# Green nanoscience: Opportunities and challenges for innovation

Jim Hutchison

Department of Chemistry, University of Oregon

Director, UO Materials Science Institute

Director, ONAMI Safer Nanomaterials and Nanomanufacturing Initiative (SNNI)

green Chemistry

At the University of Oregon

ONAMI

OREGON NANOSCIENCE AND MICROTECHNOLOGIES INSTITUTE

# Merging green chemistry and nanoscience

Design and manufacture it right the first time!

Gain competitive advantage:  Higher performance and greener

Focus on important, core R&D challenges

- Develop means to **manufacture** complex nanomaterials efficiently, without the use of hazardous substances

- **Design** nanomaterials that provide new properties and performance, but do not pose harm to human health or the environment

- Optimize the **application** of nanomaterials to the maximum benefit for society and the environment

# Nanoscience and nanotechnology will impact nearly all technological sectors

Imaging agents

Cosmetics

Therapeutics

Drug delivery

Diagnostics

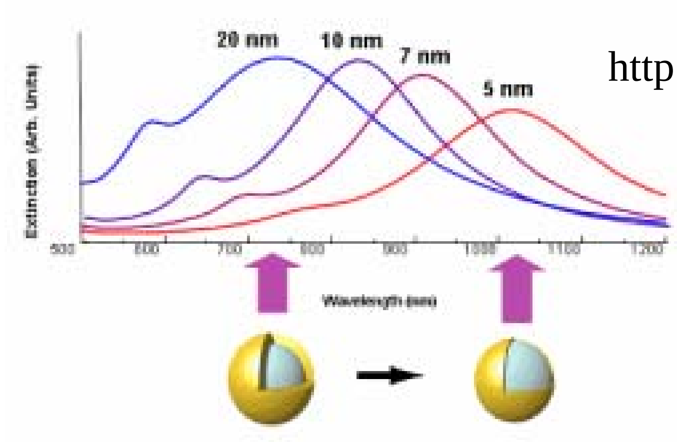
Nanoelectronic devices

Sensors and biosensors

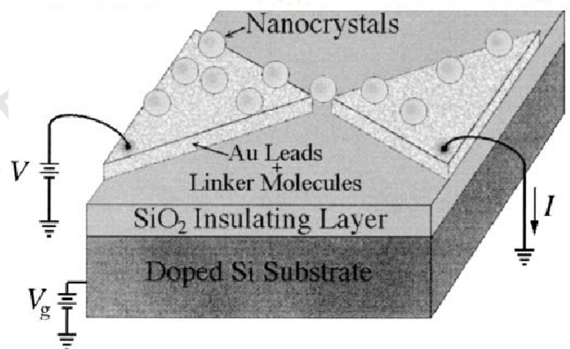
Optical apps - waveguides, optical probes

Catalysis

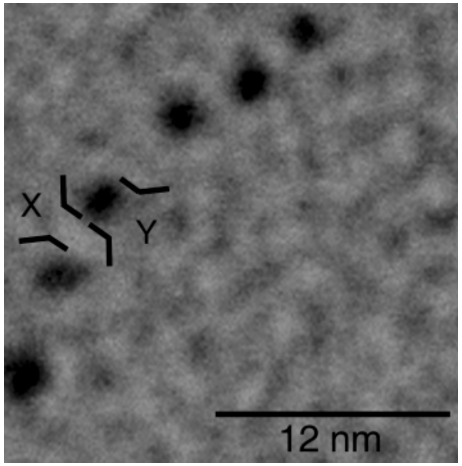
Bioremediation




http://www.nanospectra.com/




Klein, Roth, Lim, Alivisatos, McEuen, *Nature* **1997**, *389*, 699




Warner and Hutchison *Nature Mater*. **2003,** 272

*New properties found at the nanoscale will make these innovations possible*

# Environmental impacts of microelectronics

*e-waste*

300-600 million obsolete computers in US
Hazardous materials: Pb, Cd, Cr, Hg
~ $10^9$ pounds of Pb

**The 1.7 Kilogram Microchip: Energy and Material Use in the Production of Semiconductor Devices**

ERIC D. WILLIAMS,*,† ROBERT U. AYRES,‡ AND MIRIAM HELLER§

*United Nations University, 53-67 Jingumae 5-chome, Shibuya-ku, Tokyo, Japan, INSEAD, Boulevard de Constance, Fontainebleau, 77305 Cedex, France, and National Science Foundation, 4201 Wilson Boulevard, Arlington, Virginia 22230*

For a 2-g DRAM chip:

Chemical input ~72g
Energy (fossil fuels)
~1,600 - 2,300 g
Water ~ 20,000 g
Gases ~ 500 g

*Environ. Sci. Technol.* **2002**, *36*, 5504−5510

*What about nanotechnology?*

# Growing concerns about nanotechnology stem from new, unknown properties and manufacturing challenges

Will the **products** of nanotechnology….

