Nanotechnology and the Environment: Beauty and the Beast?

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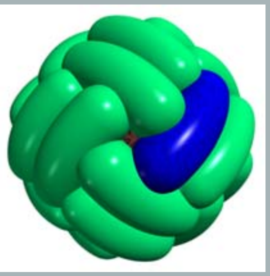
ChE 311, October 4, 2004

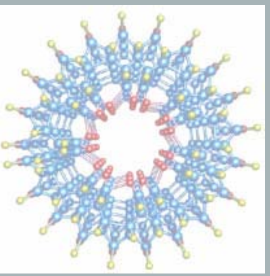
Primary references:

- *Nanotechnology: An Opportunity for Industrial Ecology*



  - *Presented by Barbara Karn at the Gordon Research Conference on Industrial Ecology, Oxford, England, August 2, 2004*

- *Nanoscience and Nanotechnologies: Opportunities and Uncertainties*



  - *The Royal Society and The Royal Academy of Engineering, July 2004*

Nano-

- *From the Greek word for "dwarf"*
- *Idea of manipulating materials at the atomic/molecular level first introduced by Richard Feynman in 1959*
- *Term "nanotechnology" was first used in 1974 by Norio Taniguchi*
- *One nanometer (nm) = 10^{-9} meters*
- *Size of greatest interest is 0.2 to 100 nm*

Royal Society & Royal Academy of Engineering, 2004

What is Nanotechnology?

- *National Nanotechnology Initiative* (NNI) calls it "nanotechnology" only if it involves **all** of the following:*
  - *Research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately* ***1 - 100 nanometer*** *range*
  - *Creating and using structures, devices and systems that have* ***novel properties and functions*** *because of their small and/or intermediate size.*
  - *Ability to control or* ***manipulate on the atomic scale***

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**A group of 10 US government agencies including NSF, DOD, and EPA*

