NANOTECHNOLOGY:

What Is It?
Are There Associated Environmental Concerns?

Michael D. Gill
US EPA
ORD Hazardous Waste Technical Liaison to Region 9

Regional Science Council Seminar Series
San Francisco - November 16, 2004

Research and Development at EPA

- 1,950 employees
- $700 million budget
- $100 million extramural research grant program
- 13 lab or research facilities across the U.S.
- Credible, relevant and timely research results and technical support that inform EPA policy decisions

Making decisions with sound science requires...

- Relevant, high quality, cutting-edge research in human health, ecology, pollution control and prevention, economics and decision sciences
- Proper characterization of scientific findings
- Appropriate use of science in the decision process

Research and development contribute uniquely to...

- Health and ecological research, as well as research in pollution prevention and new technology
- In-house research and an external grants program
- Problem-driven and core research

High Priority Research Areas

- Human Health
- Particulate Matter
- Drinking Water
- Clean Water
- Global Change
- Endocrine Disruptors
- Ecological Risk
- Pollution Prevention
- Homeland Security

...as we know, there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns -- the ones we don't know we don't know.

Secretary Rumsfeld,

*Feb. 12, 2002, **DoD News Briefing***

http://www.dod.mil/transcripts/2002/t02122002_t212sdv2.html

Outline

What is nanotechnology?

What is different/special about nano (Applications)?

What is the scope of nanotech now that might impact the environment (Implications)?

What is the relationship of environmental protection to nanotechnology? (Our big challenge!)

What are governments doing, including at US EPA?
- -Regulation
- -Research

What is nanotechnology?

While many definitions for nanotechnology exist, the NNI* calls it "nanotechnology" only if it involves all of the following:

1. Research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1 - 100 nanometer range.

2. Creating and using structures, devices and systems that have novel properties and functions because of their small and/or intermediate size.

