Nanotechnology
What is it?
Any concerns?
What about the future?

Shaun F. Clancy, Ph.D.
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Presentation to AIChE

Highlights

- What is Nanotechnology?
- What is a “Nanomaterial”?
- Benefits/Applications of Nanoscale materials
- Is Nano new?
- Any problems?
- What is Industry doing?

What is Nanotechnology?

- Nanotechnology is not a single technology
- Nanotech is an “enabling technology”. It makes other technologies better!
- Nanotech takes advantage of size:
  - Surface effects (area, chemistry)
  - Electronic effects
  - Physical effects

Nanotechnology

The application of scientific knowledge to control and utilize matter at the nanoscale, where size-related properties and phenomena can emerge. The nanoscale is the size range from approximately 1 nm to 100 nm. (ISO TC229: 11/2008)

Possible benefits:

- Do more with less
- More effective catalysts
- Targeted pharmaceuticals
- New pharmaceuticals
- New pesticides
- Stronger, lighter materials – Boeing 787
- Better cosmetics – Transparent TiO_2 Sunscreens

Nanotech Development Stages

- First Generation - Passive nanostructures
  Stage started ~2001
- Second Generation - Active nanostructures
  Currently Developing Stage
- Third Generation – Nanostructure Systems
  Stage predicted to emerge around 2010.
- Fourth Generation - Molecular Nanosystems
  Stage predicted to start 2010-2015 and beyond.

Nanotech Development Stages

- Passive nanostructures – Includes basic materials – Nanoparticles, Nanostructured Coatings, Polymers, Ceramics, Composites, Displays

- Active nanostructures – Includes advanced materials – Transistors, Amplifiers, Targeted Drugs & Chemicals, Sensors, Diagnostic Assays, Nanocomposites, Ceramics

Nanotech Development Stages

- Systems of nanostructures - Active nanostructures working together. e.g. Self-assembly, Novel Therapeutics/(even) More Targeted Drug Delivery

- Molecular nanosystems – Molecular scale computing, manufacturing, etc.

Are Nanoscale Materials New?

- Not really
- Nanoscale Gold was used to color ancient glass (BCE)
- Carbon Nanotubes found in ancient Damascus steel (1400's)
- Buckyballs identified in 1980's

Are all Nanoscale Materials Man-made?

No

- Volcanic Dust
- Nano Sea Salt in Sea Spray
- Combustion products

What is a Nanoscale material?

Nanometer = 1 Billionth of a Meter (1×10^{-9})