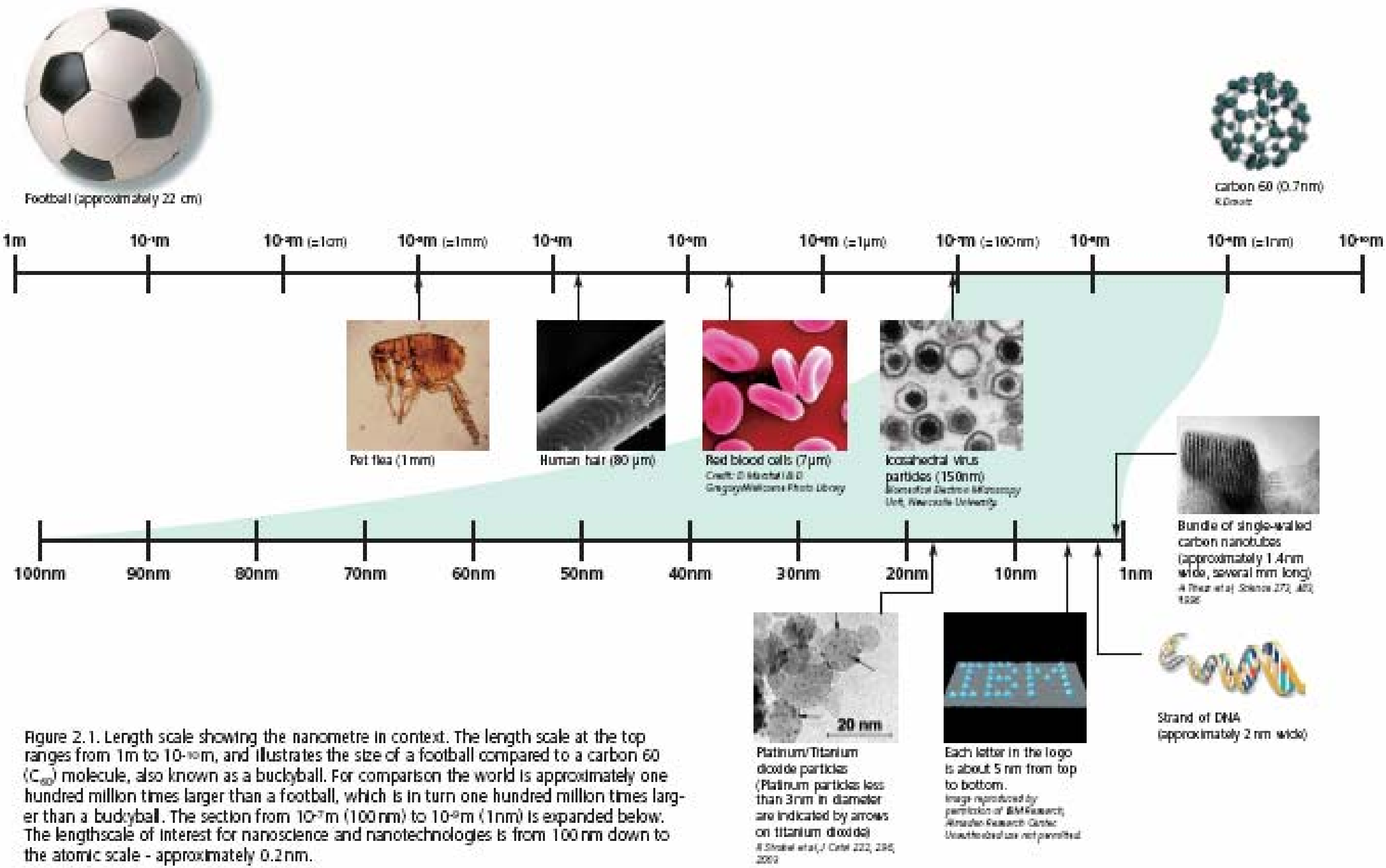

Figure 2.1. Length scale showing the nanometre in context. The length scale at the top ranges from 1m to 10^{-10}m, and illustrates the size of a football compared to a carbon 60 (C_{60}) molecule, also known as a buckyball. For comparison the world is approximately one hundred million times larger than a football, which is in turn one hundred million times larger than a buckyball. The section from 10^{-7}m (100nm) to 10^{-9}m (1nm) is expanded below. The lengthscale of interest for nanoscience and nanotechnologies is from 100nm down to the atomic scale - approximately 0.2nm.

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9 NNI Grand Challenges

- *Nanostructured Material by Design*
- *Manufacturing at the Nanoscale*
- *Chemical-Biological-Radiological-Explosive Detection and Protection*
- *Nanoscale Instrumentation and Metrology*
- *Nano-Electronics, -Photonics and –Magnetics*
- *Healthcare, Therapeutics, and Diagnostics*
- ***Efficient Energy Conversion and Storage***
- *Microcraft and Robotics*
- ***Nanoscale Processes for Environmental Improvement***

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Nanomaterials

- *One dimensional: thin films, surface coatings (currently used in microelectronics)*
- *Two dimensional: nanowires and nanotubes*
- *Three dimensional: precipitates, colloids, quantum dots (tiny particles of semiconductor materials), nanocrystalline materials*

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What are the materials of nanotech?

Nanostructure	Size	Example Material or Application
Clusters, nanocrystals, quantum dots	Radius: 1-10 nm	Insulators, semiconductors, metals, magnetic materials
Other nanoparticles	Radius: 1-100 nm	Ceramic oxides, Buckyballs
Nanowires	Diameter: 1-100 nm	Metals, semiconductors, oxides, sulfides, nitrides
Nanotubes	Diameter: 1-100 nm	Carbon, including fullerenes, layered chalcogenides

