Four Approaches to the Environmental Issues Of Nanotechnology

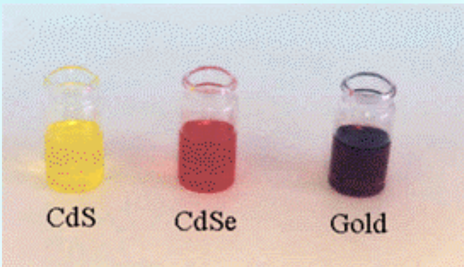
Barbara Karn, PhD
US EPA

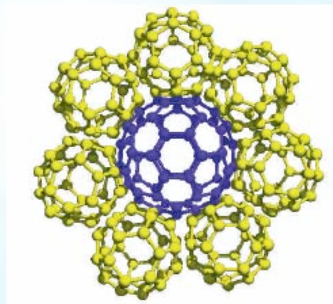
Safe Handling of Engineered Nanoscale Materials

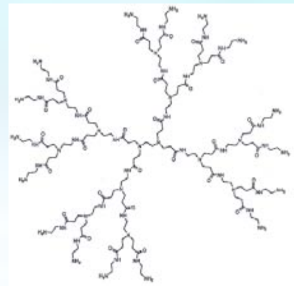
Argonne National Laboratory July 7-9, 2008

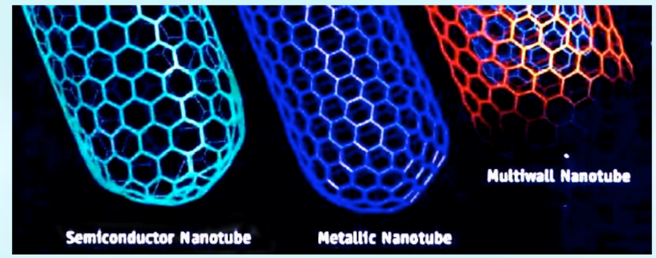
What are we dealing with?