3. Ability to control or manipulate on the atomic scale.

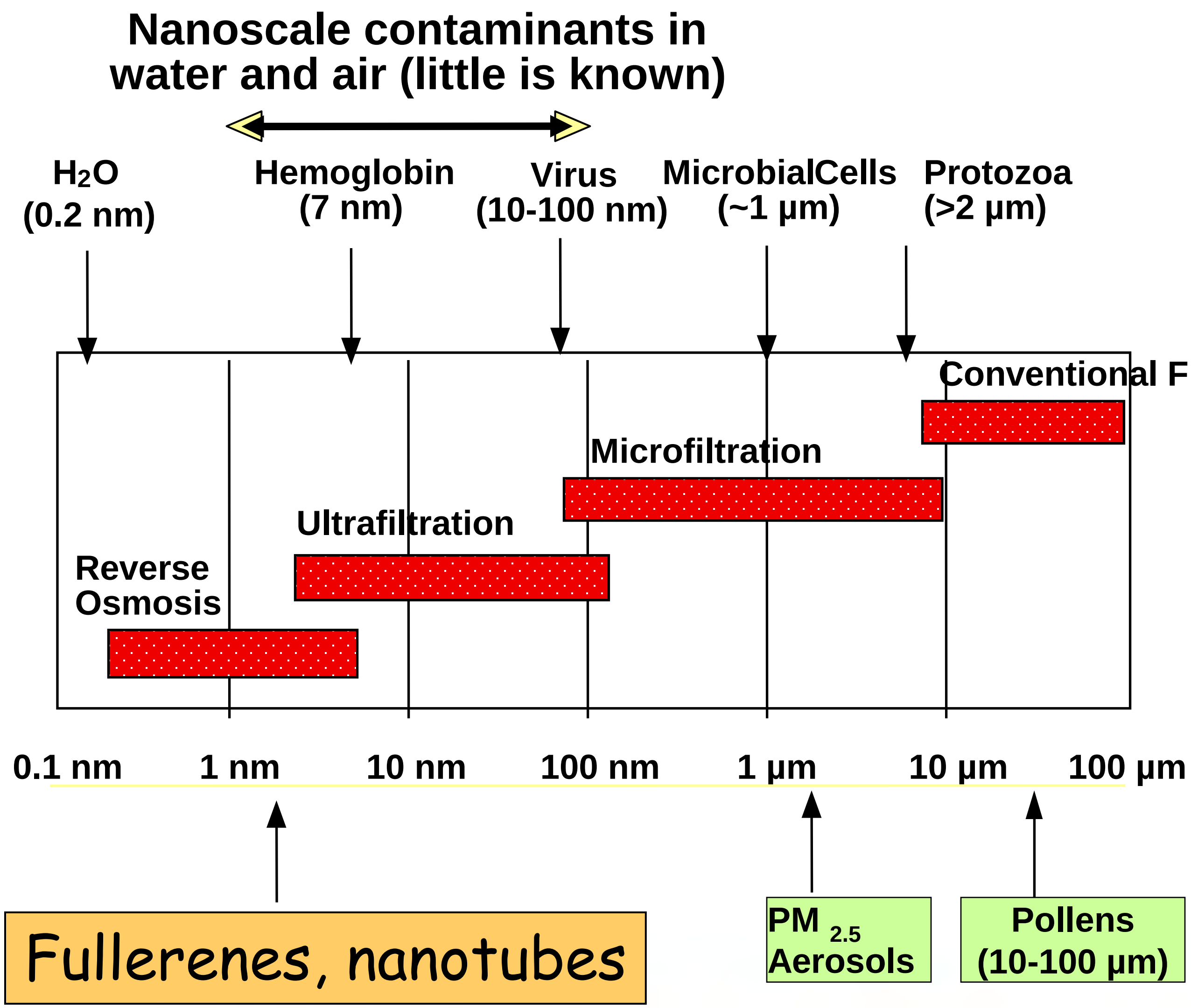
*National Nanotechnology Initiative

Also…

1. Nanotechnology is NOT a technology - it is a combination of chemistry, biology and materials science.

2. Could it be the next Industrial Revolution?

Size Spectrum of Environmental Particles



Adenovirus 75 nm

Bacteriophage 80 nm

Influenza 100 nm

E. Coli 1000 nm

After Wiesner

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

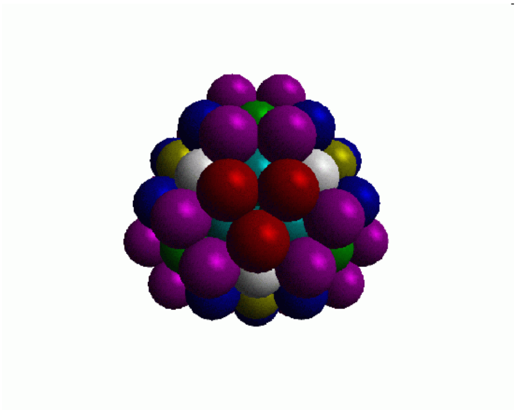
Adapted from J.Jortner and C.N.R.Rao, Pure Appl Chem 74(9), 1491-1506, 2002