Adapted from J.Jortner and C.N.R.Rao, Pure Appl Chem 74(9), 1491-1506, 2002

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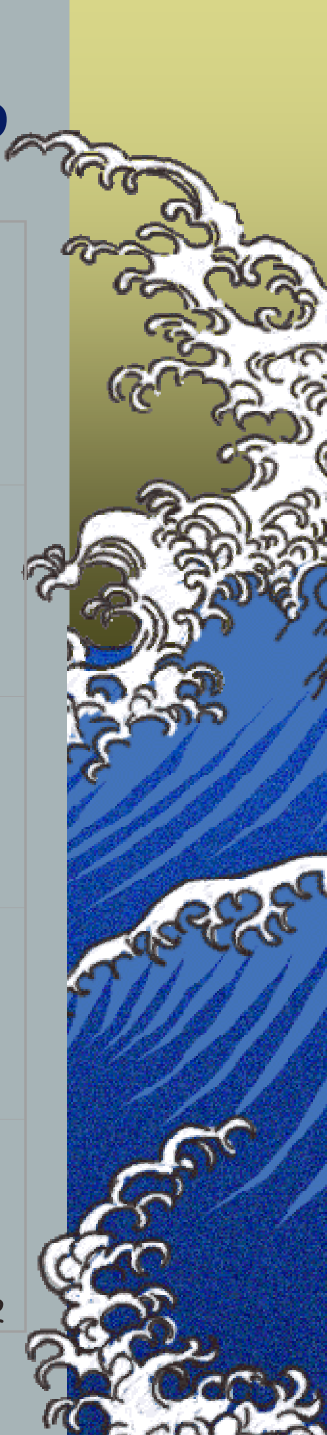

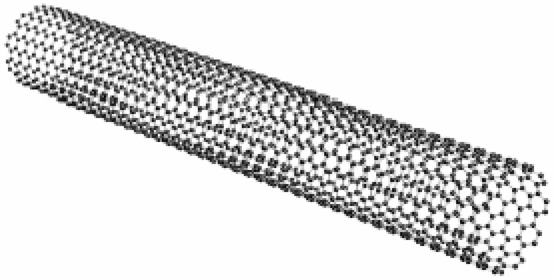

Figure 3.1a Schematic of a single-walled carbon nanotube (SWNT)

Carbon Nanotubes

- *First observed in 1991 by Sumio Iijima*
- *May be single or multi-walled*
- *Mechanically very strong, flexible, and conduct electricity well*
- *Potential applications:*
  - *reinforced composites,*
  - *sensors,*
  - *nanoelectronics,*
  - *display devices*

Figure 3.1b Schematic of a multi-walled carbon nanotube (MWNT)