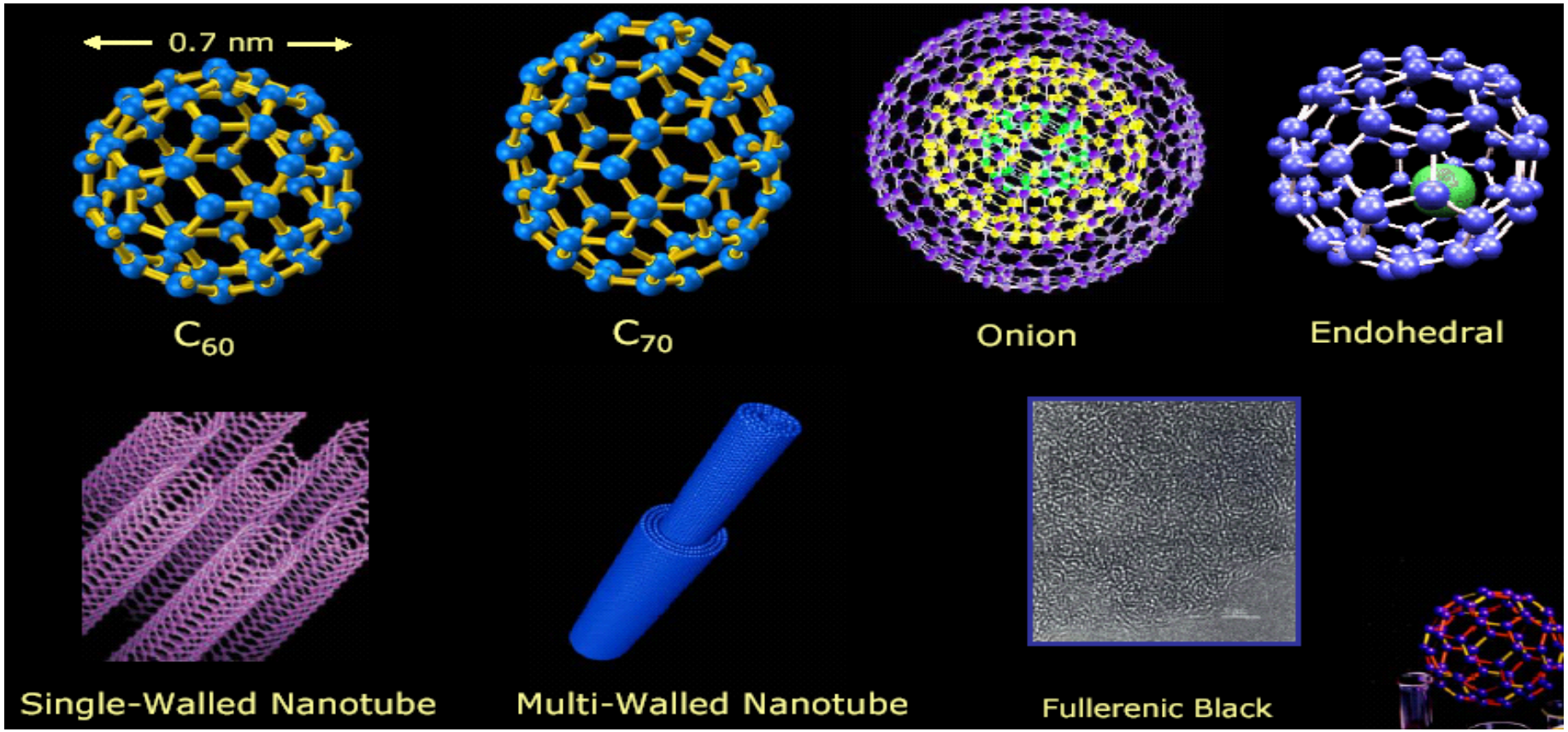
Many definitions available and they change frequently

- **e.g. National Nanotechnology Initiative, ASTM, ISO, Defra**
- **Most focus on materials with at least 1-D of 1-100 nanometers**
- **Many discussions concern "spherical" inorganic particles but nanorods (e.g. CNT), nanofilms and organics are also of interest.**
- **Perspective: Humans (10^0-10^1 meter) are closer in size to Mt. Everest (10^4 meter) than to a nanoscale particle (1-100 x 10^{-9} meter).**

The Scale of Things

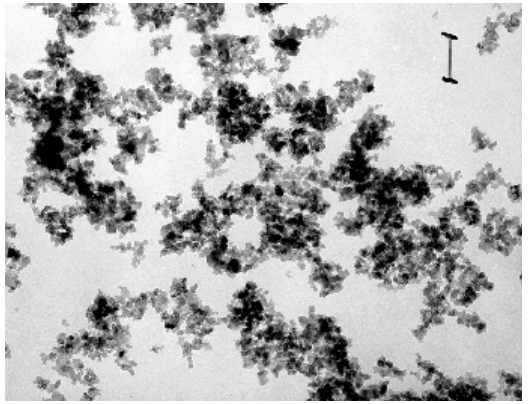
Object	Size
Width of hair	50,000 nm
Red blood cell	7,000 nm
Bacterium	1,000 nm
Virus	100 nm
Width of DNA	2.5 nm
Aspirin molecule Water molecule	1 nm 0.3 nm

Several Nanocarbon Structures

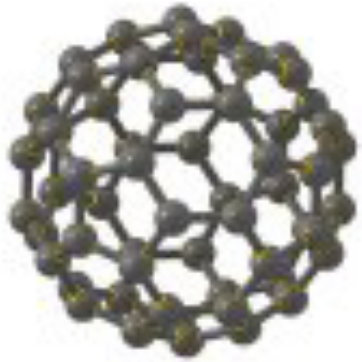


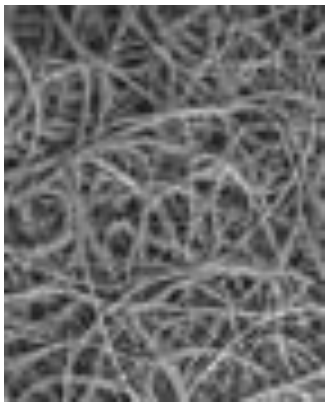
Commercial Materials that might have a Nanoscale Structure

