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)
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

New properties found at the nanoscale will make these innovations possible


Warner and Hutchison *Nature Mater.* 2003, 272

http://www.nanospectra.com/
Environmental impacts of microelectronics

*e-waste*

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

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

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

Using the new method:
- Safer, easier preparation
- Rapid synthesis of gram quantities
- Faster, more effective purification
- Cheaper (~ $500/g vs. “$300,000/g”)


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


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

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

\[ \lambda - \text{DNA} \]

1.9-nm particles separated by 1.5 nm

Nanoscale manufacturing from the top-down and bottom-up
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

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
Merging green chemistry and nanoscience

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