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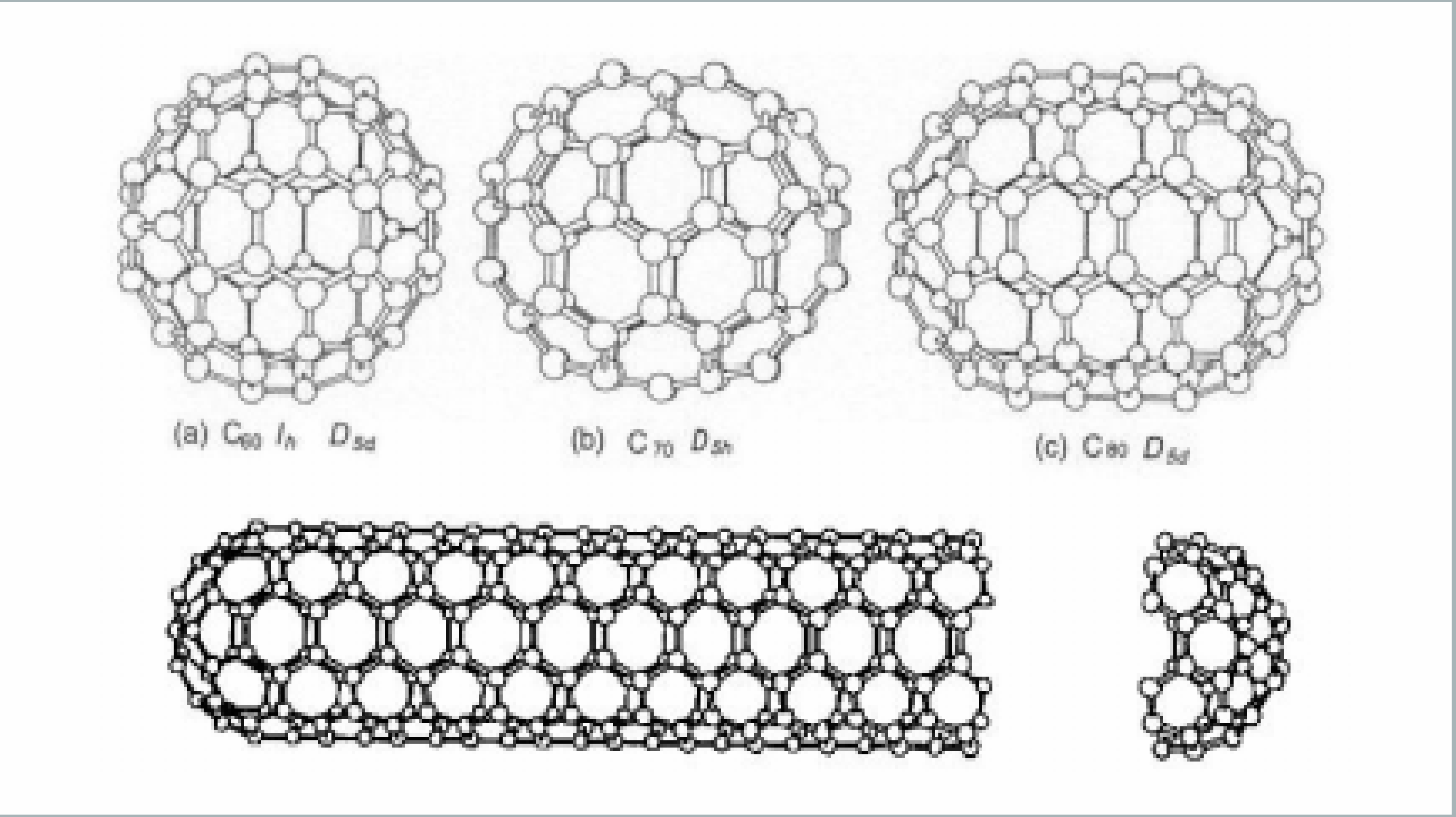
Fullerenes and Nanotubes



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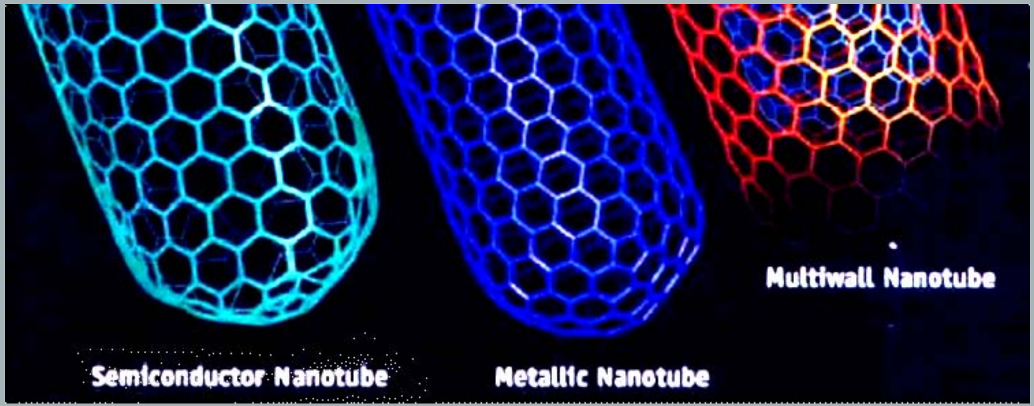
Properties of Nanotubes