Atom clusters, Quantum dots

Novel electronic, optical, magnetic and catalytic properties

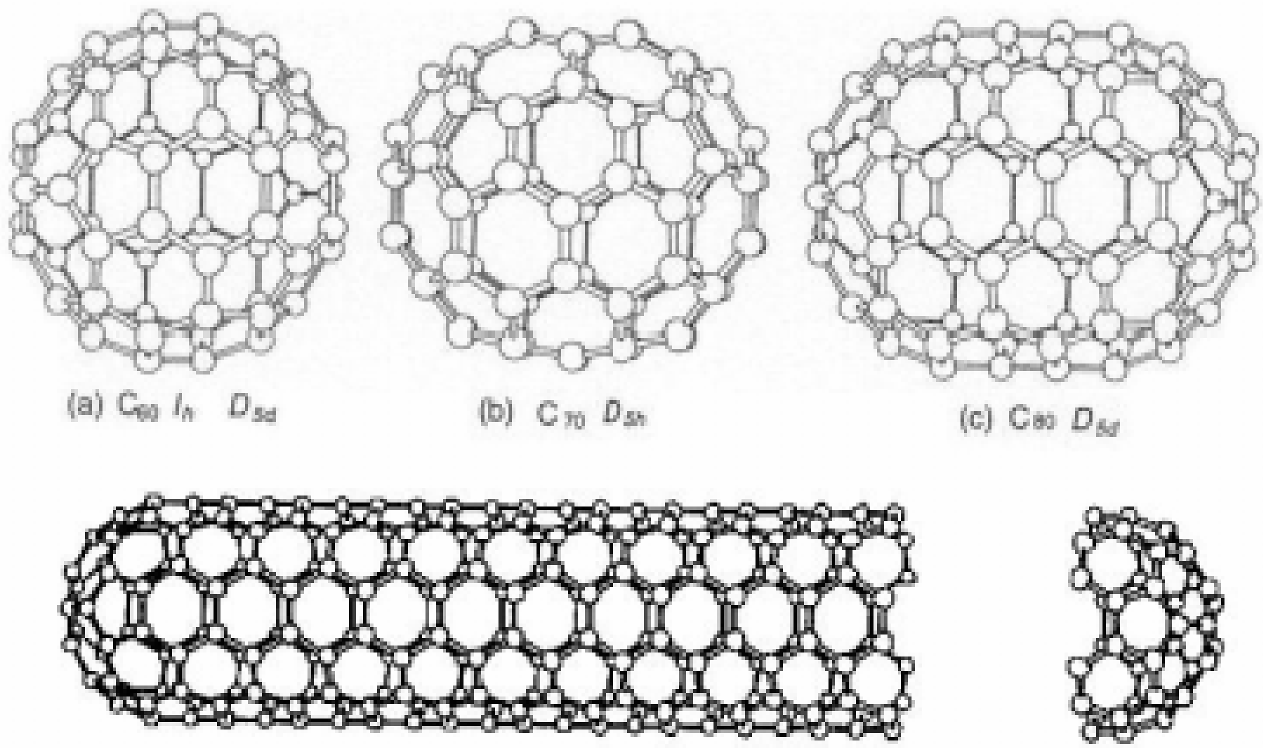
www.ccmr.cornell.edu/ ~fwise/QDAmp.html

www.oxonica.com/.../ quantumdots.html



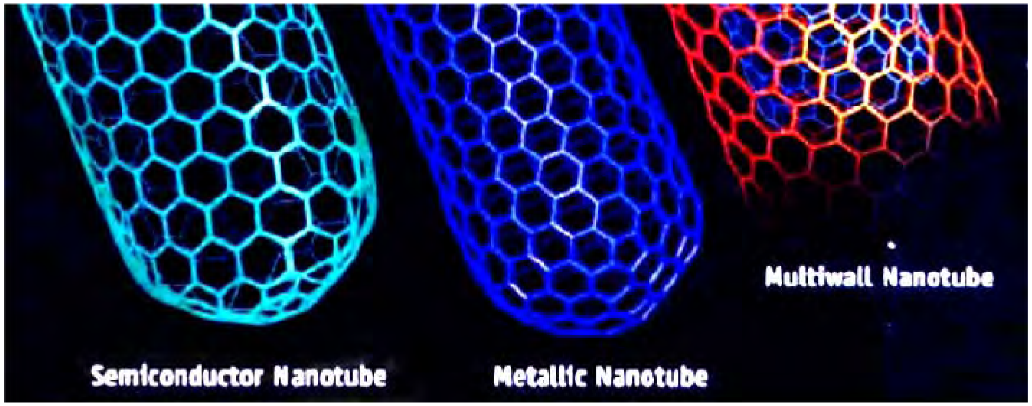
Magnetic properties possibly useful for recording; Unique thermal properties

Fullerenes, nanotubes



Nanotubes are *cool* materials

Nanotubes can be either electrically conductive or semiconductive, depending on their helicity, leading to nanoscale wires and electrical components. These one-dimensional fibers exhibit electrical conductivity as high as copper, thermal conductivity as high as diamond, strength 100 times greater than steel at one sixth the weight, and high strain to failure.