- Alumina, Zirconia, ZnO, Ceria, Silica, Titania



- Carbon Black, Buckyballs, Carbon Nanotubes





Applications of Nanotechnology

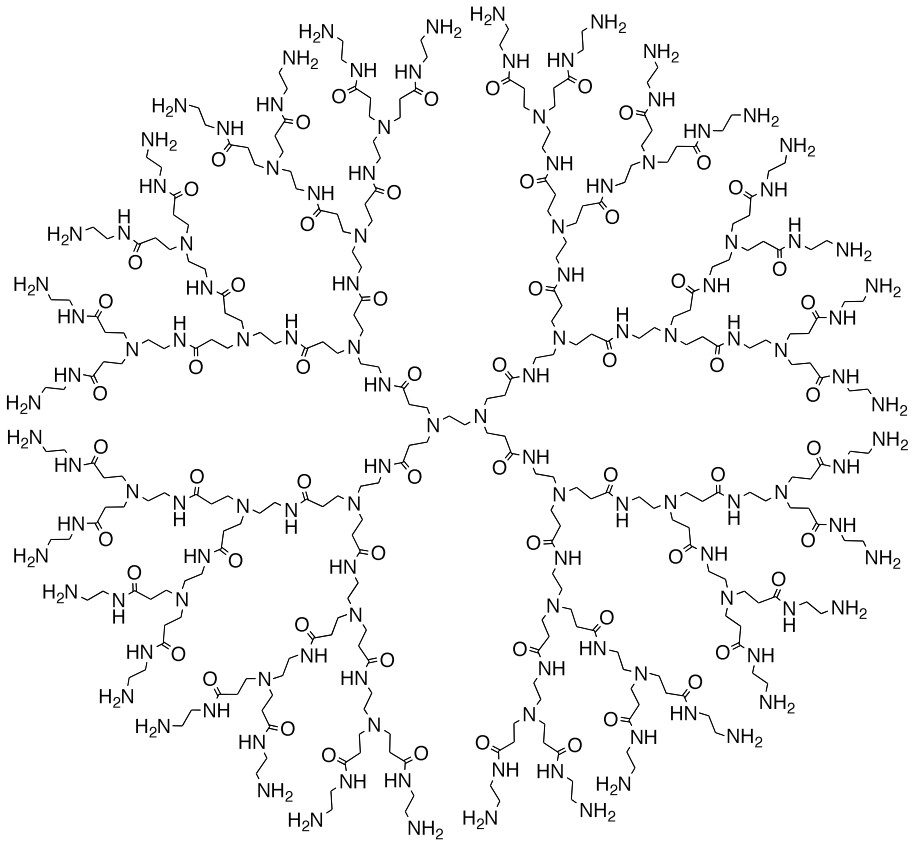
- Pharmaceuticals
- Diagnostics
- Coloring Agents
- Energy/Batteries
- Materials Reinforcement
- Electronics
- Environmental Remediation
- Pesticides
- Food
- Cosmetics/Sunscreens

Pharmaceuticals

- Gold or Silver Coated Silica (Nanoshells) – Inject into cancer cells. IR light causes local heating killing cancer cells.
- Lanthanum dioxycarbonate – Possible use in treatment of failing kidneys to remove phosphate. High surface area captures more phosphate than existing treatments