…be harmful to human health?

…pose risks to the environment?

Numerous studies and reports that suggest a need to address the hazards of these materials directly

Lessons from GMOs - public acceptance as a barrier to commercialization

Will the **manufacture** of these products generate new hazardous (toxic) wastestreams?

Hazardous reagents

Toxic solvents and high solvent usage

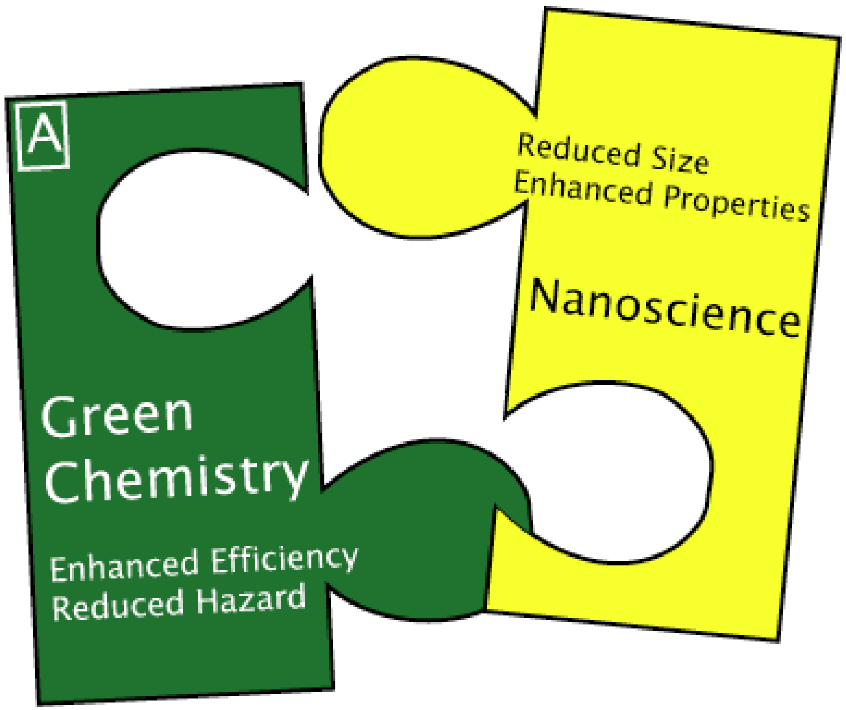
Low yields of material (poor materials use)

# Application of green chemistry to nanomanufacturing

Product

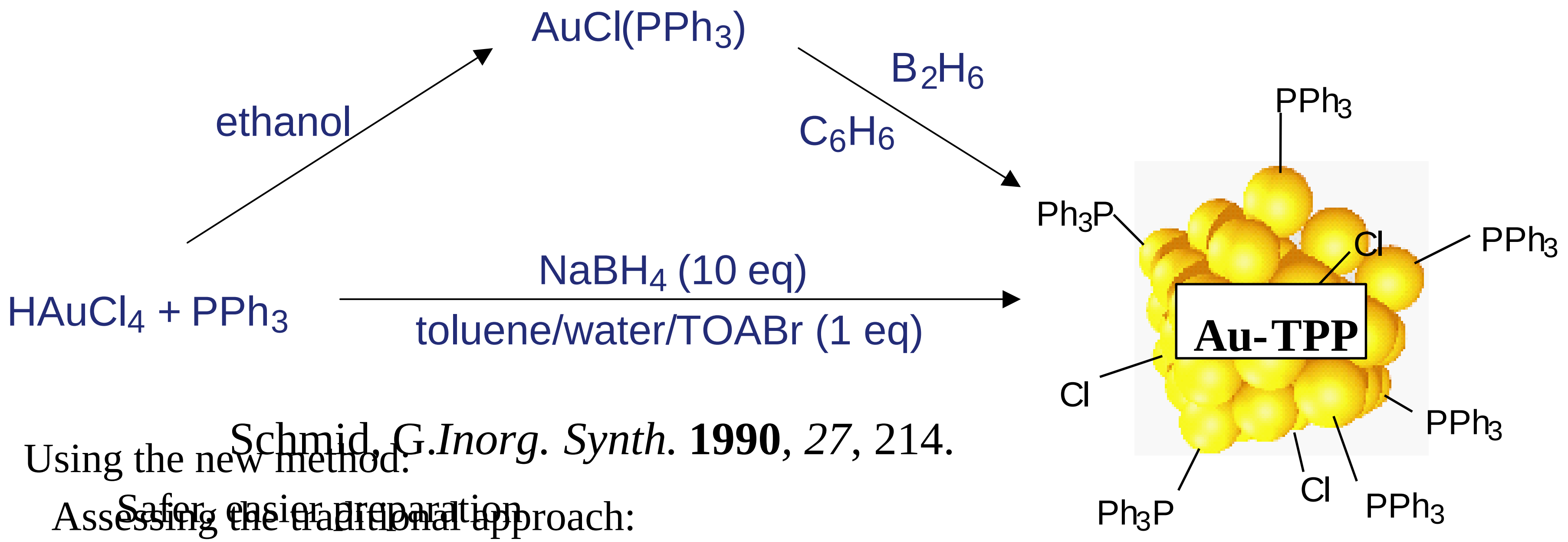
**Process**

Applications




*Nanoparticle production, purification and nanoscale patterning*

# Example: A greener synthesis of a nanoparticle building block: Triphenylphosphine-stabilized nanoparticles




Narrow dispersity
($d$ = 1.5 +/- 0.4 nm)

Schmid, G. *Inorg. Synth.* **1990**, *27*, 214.

Assessing the traditional approach:

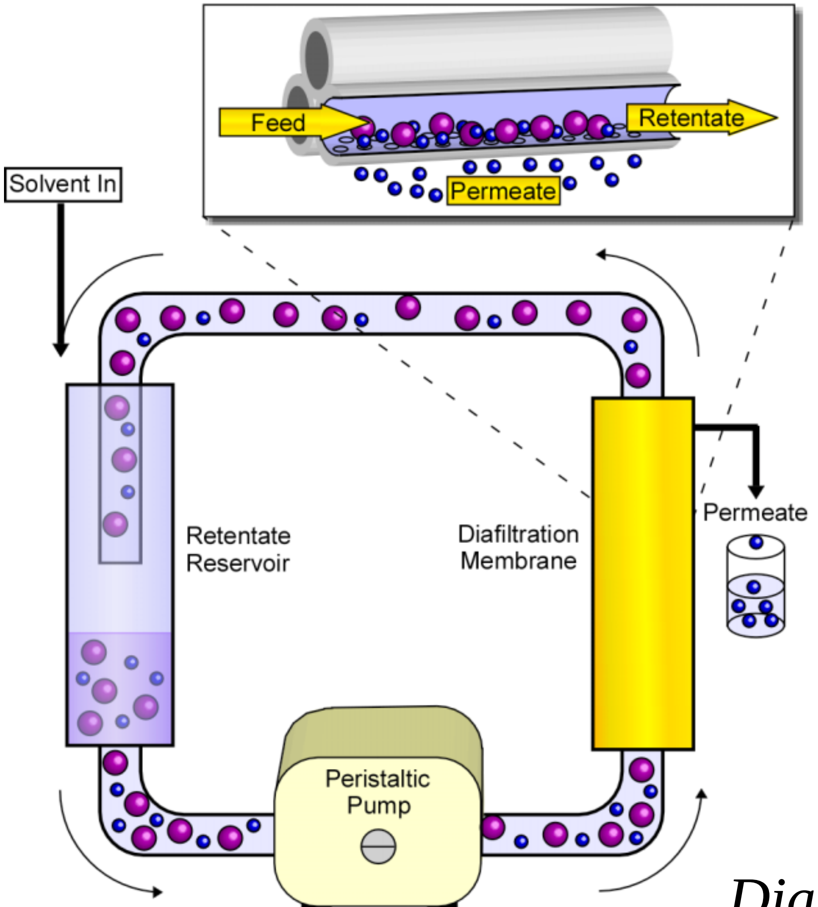
- Diborane is highly toxic and highly flammable
- Benzene presents a health hazard
- Process is time consuming and labor intensive
- Difficult scale up
- Purification requires use of large volumes of solvent

Using the new method:

- Safer, easier preparation
- Rapid synthesis of gram quantities
- Faster, more effective purification
- Cheaper (~ $500/g vs. "$300,000/g")

Weare, Reed, Warner, Hutchison *J. Am. Chem. Soc.* **2000**, *122*, 12890.
Hutchison, et al. *Inorg. Syn.* **2004**, *34*, 228.

# Example: Reducing solvent waste in the purification of nanoparticles




Nanomaterials purification

Traditional:

15L solvent per gram NP

3 days work

Diafiltration:

No organic solvent

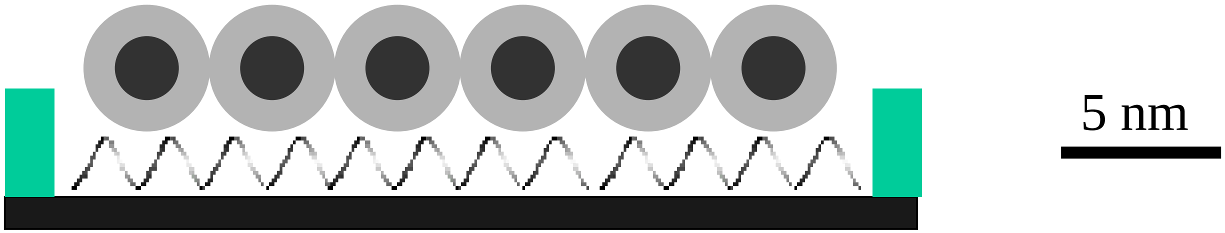
15 minutes work

*Diafiltration reduces solvent consumption and provides **cleaner, well-defined building blocks***



Sweeney, Woehrle, Hutchison *JACS*, In press.

# Example: Bottom up nanofabrication - Biomolecular nanolithography:




Target structures: 2-nm islands with 2-nm separation

**Island size** - NP dimensions precisely tuned by synthesis

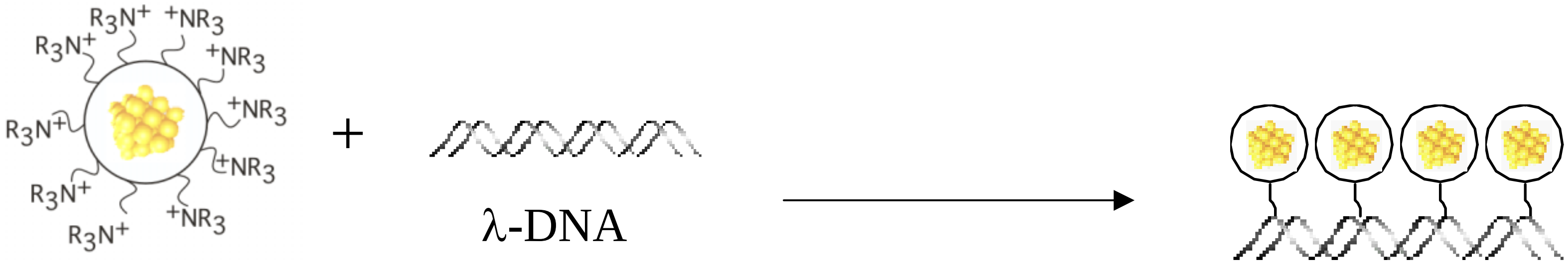
**Spacing** - Ligand shell controls interparticle spacing

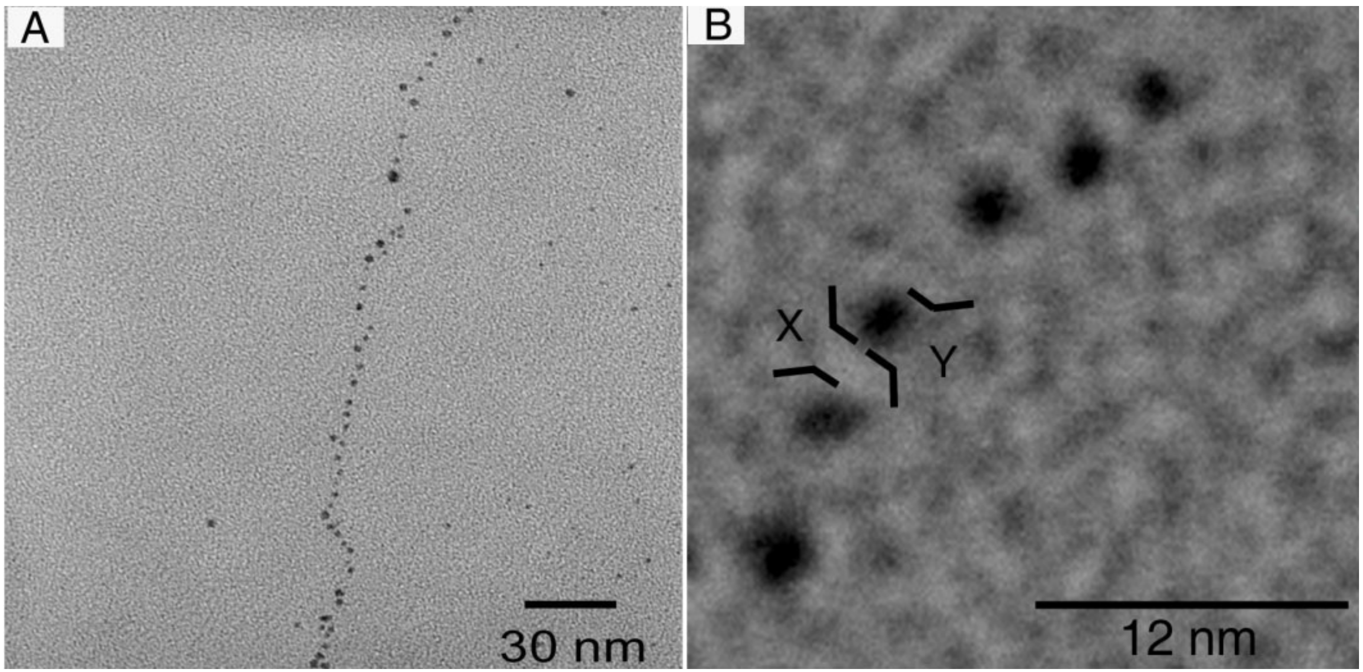
**Arrangement** - Polymeric scaffold directs arrangement

