Nanotechnology and the Environment: A Charge to EPA Nano Grantees

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Outline

What is nanotechnology?

What is Different/Special about nano?

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

The relation of environmental protection to nanotechnology

Research Framework

Research-related issues-reports

Current EPA activities

What we hope to get from sponsored academic research

What is nanotechnology?

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

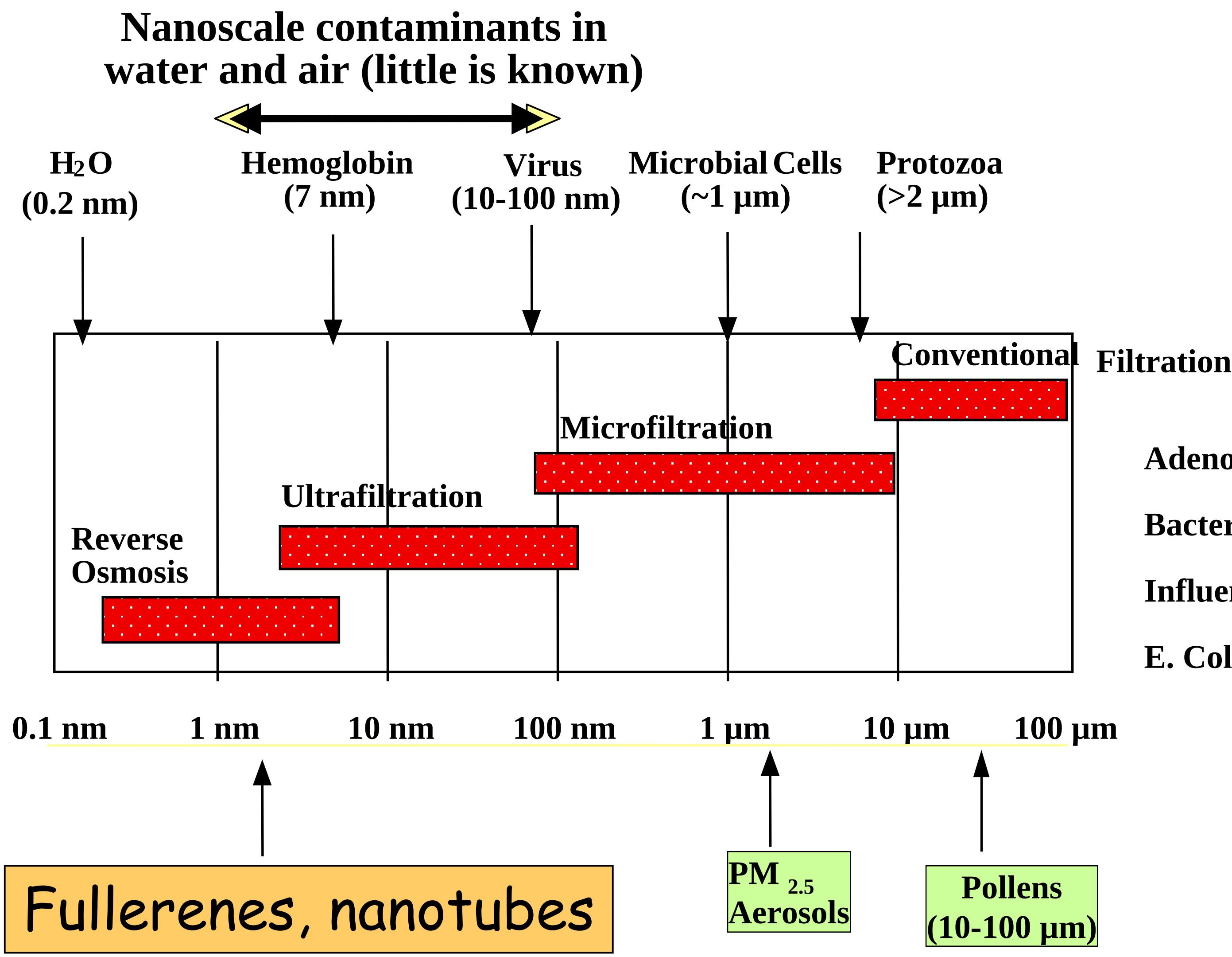
1. Research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1 - 100 nanometer range.

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

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

Nanomaterials have unique properties
How can these properties be used to protect the environment?