Characterizing Nanomaterials

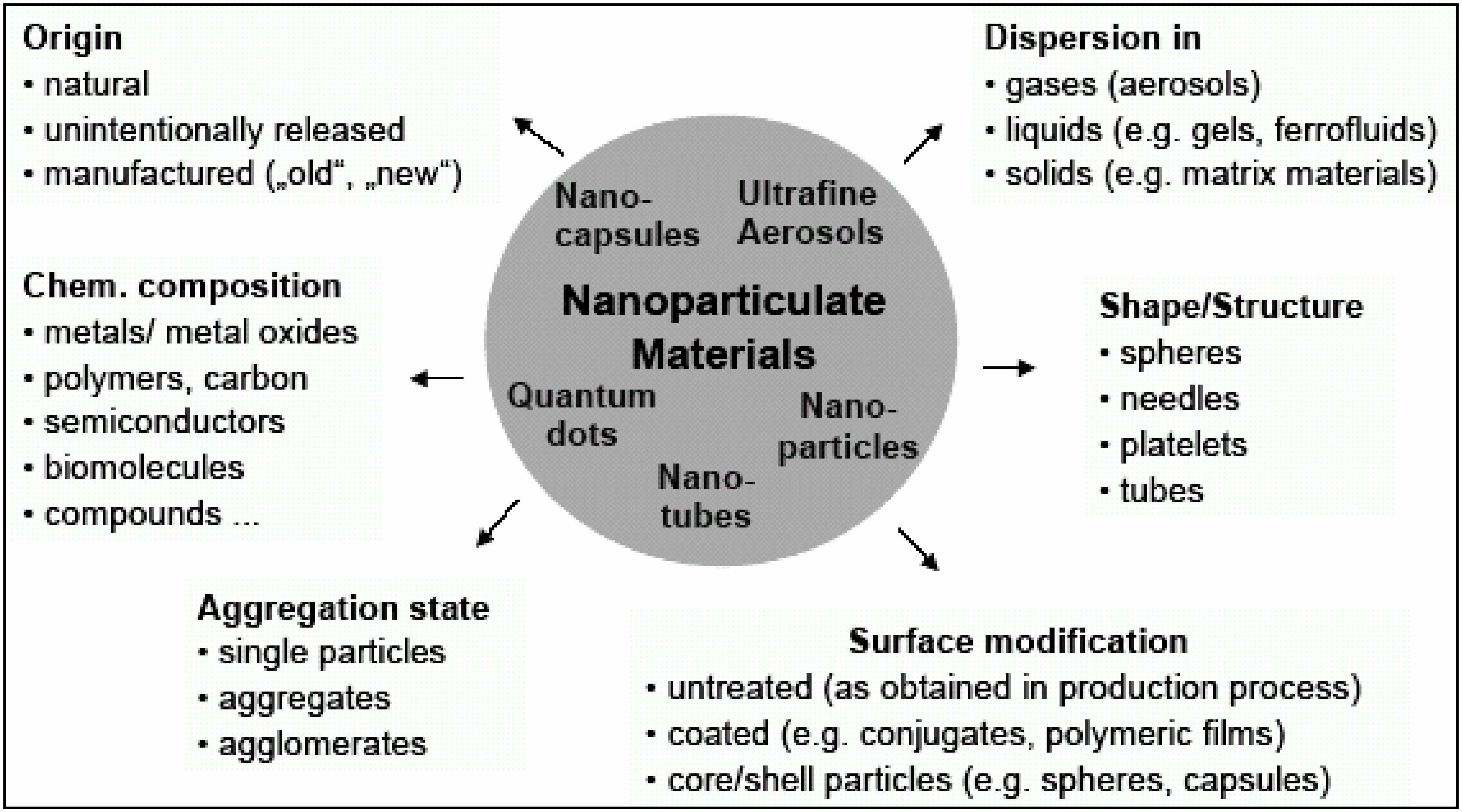


Figure 1: Characterisation parameters of nanoparticulate materials (source: VDI-TZ)

Applications of Nanotechnology

Automotive industry	Chemical industry	Engineering
• lightweight construction • painting (fillers, base coat, clear coat) • catalysts • tires (fillers) • sensors • Coatings for wind-screen and car bodies	• fillers for paint systems • coating systems based on nanocomposites • impregnation of papers • switchable adhesives • magnetic fluids	• wear protection for tools and machines (anti blocking coatings, scratch resistant coatings on plastic parts, etc.) • lubricant-free bearings
Electronic industry	**Construction**	**Medicine**
• data memory (MRAM, GMR-HD) • displays (OLED, FED) • laser diodes • glass fibres • optical switches • filters (IR-blocking) • conductive, antistatic coatings	• construction materials • thermal insulation • flame retardants • surface-functionalised building materials for wood, floors, stone, facades, tiles, roof tiles, etc. • facade coatings • groove mortar	• drug delivery systems • active agents • contrast medium • medical rapid tests • prostheses and implants • antimicrobial agents and coatings • agents in cancer therapy