Many different materials and classes of materials





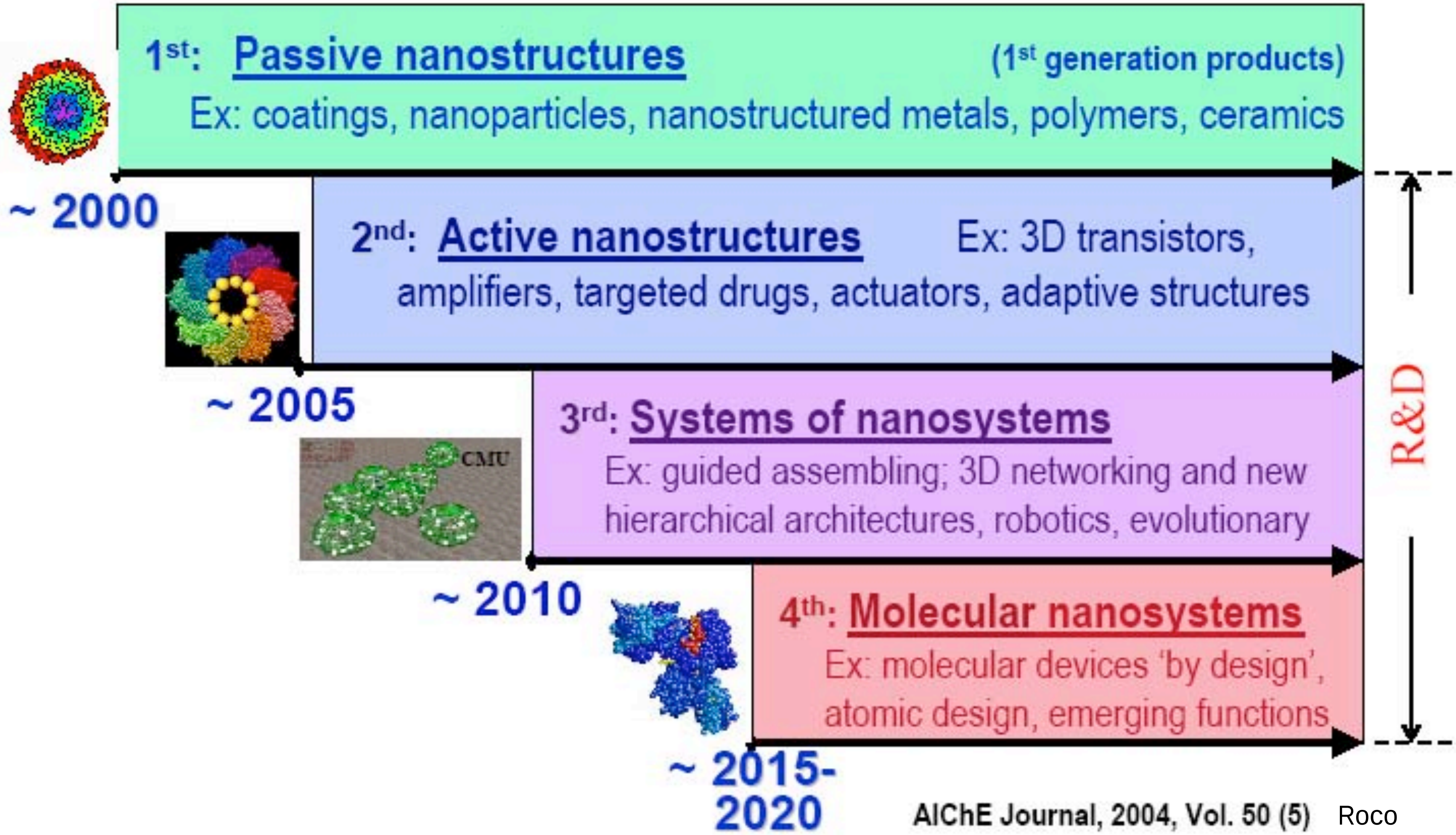




Many different industries and sectors and products

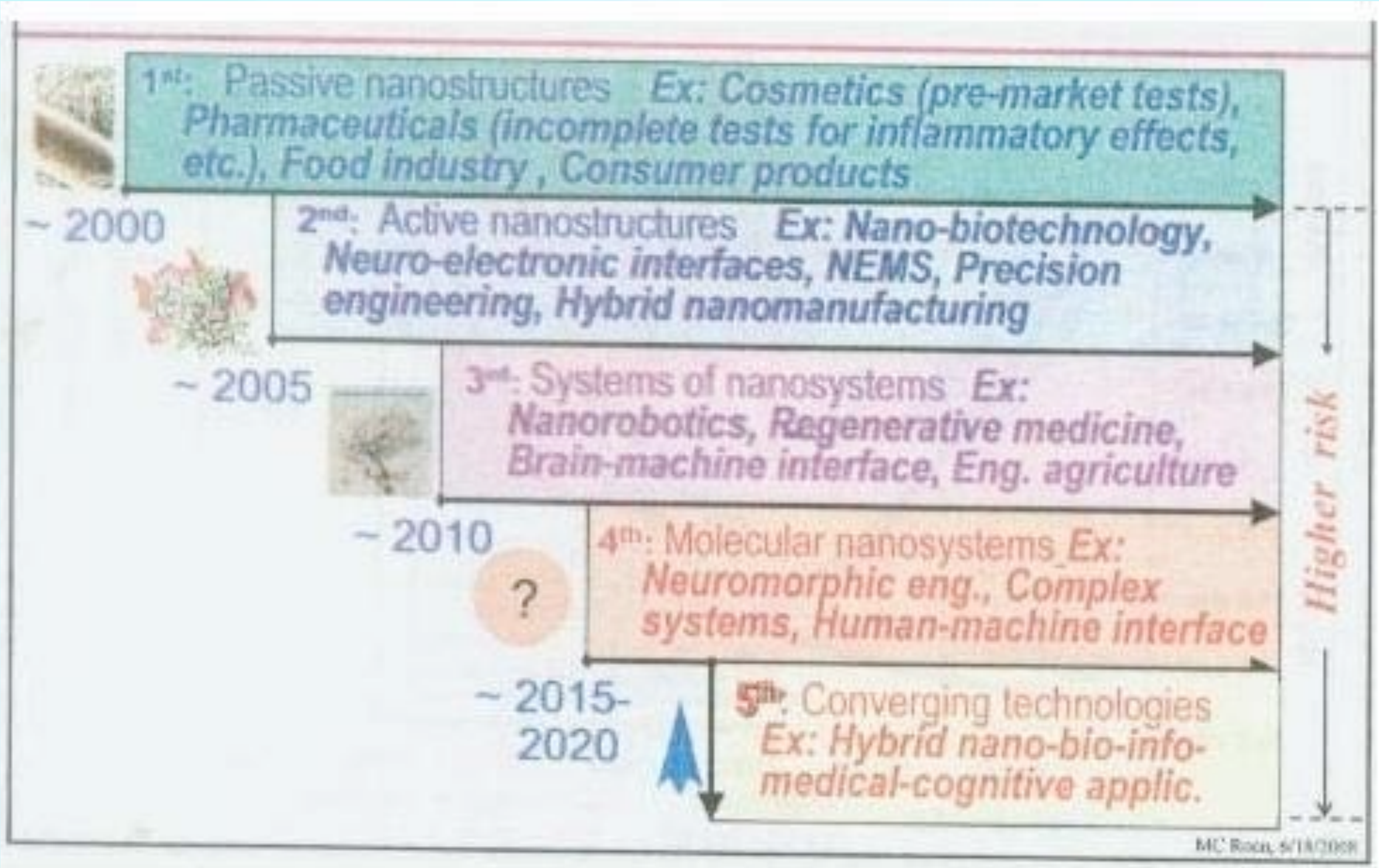
Nanotechnology converges with other technologies:
biotechnology, information technology, cognitive science

How will Nanotechnology evolve?



Roco

A More Recent View of Nanotechnology Evolution



M. C. Roco 6/18/08

Four Approaches to the Environmental Issues Of Nanotechnology

1. Knowledge-gathering Approaches: Research and Development

2. Governance Approaches: Agencies, Laws, Regulations

3. Private Sector Approaches: NGOs, Academia, Industry

4. Philosophical Approaches

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

Green Nanotechnology

- Sensors
- