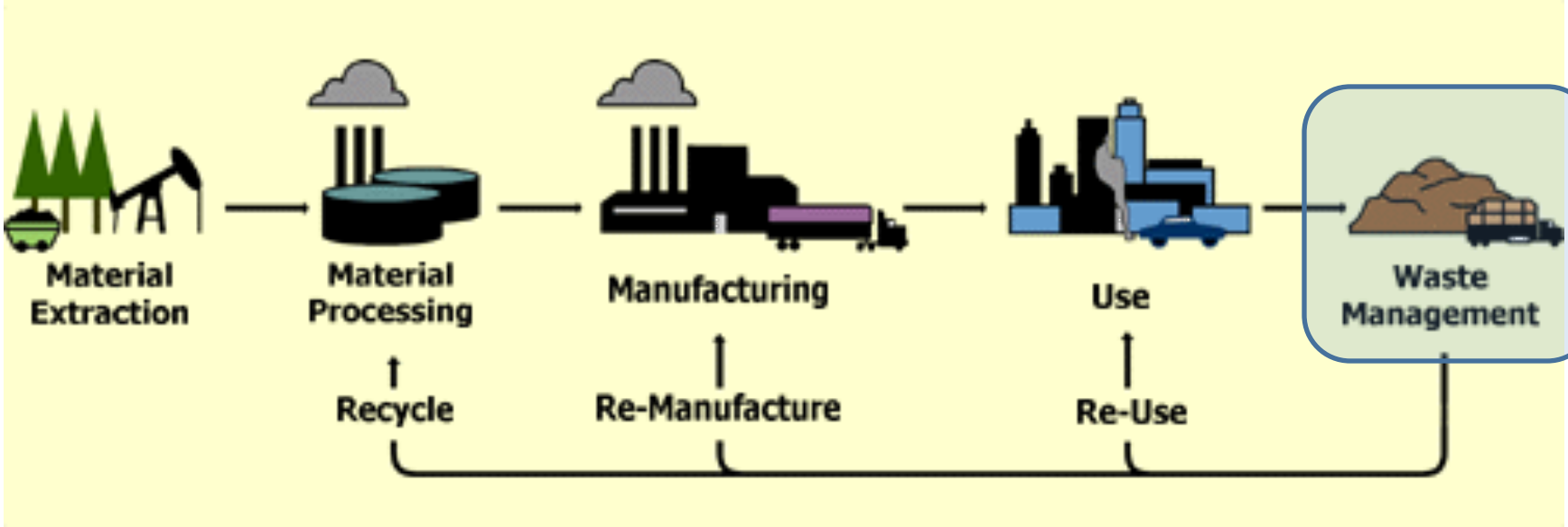
- Eliminating waste via atom economy, selective catalysts
- Alternative solvents (water, CO_2, etc.)

12 Principles / Chemical Life Cycle



- If the product itself presents toxicological hazards?
- "Intentional use" / unintended consequences

Life Cycle and Toxicological Hazards



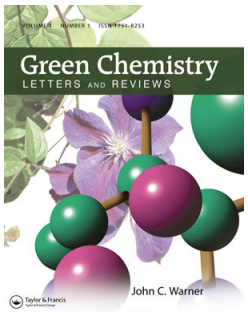
- Design for biodegradation, identify metabolites

Green chemistry: additional resources

Green Chemistry. Published by the Royal Society of Chemistry since 1999.

Journal of Chemical Education has been soliciting submissions related specifically to green chemistry for more than a decade.

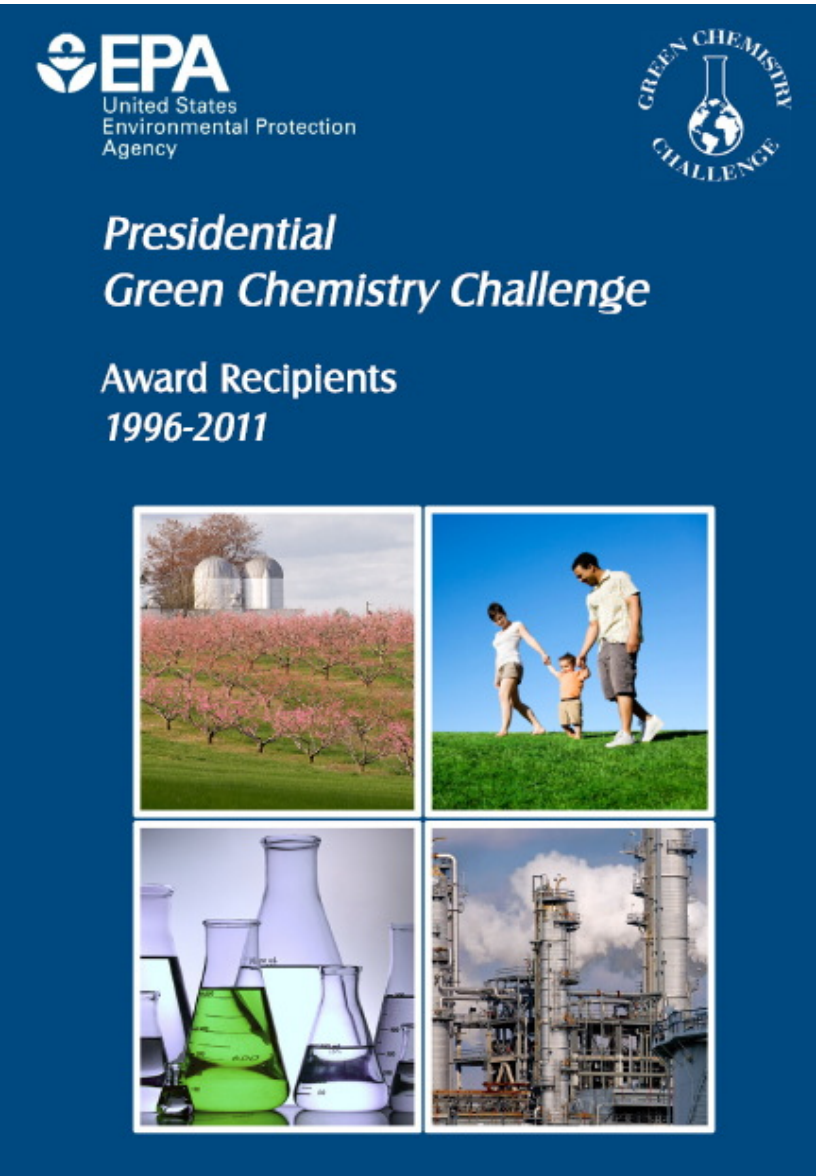
ChemSusChem. Published by Wiley since 2008.



Green Chemistry Letters & Reviews. Published by Taylor & Francis since 2008.

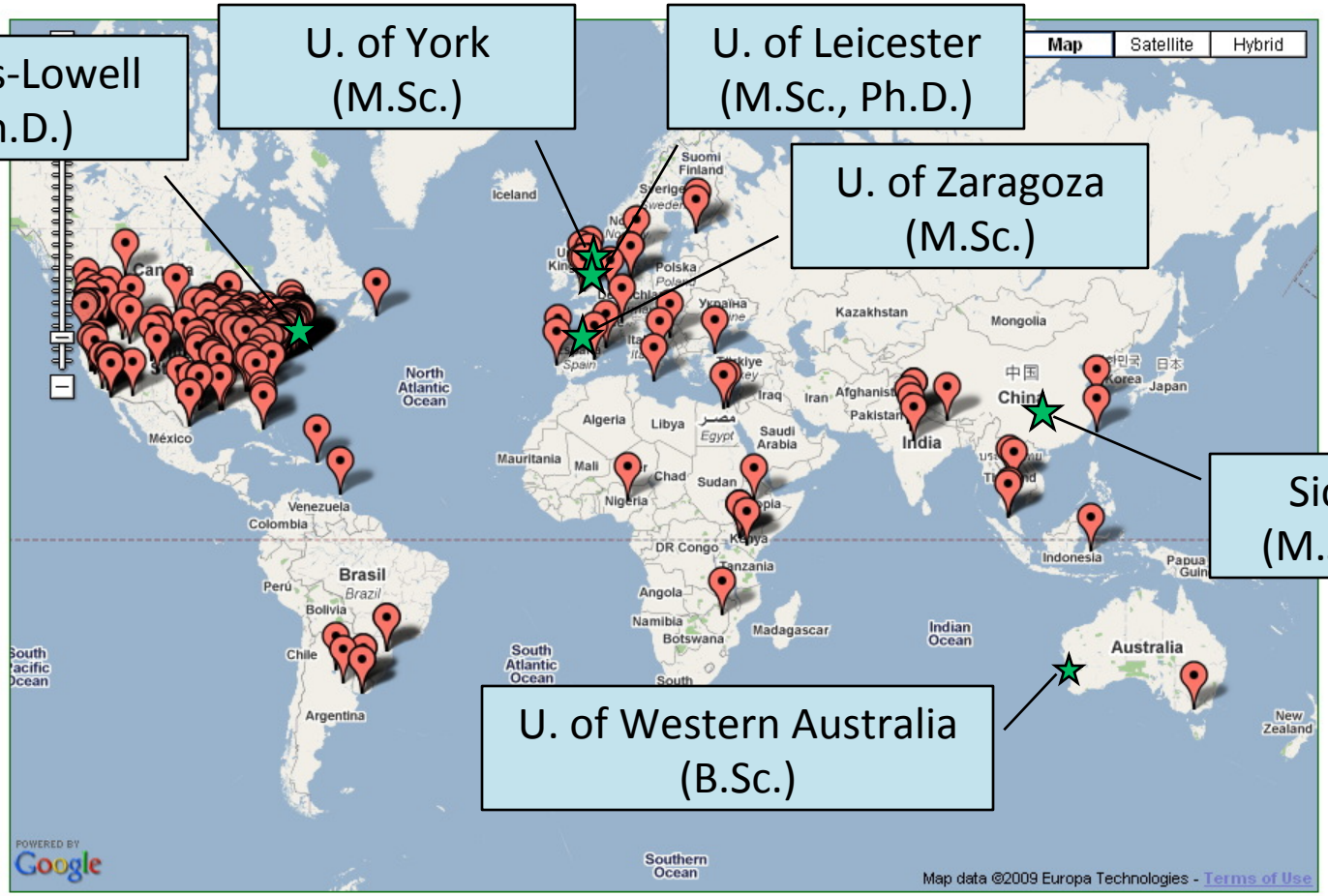
Coming soon: *ACS Sustainable Chemistry & Engineering*; *Current Green Chemistry* (Bentham)

Presidential Green Chemistry Challenge Awards



- Small Business
- Academic
- Industry / greener synthetic pathways
- Industry / greener reaction conditions
- Industry / design of greener chemicals

Safer alternatives through innovation



http://greenchem.uoregon.edu/Pages/MapDisplay.php

Take-home messages

- "Green" means new chemicals, materials, transformations, methodologies, solvents, molecules, analyses, and tools
- "Green" means design and continuous improvement at the molecular level
- Green chemistry aims to fully integrate with "regular" chemistry, bringing in elements of engineering, physics, biology, and toxicology.