VDI

Applications of Nanotechnology

Textile/fabrics/non-wovens	Energy	Cosmetics
• surface-processed textiles • smart clothes	• fuel cells • solar cells • batteries • capacitors	• sun protection • lipsticks • skin creams • tooth paste
Food and drinks	**Household**	**Sports /outdoor**
• package materials • storage life sensors • additives • clarification of fruit juices	• ceramic coatings for irons • odors catalyst • cleaner for glass, ceramic, floor, windows	• ski wax • antifogging of glasses/goggles • antifouling coatings for ships/boats • reinforced tennis rackets and balls

Table 5: Overview on applications of nanomaterial based products in different areas

VDI

ENVIRONMENTAL APPLICATIONS

SENSORS - improved monitoring and detection capabilities, better controls

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

GREEN MANUFACTURING - Use of environmentally friendly starting materials and solvents, improved catalysts, and significantly reduced energy consumption in the manufacturing process

GREEN ENERGY - Nano products such as Solar and fuel cells could lead to commercially viable alternative clean energy sources. Energy savings via light weight composites, embedded systems.

ENVIRONMENTAL IMPLICATIONS

NANO-GEOCHEMISTRY - Knowledge of formation of atmospheric aerosols, and the movement of natural nano particles in air and soil can help inform the solutions to man-made problems

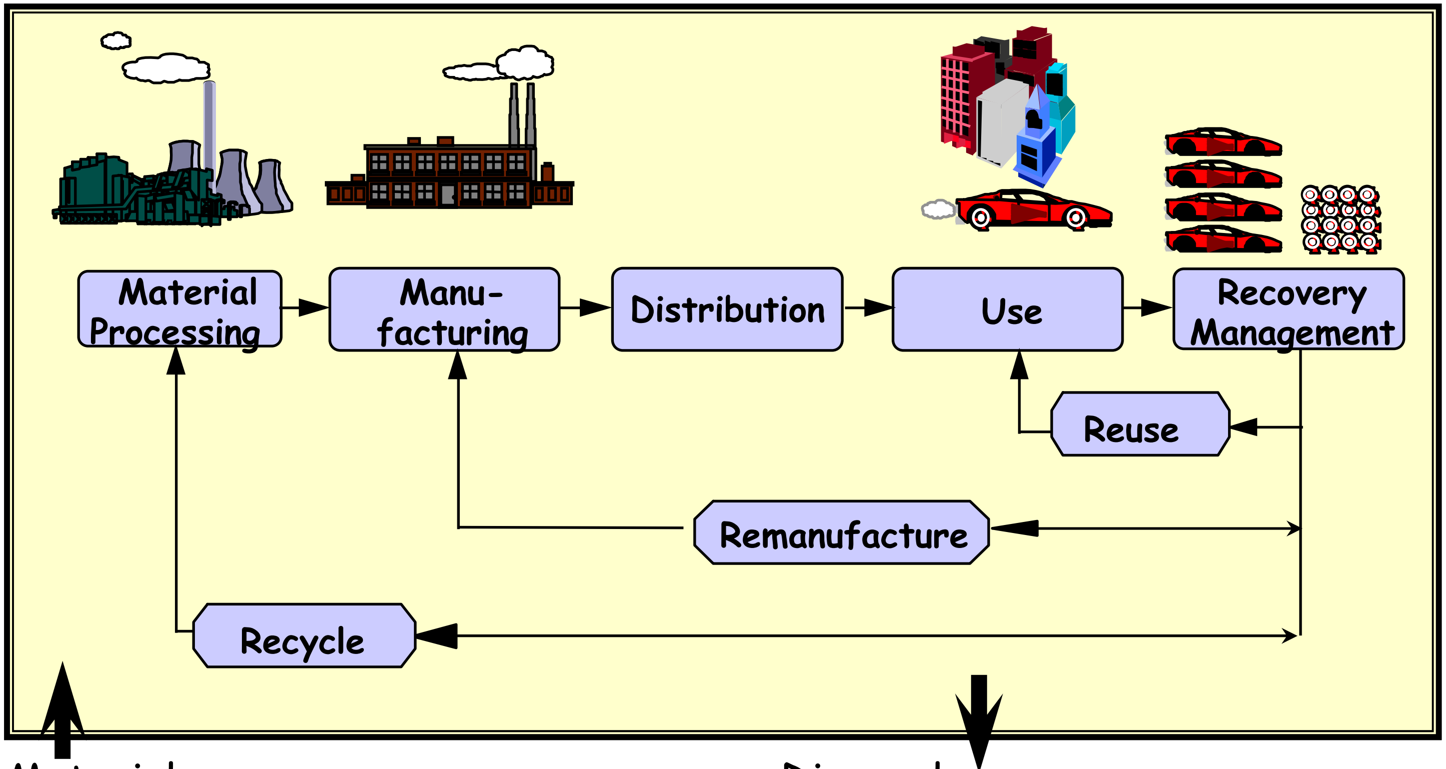
TOXICITY - Essential to risk analysis for ecosystem and human health