Properties	Examples
Catalytic	Better catalytic efficiency through higher surface-to-volume ratio
Electrical	Increased electrical conductivity in ceramics and magnetic nanocomposites, increased electric resistance in metals
Magnetic	Increased magnetic coercivity up to a critical grain size, superparamagnetic behaviour
Mechanical	Improved hardness and toughness of metals and alloys, ductility and superplasticity of ceramic
Optical	Spectral shift of optical absorbtion and fluorescence properties, increased quantum efficiency of semiconductor crystals
Sterical	Increased selectivity, hollow spheres for specific drug transportation and controlled release
Biological	Increased permeability through biological barriers (membranes, blood-brain barrier, etc.), improved biocom-patibility

Table 3: Adjustable properties of nanomaterials

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Characterizing Nanomaterials

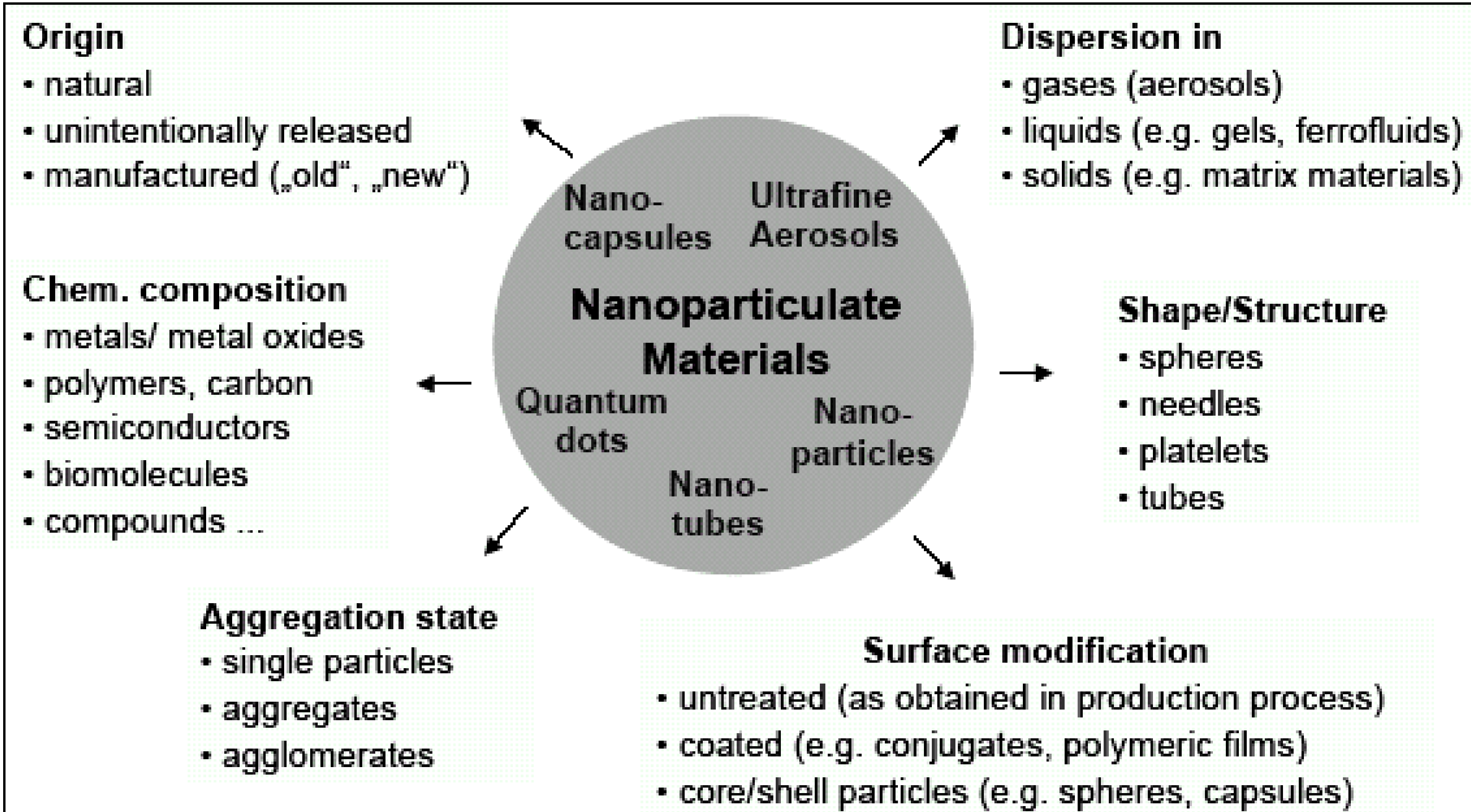

Figure 1: Characterisation parameters of nanoparticulate materials (source: VDI-TZ)

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

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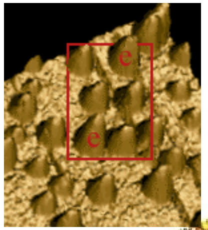
Applications of Nanotechnology

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

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

The Challenge

Use nanotechnology research to:

…Help clean up past environmental damage

…Correct present environmental problems

…Prevent future environmental impacts

…Help sustain the planet for future generations

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.