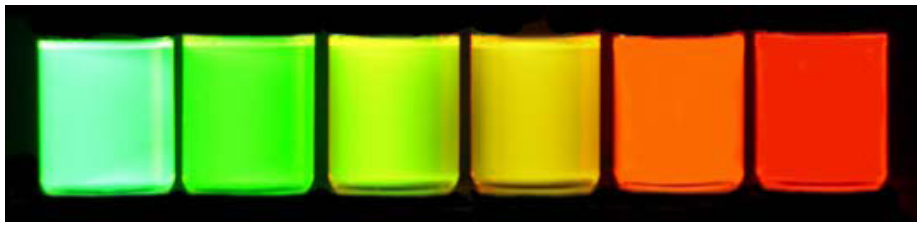
Pharmaceuticals

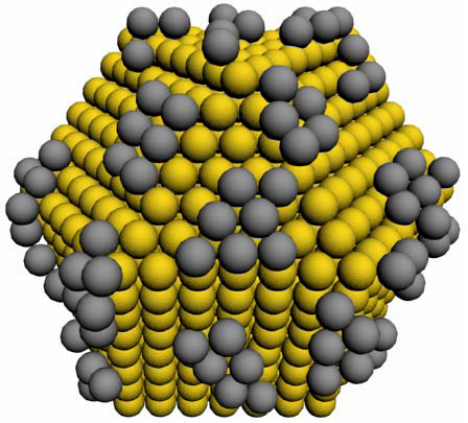
- Dendrimers – Highly branched molecules that can carry multiple payloads
- G3-PAMAM-$(NH_2)_{32}$ shown



Diagnostics

- Quantum Dots – Can be used to track biological processes
- Gold-modified Antibodies – Possible replacement for florescent probes. Possible use in seeing onset of Alzheimer's Disease



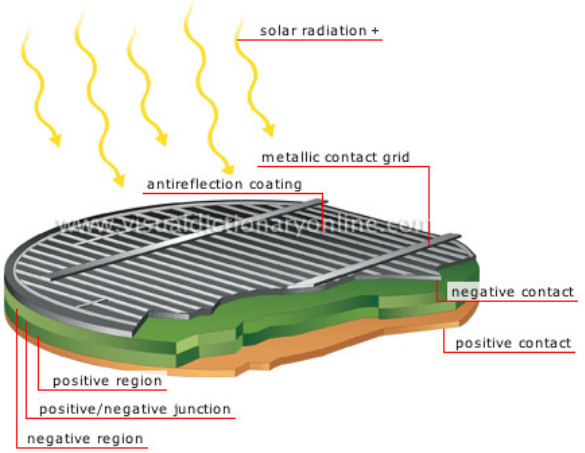


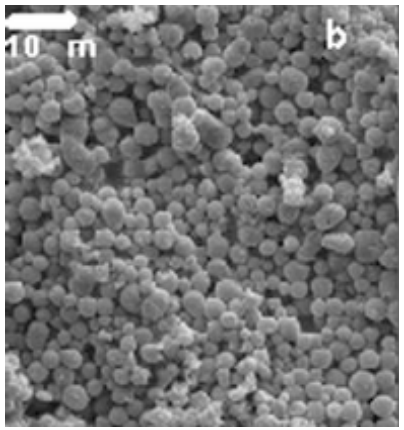
Coloring agents

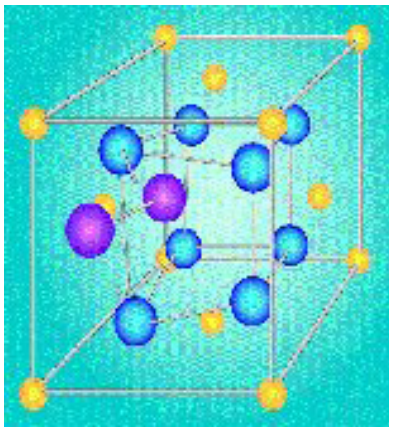
- NM already at work!
- Finer resolution inkjet printing
- More durable auto coatings

Energy/Batteries

- Solar cells – Carbon Nanotubes being evaluated for thin film solar cells
- Electrodes – NM containing electrodes being developed for high energy density batteries
- Electrolytes – Ceria used as a fuel cell electrolyte (see right)