FATE, TRANSPORT, TRANSFORMATION - Also essential to risk analysis

EXPOSURE, BIOAVAILABILITY, BIOACCUMULATION - Determine exposure routes for both natural organisms in a variety of ecosystems and for humans in the environment

INDUSTRIAL ECOLOGY ASPECTS - Determine where in its lifecycle a nano material may cause impact to the environment, examine materials flow changes and environmental effects; use DfE, MFA, LCA tools

Nanotechnology must involve a **Systems Approach** to Environmental Protection: Life Cycle Assessment, Materials Flow Analysis



Raw Materials
(Energy, Renewable Resources, Nonrenewable Resources)

Disposal
(Air Emissions, Liquid and Solid Wastes)

J. Golden

The opportunity exists right now for doing nano right in the first place!

A Simple MFA example: Switching to nano

Each EPA employee has 1 computer with 1 CRT monitor

20,000 employees replace their CRTs with flat screen LCDs

0.45 kg Pb/17 inch CRT (DfE Report, US EPA)

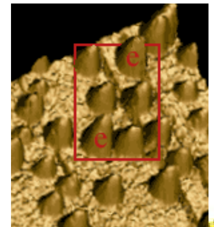
9 tons of Lead to be disposed of from EPA monitors!

0.8 M^3 Lead ~ volume of 7 oil barrels

Nanotechnology can change this waste picture!

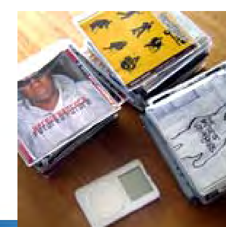
We are at the beginning of a Revolution in:

How things are made



Where things are made

And whether they are made



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
and
Regulation 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

Rejeski, 2003

Government R&D Expenditures 1997-2003

Table 1. Estimated government nanotechnology R&D expenditures in 1997–2003 (in $ millions/year)

Region	1997	1998	1999	2000	2001	2002	2003
Western Europe	126	151	179	200	~225	~400	~600
Japan	120	135	157	245	~465	~700	~810
USA*	116	190	255	270	422 (465)**	600 (697)**	774
Others	70	83	96	110	~380	~550	~800
Total	432	559	687	825	1492	2347	2984
(% of 1997)	100%	129%	159%	191%	346%	502%	690%

Notes: 'Western Europe' includes countries in EU and Switzerland; the rate of exchange $1 = 1.1 Euro until 2002; $1 = 1 Euro in 2003; Japan rate of exchange $1 = 120 yen in 2002; 'Others' include Australia, Canada, China, Eastern Europe, FSU, Israel, Korea, Singapore, Taiwan, and other countries with nanotechnology R&D.
Estimations use the nanotechnology definition as defined in NNI (Roco et al., 2000; this definition does not include MEMS), and include the publicly reported government spending.
* A financial year begins in USA on October 1 of the previous calendaristic year, six months before in most other countries.
** Denotes the actual budget recorded at the end of the respective fiscal year.

Roco, J Nanopart. Res., Aug., 2003

Government Activities

- National Nanotech Coordination Office (NNCO) created
    - 20 government agencies involved

- "Best Management Practices" guide for industry being worked on by a multi-agency workgroup

- NIOSH is aware of need for worker surveillance - not there yet

- National Nanotech Initiative (NNI) created (http://www.nano.gov)
    Purpose:
    - conduct R&D
    - better understand social, ethical, health, environmental implications
    - facilitate transfer of new technologies into commercial products

- European Union has started developing testing standards (for occupational health)

Regulations and Nanotechnology / Nanoparticles

- 21st Century Nanotechnology Research and Development Act of 2003 requires that the program ensure "that ethical, legal, environmental, and other appropriate societal concerns, including the potential use of nanotechnology in enhancing human intelligence and in developing artificial intelligence which exceeds human capacity, are considered during the development of nanotechnology ..." *