Applications-Sensors

improved monitoring and detection capabilities, better controls

Information for Environmental Protection/Risk Management--More efficient use of materials, more data on wastes

real-time, accurate sensing of many compounds simultaneously at extremely low concentrations frequently in hostile environments

Applications-Treatment

Cleaning up waste streams of contaminants, particularly those substances that are highly toxic, persistent within the environment, or difficult to treat

promise for cost-effective, specific, and rapid solutions for treatment of contaminants

Applications-Remediation

Cleanup of contaminated sites with problems brought about by prior technologies and past practices.

Applications-Green Manufacturing

Atom-by-atom construction--Less material to dispose of

two aspects:

--using nanotechnology itself to eliminate the generation of waste products and streams by designing in pollution prevention at the source.

--manufacturing nanomaterials themselves in a benign manner.

Both aspects involve use of environmentally friendly starting materials and solvents, improved catalysts, and significantly reduced energy consumption in the manufacturing process

Dematerialization- less “stuff” to begin with

Applications-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

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

Implications-Toxicity

Essential to risk analysis for ecosystem and human health

Implications-Fate, Transport, Transformation

Determine exposure routes for both natural organisms in a variety of ecosystems and for humans in the environment

Implications-Exposure, Bioavailability, Bioaccumulation

Also essential to risk analysis

Implications-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

9 NNI Grand Challenges for Research in Nanotechnology

1) Nanostructured Material by Design
2) Manufacturing at the Nanoscale

3) Chemical-Biological-Radiological-Explosive Detection and Protection
4) Nanoscale Instrumentation and Metrology

5) Nano-Electronics, -Photonics and –Magnetics
6) Healthcare, Therapeutics, and Diagnostics

7) Efficient Energy Conversion and Storage
8) Microcraft and Robotics

9) Nanoscale Processes for Environmental Improvement

GRAND CHALLENGE –Environment

1. Applications for Measurement in the Environment

Vision: *The unique properties of nanoscale materials will enable the development of a new generation of environmental sensing systems. In addition, measurement science and technology will enable the development of a comprehensive understanding of the interaction and fate of natural and anthropogenic nanoscale and nanostructured materials in the environment.*

2. Applications for Sustainable Materials and Resources

Vision: *A society that uses nanotechnology to transform the way it extracts, develops, uses and dissipates materials and the flow, recovery, and recycling of valuable resources, especially in the use of energy, transportation of people and goods, availability of clean water, and supply of food.*

3. Applications for Sustainable Processes

Vision: *Sustainable manufacturing processes based on the use of nanoscale science and nanotechnology – integrated processes and bottom-up assembly – that can serve human needs and are compatible with the surrounding ecosystems and human population.*

4. Implications in natural and global processes

Vision: *The ability to understand and quantify nanoparticles in Earth system processes in order to anticipate their impacts and thus optimize and integrate environmental sustainability and nanotechnology.*

5.Implications in health and environmental safety

Vision: *Development of nanotechnology responsibly with a full appreciation of its health and environmental impacts.*

Research challenges and needs include:

- Develop high throughput/multi-analyte toxicological methodologies with focus on mechanism and fundamental science of particle toxicity and access to well-characterized nanomaterials for conducting risk assessment research
- Better understand the diversity of anthropogenic nanoparticles through the development of a nanomaterial inventory
- Gain information on exposure to nanomaterial resulting from medical, occupational, environmental, and accidental release of nanomaterial with regard to the concentration as well as what form(s) the nanoparticles may assume upon release into the environment
- Predict biological properties of nanomaterials through toxicological assessment of nanomaterials that includes relevant and scientifically appropriate acute and chronic toxicokinetics and pharmacokinetic studies