Materials Reinforcement

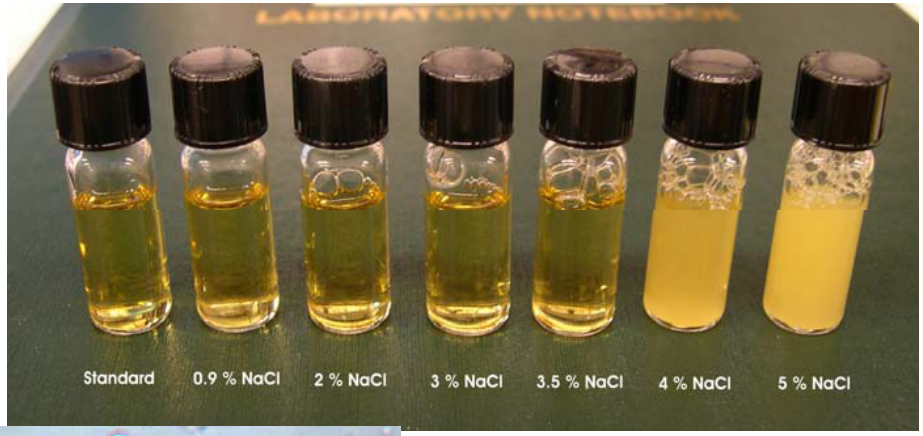
- Carbon Nanotubes added to polymers to increase torsion and flex resistance.
- Applications include tennis racquets, golf club shafts and fuel lines.

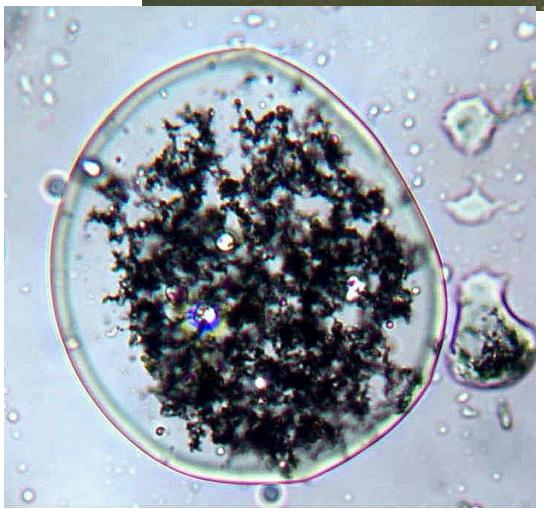
Electronics

- Sensors – Sensitive to single molecules
- Displays – Very thin displays with high quality images, wide viewing angles, no burn-in
- Memory – Fast, non-volatile storage
- Low power consumption

Environmental Remediation

- Nanoscale Iron – Already at use in remediating sites contaminated with trichloroethylene. 1 pound of nano-Fe can remediate 10,000-30,000 lbs TCE contaminated water.





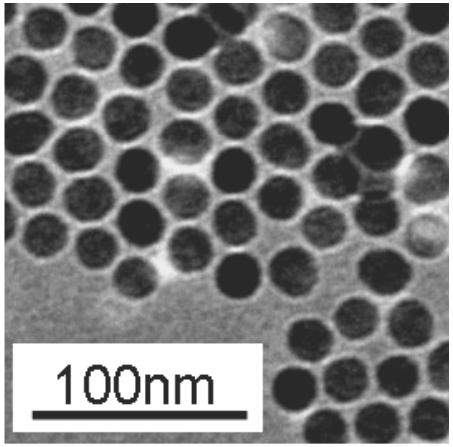
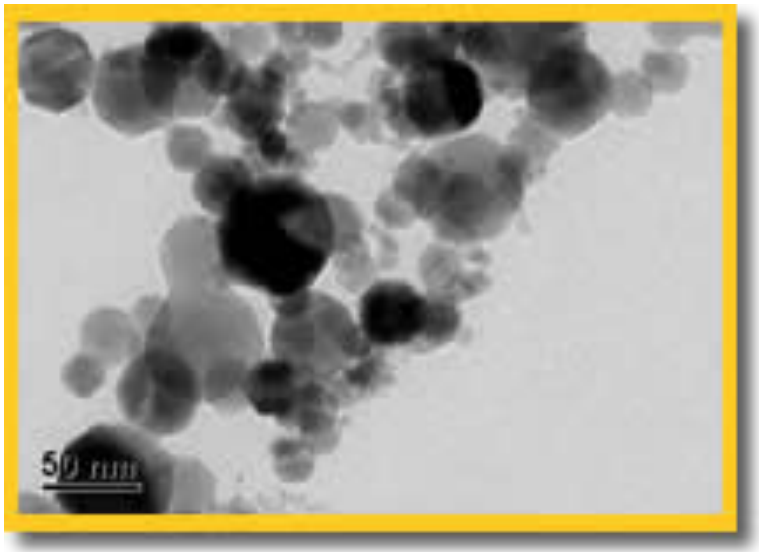


Figure 13. Nanoscale zero-valent iron encapsulated in an emulsion droplet.