**Positioning** - Self-assembly positions scaffold on substrates

Warner and Hutchison, *Nature Mater*. **2003,** 272-277.

# Extended linear chains of closely-spaced particles are accessible using this assembly method




1.9-nm particles separated by 1.5 nm

Warner and Hutchison, *Nature Mater*. **2003,** 272-277.

# Nanoscale manufacturing from the top-down and bottom-up

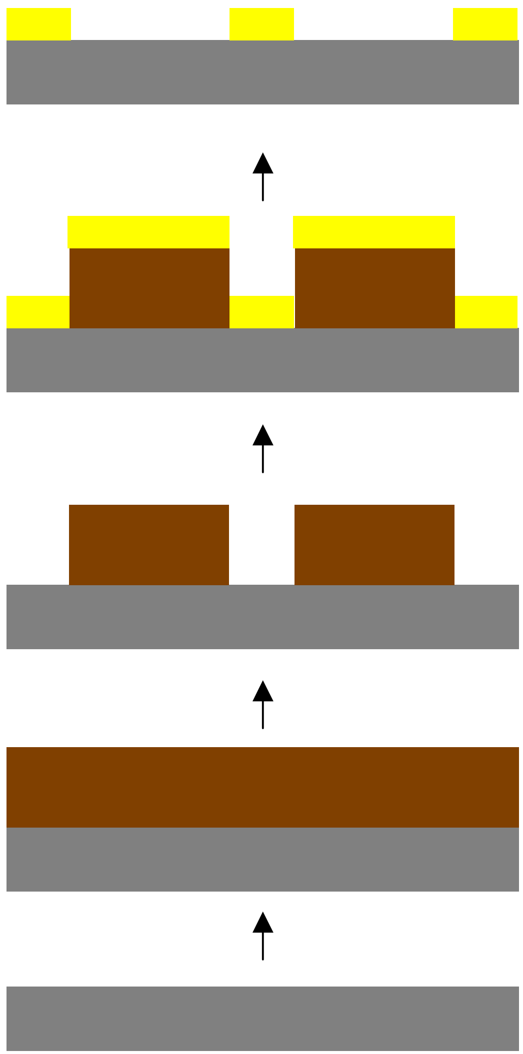
top-down

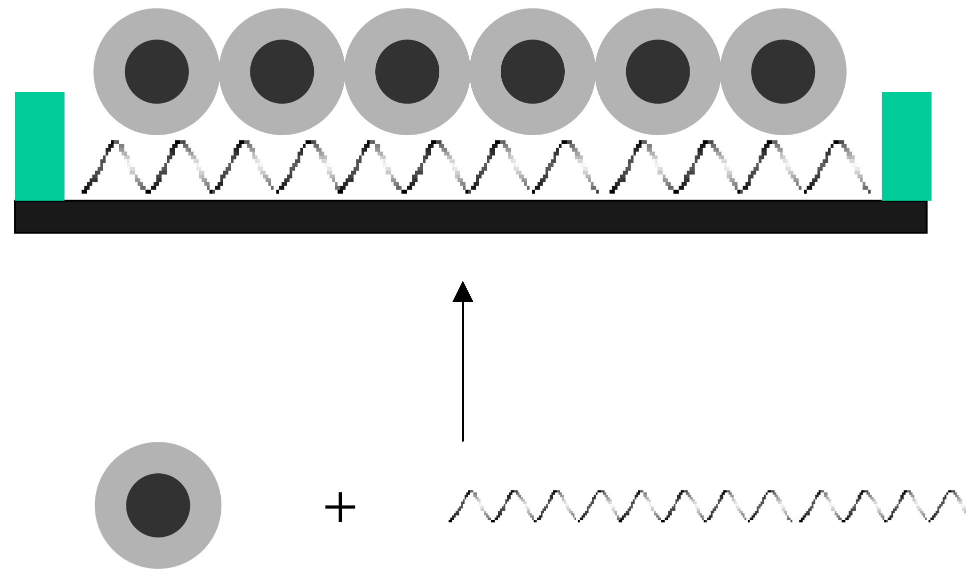
Franklin

bottom-up

The Tick

# Assembling from the bottom up offers green chemistry advantages





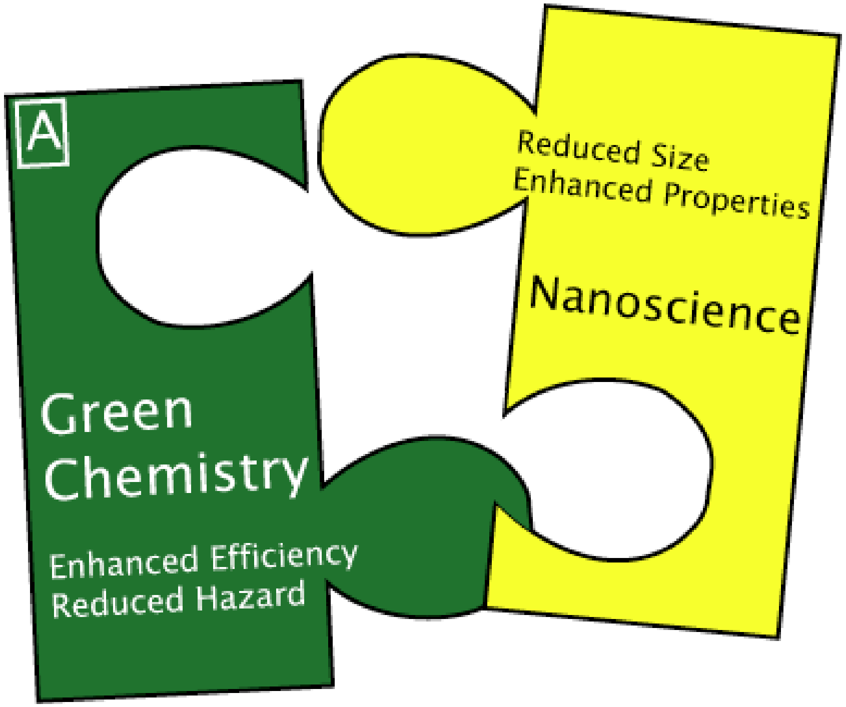

Eliminates processing steps

Incorporates more raw materials in product

Reduces water and solvent use

Provides access to smaller structures