- *Either electrically conductive or semiconductive*
- *Electrical conductivity as high as copper*
- *Thermal conductivity as high as diamond*
- *Strength 100 times greater than steel at one sixth the weight*
- *High strain to failure*



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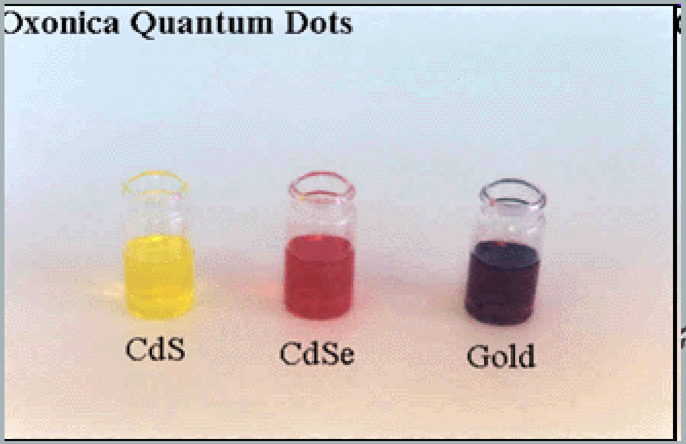
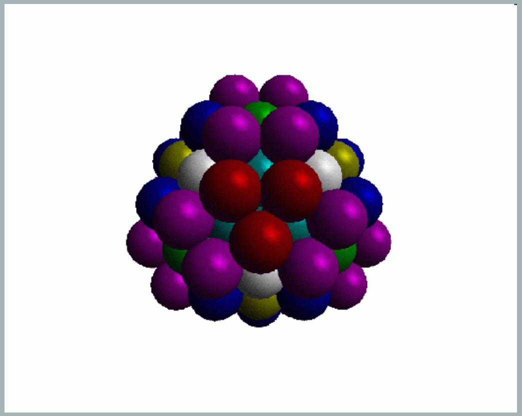
Atom clusters, Quantum dots

Novel electronic, optical, magnetic and catalytic properties

www.ccmr.cornell.edu/~fwise/QDAmp.html



www.oxonica.com/…/ quantumdots.html



Quantum dots: Semiconductor nanocrystals CdSe (cadmium selenide) of different sizes dispersed in a polymer matrix and excited with UV light. Color indicates energy-level which facilitates “tuning”

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Beauty (Potential Benefits) of Nanotechnology

- *Processes and Materials:*
  - *As a replacement for toxic or scarce materials (such as Pt group elements in catalysts)*
  - *Environmental remediation*
- *Systems or Life Cycle:*
  - *Potential to reduce total volume of material per product function (e.g., electronics)*
  - *Potential to reduce energy costs during use-phase of products*

Beastly Aspects? (Potential Problems) of Nanotechnology

- *Processes and Materials :*
  - *Small size increases potential for dispersion and exposure (crossing of cell membranes)*
  - *Relatively large surface area to mass increases chemical reactivity; could act as carrier for other contaminants providing rapid and long range transport*
  - *Quantum effects begin to dominate affecting optical, electrical, and magnetic behavior*

Potential Problems, cont

- *Systems or Life Cycle:*
  - *Virtually no knowledge base (must convert from a chemical/functional data set to size/structural information)*
  - *May result in increased process material flows (similar to current issues with electronics)*
  - *May create extremely complex problems for material recovery at end of life*

Environmental Aspects of Nano

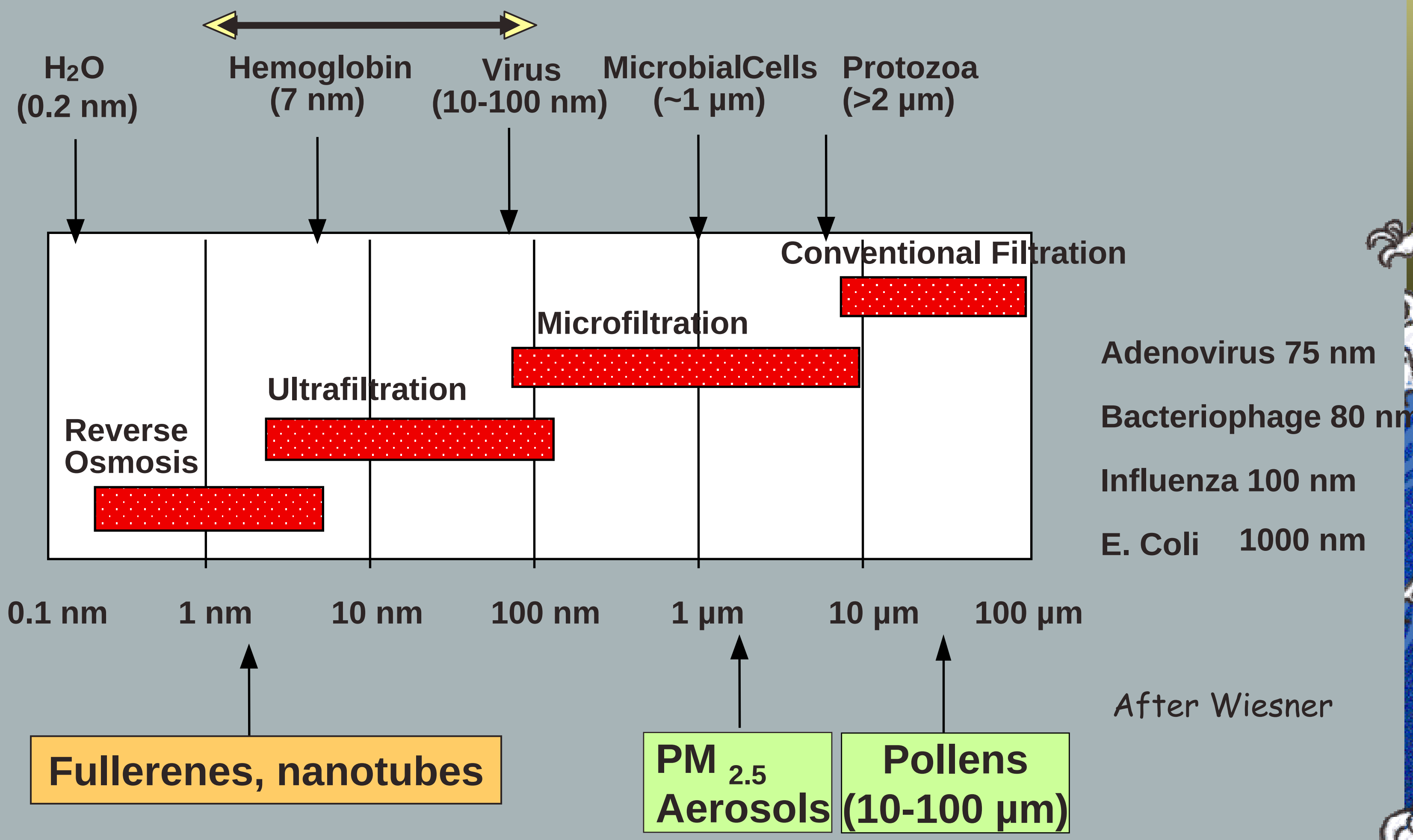
- *Green Peace Report –*
  Future Technologies, Today's Choices
  - *http://www.greenpeace.org.uk/MultimediaFiles/Live/FullReport/5886.pdf*
- *Royal Society/Royal Academy of Engineering –*
  Nanoscience and Nanotechnologies: Opportunities and Uncertainties
  - *http://www.nanotec.org.uk/finalReport.htm*
- *National Science and Technology Council –*
  Nanotechnology Grand Challenge in the Environment
  - *http://es.epa.gov/ncer/publications/nano/nanotechnology4-20-04.pdf*
- *EPA Nanotechnology and the Environment STAR Progess Workshop Proceedings*
  - *http://es.epa.gov/ncer/publications/workshop/nano_proceed.pdf*