These nanoparticles have been used for remdiation of sites contaminated with variuos organic pollutants. (Image cortesy of Dr. Jacqueline W. Quinn, Kennedy Space Center, NASA)

Pesticides

- Nanoscale Silver
- Socks
- Appliances (Washing machines, Refrigerators)
- Food storage containers
- Is it really nano-Ag?
- Nano-encapsulated AI's

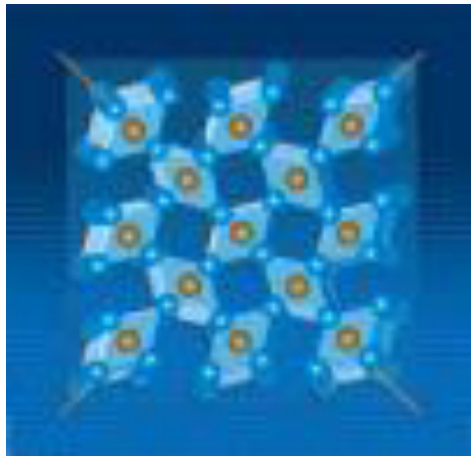


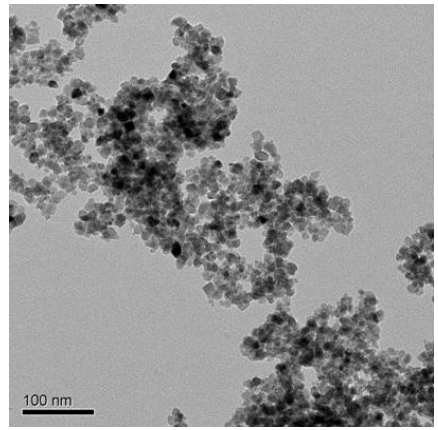
Food

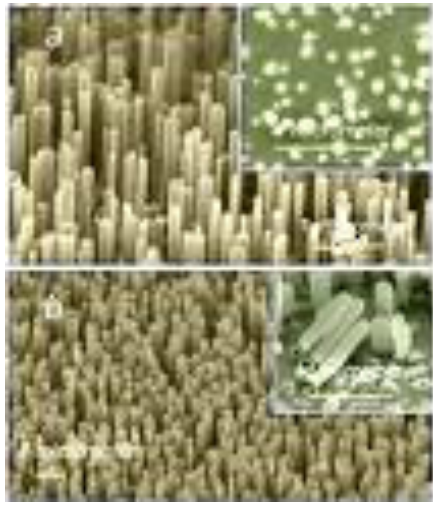
- Genetic engineering of seeds
- Nanoclays used to create more effective O_2, CO_2, H_2O barriers in packaging
- Nanocapsules for delivery of flavors, nutrients, etc. have been developed
- TiO_2 used as UV absorber in packaging

Cosmetics/Sunscreens

- TiO_2 – When forumulated into sunscreens titania is an effective UV absorber yet is optically transparent.
- ZnO







Any problems?

Public perceptions

- Statements from NGO's, media
- Fallout from GMO's

Is the toxicity of "legacy" materials known? Are the toxicological test methods applicable to nanoscale materials? Is the toxicity of a Nanoscale material the same as the same material in non-nano form?

- Inhalation – Deeper penetration into lung?
- Dermal – Any penetration?
- Elimination from the body – Overwhelming of macrophages?
- Translocation – Does small size mean unusual mobility?

- e.g. Buckyballs crossing Blood-Brain barrier

Is there a really a problem?

- Little evidence of a problem for “legacy” nano, and uncertain for new nano
- Existing evidence isn’t strong (good or bad), because some types of pertinent tox testing is difficult to perform and materials were not characterized for nano in that past
- Not much data to “prove” safety; past testing emphasized larger sized material
- Presently, the Precautionary Principle is not being followed in the view of some stakeholders

Are “Nanoscale materials” really nanoscale?