- Currently, there are no specific regulations or guidance for nanoparticles at OSHA, NIOSH, FDA, or EPA**

* John Marburger (Director OSTP), speech at Sept 8, 2004 "Research Directions II Workshop"

** Neil Patel (EPA/OPPTS) email of 8/23/04)

Regulations and Nanotechnology / Nanoparticles

- EPA beginning to formulate regulatory and voluntary options on how to handle nanomaterials. The information developed on detection equipment, engineering controls, personal protective equipment, will be important in the development of these options.*

Without the development of new control technologies, the short term and long term environmental and health impacts (through air, water, and landfill releases, as well as human inhalation, ingestion, or dermal contact) remain unknown and potentially high risk.*

* Neil Patel (EPA/OPPTS) email of 8/23/04)

Why Are There No Regulations???

Prior to writing a regulation, one must:

- develop consistent terminology (ANSI)
- be able to classify the compound(s) in question
- be able to monitor them ...and...
- determine their environmental impacts (eco/HH)

Types of nanoparticles that may have environmental impacts:

- carbon nanotube structures (for water filtration)
- "quantum dots" or crystalline semiconductors (envir sensing/telecom)
- metal oxide particles (for sunblock and various plastic components)

Much more research needed before regs can be written

Is TSCA Applicable?

Toxic Substances Control Act - TSCA

- passed in 1976

- gave EPA the power to regulate chemicals in commercial use with risk or potential risk to the environment, with concern given to economic and societal impacts (Precautionary Principle in mind)

- TSCA seems to be the best regulation, at least as a model, for nanotechnology and nanoparticles.

- "Regulation should be a process, not an event" (Reynolds, "Environmental Regulation on Nanotechnology: Some Preliminary Observations", Environ. Law Reporter, 2001)

- The time is NOW, not 5 years from now.

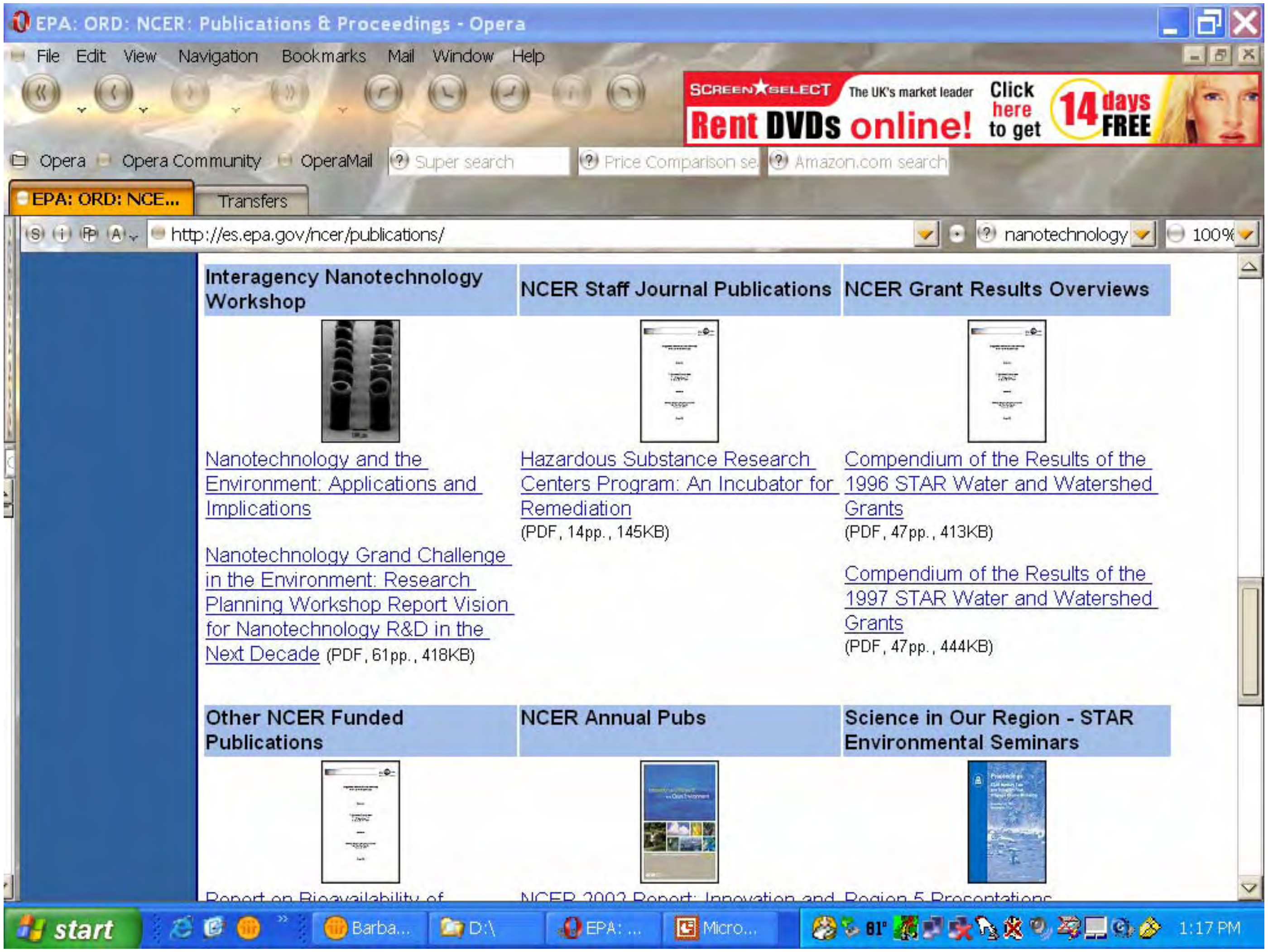
- UK has no existing laws either, but similar process has been proposed, that is to modify existing laws for nanotech and be flexible as more is learned (Royal Society Report- "Nanosciences and Nanotechnologies" - Jul '04)