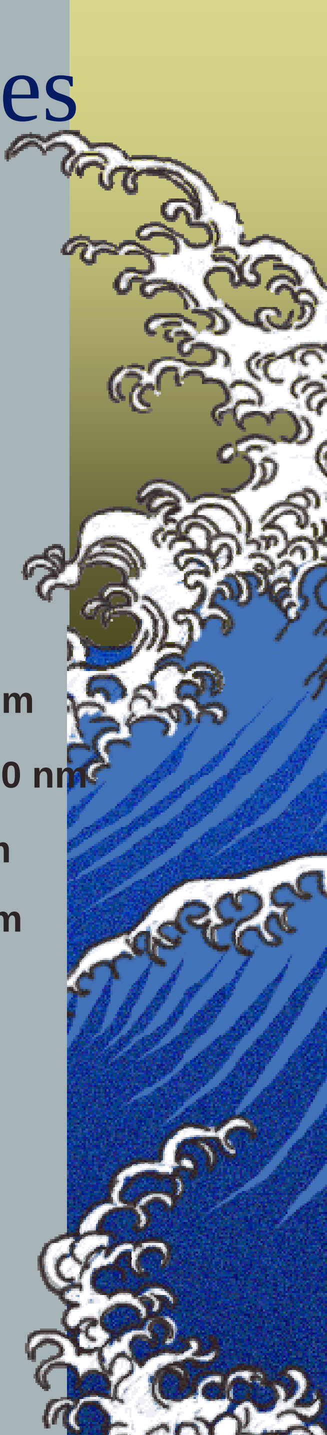
Environmental Aspects of Nanotechnology in the Literature

- *Very little in standard literature*
  - *Search of ACS Journals for "nanotechnology" returns 100's of relevant papers*
  - *Search on ES&T returns 7, only one of which has nanotechnology as the primary focus*

Size Spectrum of Environmental Particles

Nanoscale contaminants in water and air (little is known)





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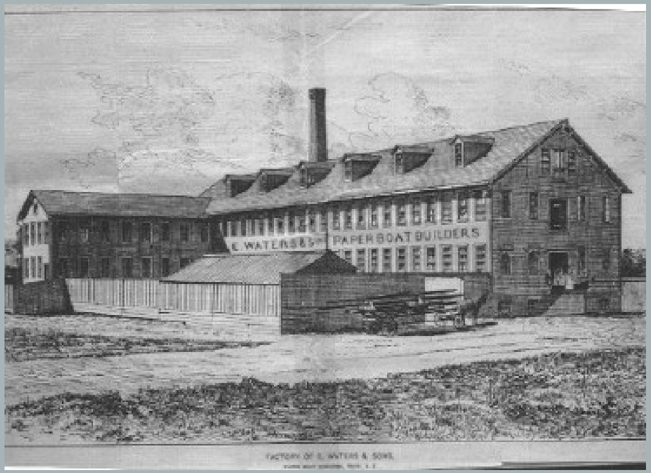
Different Worlds/Different Challenges