- It depends.
- Most commercial forms of readily available “nanomaterials” are aggregates and/or agglomerates of particles
- It can take a lot of energy to deaggregate/deagglomerate
- It has been stated that automobile tires are nanomaterials because they contain aggregates/agglomerates that have a nanoscale structure
- With above in mind - Is there an exposure to Nanoscale materials?

Issues

- Definitions and Characterization
- Hazard and Risk Assessment
- Risk (Safety) Management
- Lifecycle Assessment
- Legislation/Regulation
- Public Perception/Acceptance

Definition & Characterization

- Definition – Not available yet. 1-100 nm simple but not sufficient.
- Composition – Impurities may contribute significantly to toxicity
- Particle Size – Aggregates, Agglomerates, Primary Particles. Toxicology may be size-dependent (10 vs. 20 vs. 50 vs. 100 nm vs...)
- Morphology – Spheres, Rods, Films, Dendrimers, Tubes. Rod-structure suspect (Nature Nanotech 2008).
- Surface Area – Relative amount of area increases with decreasing particle size. Surface is more reactive than insides.
- Solubility – Dissolution may reduce/eliminate hazard

Hazard Assessment

- Inhalation Tox
- Dermal Tox
- Oral Tox
- Gene Tox
- Aquatic Tox
- Bacterial Tox - POTW
- Chronic Tox
- Bioaccumulation

- Problem – Characterization and Methods

Risk Characterization

Risk = Hazard x Exposure

- Application – Is there an exposure?
- Bound in a matrix? – May limit exposure. Possible release after use?
- Disposal – May increase exposure
- Breakdown – Matrix and Nanoscale material
- Problem – Need good hazard information

Risk (Safety) Management

How can Risk/Safety be managed when it hasn't been determined?

Assume the worst!

- Reduce exposure
- Engineering Controls
- Protective Equipment

Life Cycle Assessment

- “Cradle to Grave” Manage Risk at every step
- Preparation
- Use
- Disposal
- Break down

Legislation/Regulation

- No Nano-specific regulations at Federal level – Vol. U.S. Nanoscale Material Stewardship Program just ended
- TSCA/CEPA – Probably will be affected
- FFDCA/FDA – Agencies believe they can handle Nano (Cosmetics?)
- FIFRA – Just getting started. EPA expected to target NM Active Ingredients (e.g. Nano Silver)
- REACH – Does regulate NM but more being specifics considered.
- Local laws – e.g. Berkeley, CA, Cambridge, MA (proposed, not approved)

Agencies who care

- EPA – NanoMaterial Stewardship Program (NMSP)
- FDA – Solicited public input
- NIOSH – Conducting sampling at volunteer sites/Website
- OSHA – Hazard communication (Graphite vs CNT)
- NNI/NNCO – Coordinating US Fed. Agency Nanotech activities
- Environment Canada – Planning first regulatory program
- Health Canada – Lead agency in Canada
- Defra (UK) – Instituted first voluntary program
- EU – NM-specific considerations being considered

International Organizations who care

Organization of Economic Cooperation & Development (OECD)

- Established the Working Party on Nanotechnology (WPN) to promote the benefits of Nanotechnology
- Established the Working Party on Manufactured Nanomaterials

International Organization for Standardization (ISO)

- Established Technical Committee 229 (TC 229) on Nanotechnology
- Established Technical Group on Nanotech & Sustainability
- Established Technical Group on Nanotech and Societal & Consumer Impacts

Others that care

- ACC, SOCMA, PCPA, GMA, NbA
- ICG (Canada), Cefic (EU), JCIA (Japan) & ICCA (global)

- Environmental Defense Fund
- National Resources Defense Council
- Consumers Union
- Greenpeace
- Friends of the Earth
- Environmental Working Group

- Many Universities

Public Perception/Acceptance

- The “Jury” is still out
- Don’t want to follow GMO experience
- Should the “public” be engaged?
- How should the “public” be educated/ informed?
- What are the Societal/Consumer issues?
- Applications vs. Implications
- Value vs. Cost