# Application of green chemistry to the design of nanoscale materials




**Product**

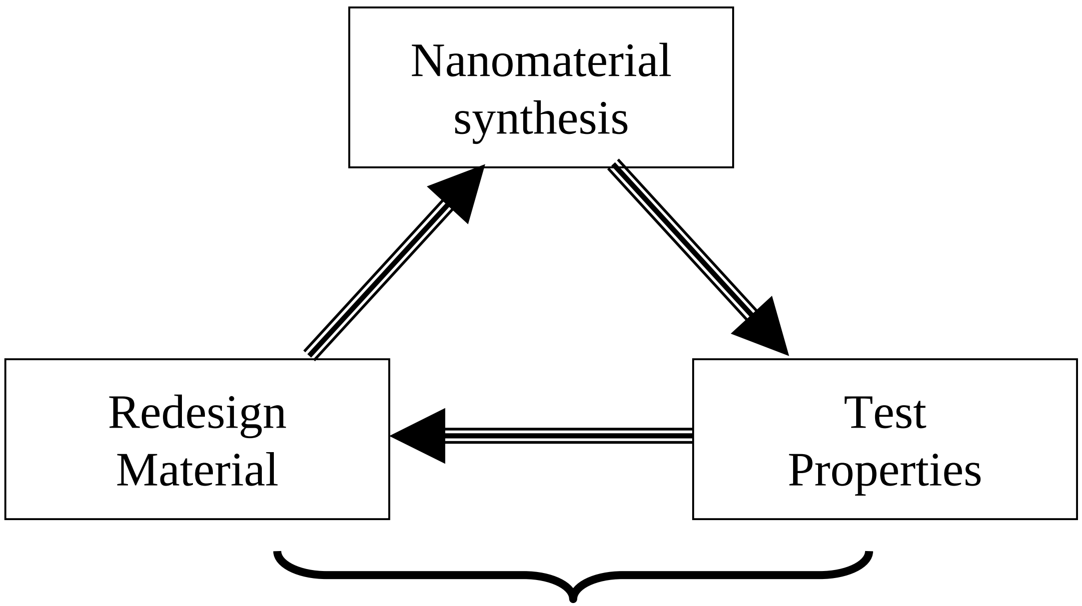
Process

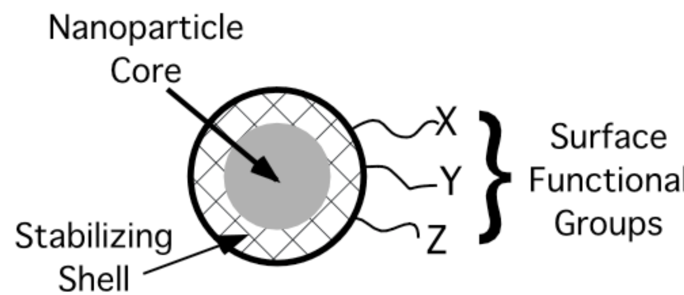
Applications

McKenzie, L.C; Hutchison, J.E. “Green nanoscience,” *Chemistry Today*, **2004**, 30-33.

# Designing safer nanoparticles

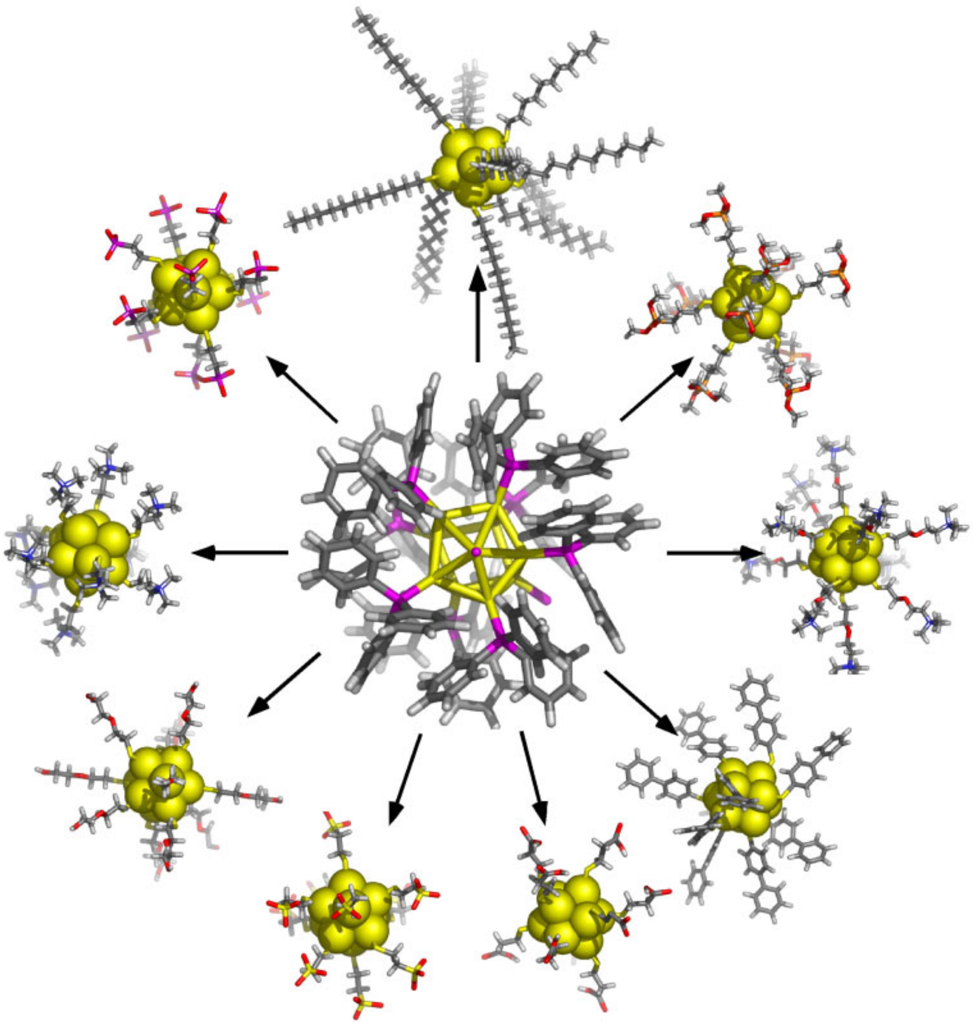
Anticipate broad application (and distribution) in medicine, cosmetics, environmental remediation…