First Industrial Revolution

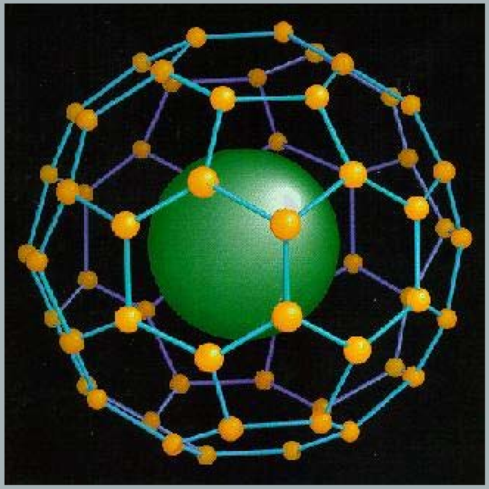
Adaptation

Atoms

Sharp boundaries

Incremental change

Science of discovery



Second Industrial Revolution

Shaping

Atoms/Bits (Digital/physical Converge)

Fluid, mobile, interconnected

Exponential change

Science of disruption

Karn, 2004 (Rejeski, 2003)

Two Scenarios for Coping with the New Revolution

Rip van Winkle Scenario
Slow Learning/Adaptation

Environmental impacts are an unintended consequence of technology development and deployment. Regulations must be applied to reduce impacts

Vulcan Scenario
Fast Learning/Shaping

Environment is co-optimized as a part of technology development and deployment, or is the primary goal

Karn, 2004 (Rejeski, 2003)

EPA's Research Framework for Nano and the Environment

- *Applications*
  - *Reactive to existing problems*
  - *Proactive in preventing future problems.*
- *Implications*
  - *Interactions of nanomaterials with the environment*
  - *Possible risks that may be posed by the use of nanotechnology*

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Applications

- *Sensors:*
  - *Improved monitoring and detection capabilities, better controls (more efficient use of materials, more data on wastes)*
- *Treatment:*
  - *Cleaning up waste streams of contaminants, particularly those substances that are highly toxic, persistent within the environment, or difficult to treat*
- *Remediation*
  - *Cleanup of contaminated sites with problems brought about by prior technologies and past practices*

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Applications, cont

- *Green Manufacturing*
  - *Atom-by-atom construction (less material waste)*
  - *Elimination of waste products and streams for all types of products by designing in pollution prevention at the source using nanotechnologies*
  - *Manufacture of nanomaterials themselves in a benign manner*
- *Green Energy*
  - *Solar and fuel cells that use nanomaterials*
  - *Energy savings via light weight composites, embedded systems*

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Implications

- *Nano-Geochemistry*
  - *Understanding formation of atmospheric aerosols*
  - *Understanding movement of natural nano particles in air and soil can help inform the solutions to man-made problems*
- *Toxicity*
  - *Risk analysis for ecosystem and human health*
- *Fate, Transport, Transformation*
  - *Exposure routes for both natural organisms (in a variety of ecosystems) and for humans*

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Implications, cont

- *Exposure, Bioavailability, Bioaccumulation*
  - *Risk analysis for ecosystem and human health*
- *Industrial Ecology*
  - *Materials flow changes and environmental effects*
  - *Design for Environment (DfE), Materials Flow Analysis (MFA) and Life Cycle Assessment (LCA)*
  - *Determination where in its lifecycle a nano material may cause greatest impact to the environment*
  - *Trade-off analyses**

**added - not on original slide*

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Tradeoff Analyses

- *First studies are likely to be between conventional and nanotechnology applications*
  - *Life Cycle Economic and Environmental Implications of Using Nanocomposites in Automobiles, Lloyd and Lave, 2003, ES&T, 37(15)*
  - *The ripple effects of nanotechnology:Improving automobile catalysts, Lloyd and Lave, 2004 ACS Presentation*
    - *http://www.andrew.cmu.edu/user/slloyd/SLloyd2004ACS.pdf*
- *Next steps will be to examine within the nanotechnology paradigm*

Opportunities

- *Current concerns are primarily with toxicity (related to dispersion and exposure)*
- *Assuming that toxicity can be controlled in an acceptable manner, MUST consider nanotechologies at the systems level in the context of environmental life cycle assessment*
- *A unique opportunity to develop environmental policy contemporaneous with emerging technologies*