Other Grand Challenges and Related Issues

Metrology

Fundamental to study of nanotechnology
Grand Challenge Workshop

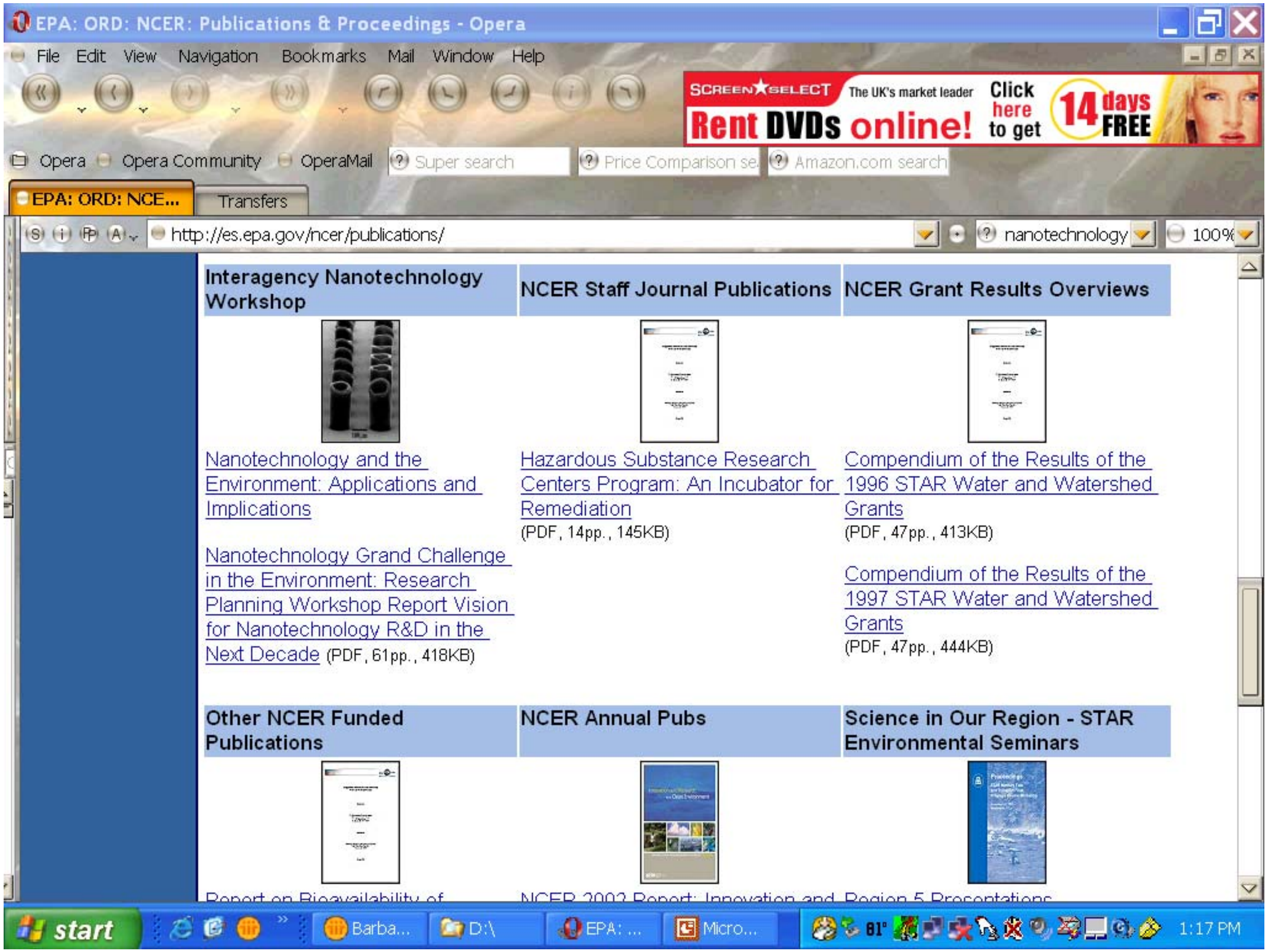
Energy

Inseparable from environmental aspects
Initiative in hydrogen economy:
Production, storage, use in fuel cells
Smalley's Energy Challenge
Grand Challenge Workshop

Nomenclature/Classification

Necessary for environmental assessment
Colvin/Kulinowski proposal, Vision 20/20,NNI

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



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/crss prgm/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

Nanotech is both top down and bottom up—like Nature

The Cell is a Nano Factory!

A. Uses "natural" ingredients-simple atoms
B. at room temperature,
C. With small machines for assembling,
D. in non-toxic solvents,
E. And the end of life disposal is accounted for

EPA (NCER) Nanotechnology Activities

Dec. 2003 Societal Implications II

Environmental Applications

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

Grantees' workshops
Aug.` 02, '04

EPA NanoMeeters

Wilson Center Meetings

Implications

2003/04 RFAs
Health 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

THE CHARGE!

RESEARCH For ENVIRONMENTALLY RESPONSIBLE NANOTECHNOLOGY

Questions??

Come forth into the light of things,
Let nature be your teacher

William Wordsworth

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