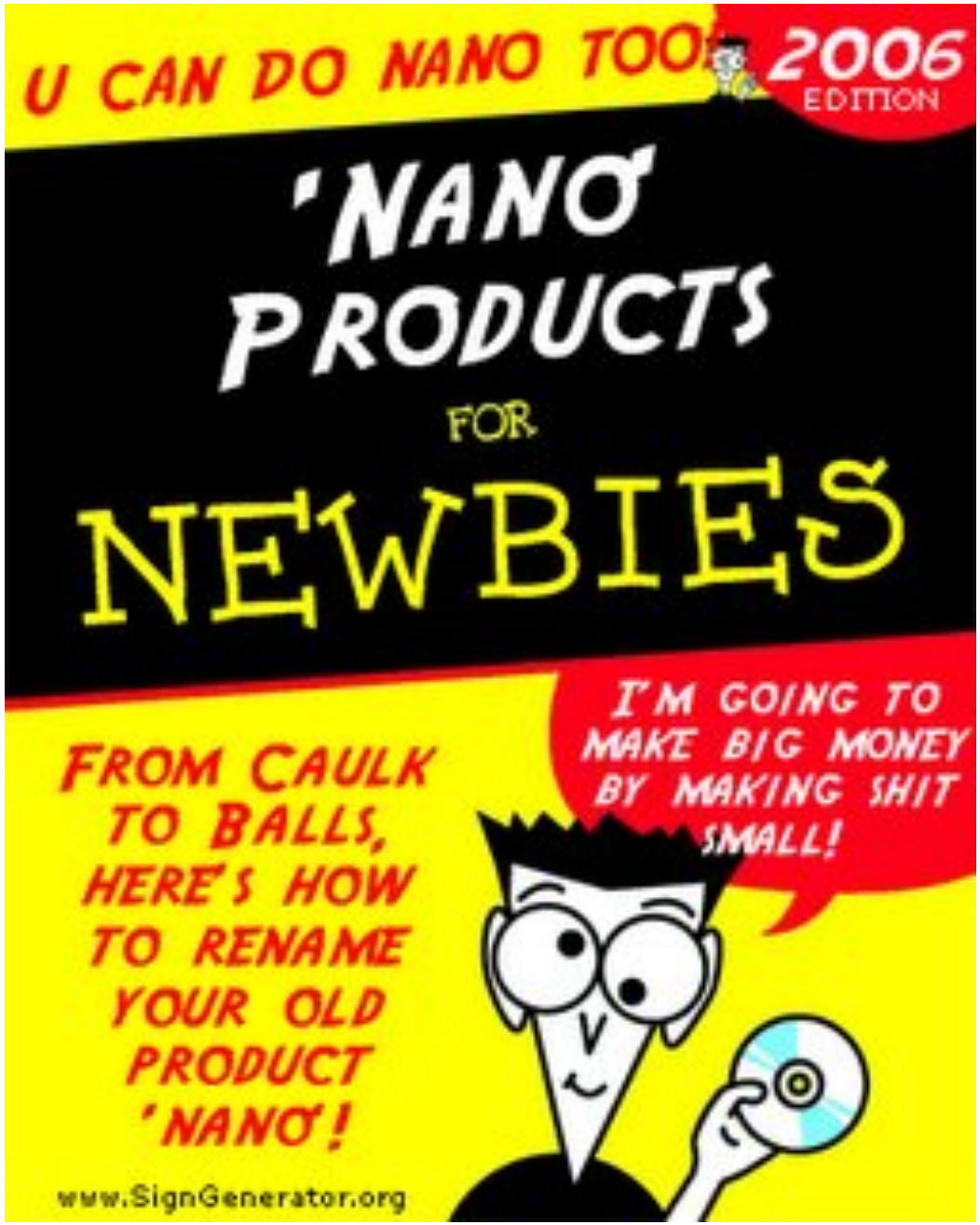
Proposed Nano Hazard Labels

Winners of 2006 ETC Contest

Dimitris Deligiannis, Greece

Shirley Gibson, Scotland

Kypros Kyprianou, England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Contact Information

Shaun F. Clancy, Ph.D.
Evonik Degussa Corporation
Director - Product Regulatory Services
North America Services
379 Interpace Parkway
Parsippany, NJ 07054
USA
+1-973-541-8047
+1-973-541-8040 fax
Shaun.Clancy@evonik.com