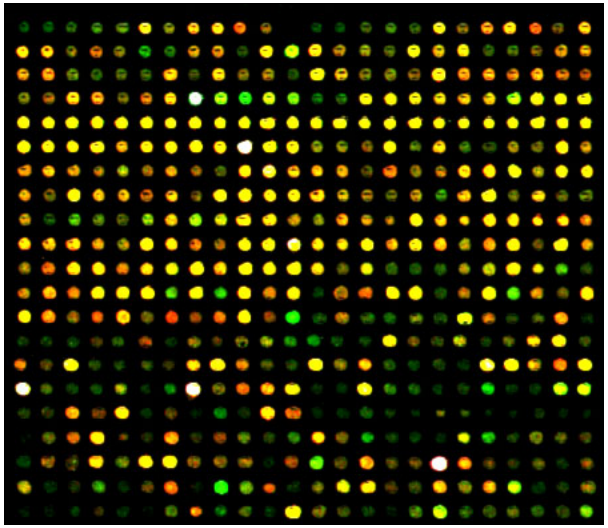




Structure/Property Relationships needed to optimize for performance *and* hazard

# What are the research needs for designing safer nanomaterials?



- Diverse libraries
- Well-defined materials
- Appropriate bioassays



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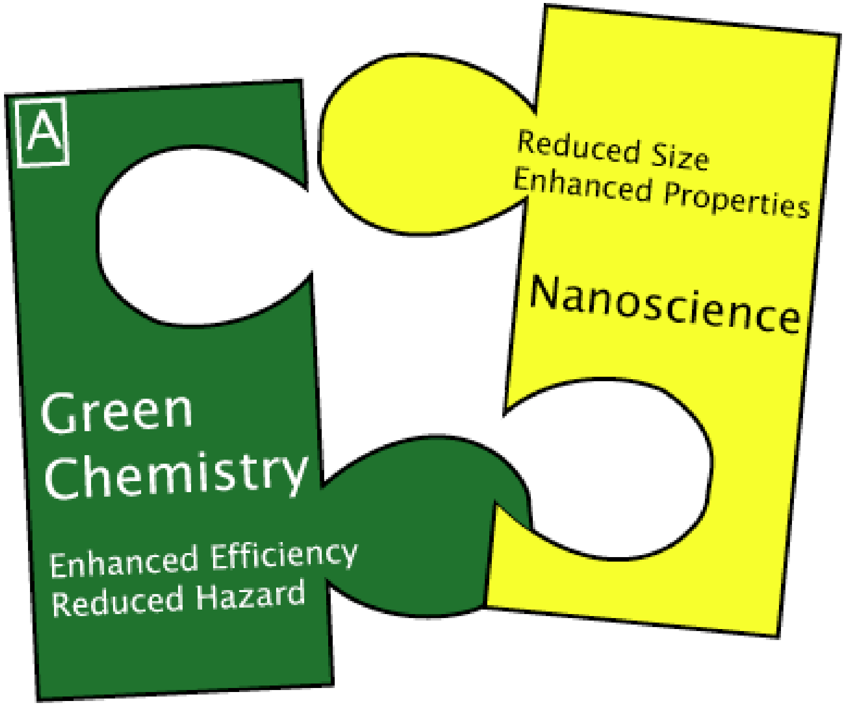
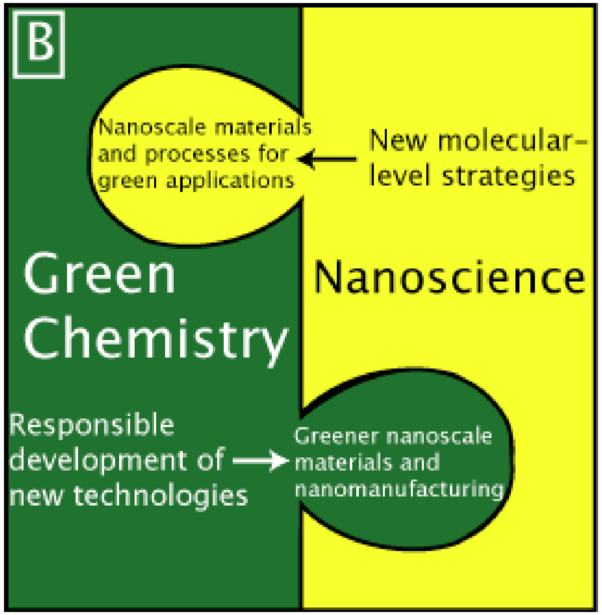
# Merging green chemistry and nanoscience




McKenzie, L.C; Hutchison, J.E. "Green nanoscience," *Chemistry Today*, **2004**, 30-33.

# Summary - Green Nanoscience

The combination of green chemistry and nanoscience offers opportunities to **gain competitive advantage and get the technology right the first time**

Green chemistry will drive the development of **higher performance, as well as, environmentally friendlier** products and processes

**Examples of successes** that will be possible if we focus efforts and resources on green approaches to:

- Nanomaterials design
- Nanomanufacturing approaches
- Optimal application of nanomaterials