A Research Framework for Nano and the Environment

Applications
reactive to existing problems
or
proactive in preventing future problems.

Implications of
interactions of nanomaterials with the environment
and
possible risks that may be posed by the use of nanotechnology.

WWW.EPA.GOV/NCER Go to Publications/Proceedings



EPA (NCER) Nanotechnology Activities

Environmental Applications

2001 RFA
- Synthesis and Processing;
- Characterization and Manipulation;
- Modeling and Simulation;
- Device and System Concepts

Grantees' workshops Aug.`02, '04

Dec. 2003 Societal Implications II

EPA NanoMeeters

Wilson Center Meetings

Implications

2003/04 RFAs
Health/Eco effects of manufactured nanomaterials

SBIR
Nanomaterials and Clean Technologies

Applications and Implications

2002 RFA
- Environmentally Benign Manufacturing and Processing;
- Remediation/Treatment;
- Sensors;
- Environmental Implications of Nanotechnology

- ACS Symposia-2003,04,05
- Gordon Conference- 2006?
- Grand Challenges Workshop
- Interagency Environmental Conference
- Edited journals

Building a Green Nanotech Community

Some Documents to be aware of:

Societal Implications of Nanotechnology (http://nano.gov/html/res/home_res.html)

Chemical Industry R&D Roadmap for Nanomaterials By Design: From Fundamentals to Function (www.chemicalvision2020.org/pdfs/nano_roadmap.pdf

Swiss Re:Nanotechnology Small Matter, Many Unknowns (http://www.swissre.com/)

International Dialogue on Responsible Nanotechnology(http://www.nsf.gov/home/crssprgm/nano/dialog.htm)

Royal Society Report (http://www.nanotec.org.uk/finalReport.htm)

"it is important that claims of likely environmental benefits are assessed for the entire lifecycle of a material or product, from its manufacture through its use to its eventual disposal.

We recommend that lifecycle assessments be undertaken for applications of nanotechnologies."

VDI Report:Technological Analysis Industrial application of nanomaterials - chances and risks

http://imperia5.vdi-online.de/imperia/md/content/tz/zuknftigetechnologien/11.pdf

Call for open public dialog

Take Home Messages:

- Nanotechnology is a very powerful new approach that will change our industries and our lives.

- We have a very small window right now to bring up this technology right—to learn from past mistakes and concurrently look at the possibility of harmful implications as we increase the applications.

- It's a topic too important to neglect. Let's not replay the last Industrial Revolution wrt pollution.

- P2 can make a difference……

B. Karn, 2004

Acknowledgements

Barbara Karn, Jeff Morris, Pasky Pascual

(EPA's Office of Research and Development)

King Features Syndicate, September 22, 2004

Questions??

Gill.Michael@epa.gov

415-972-3054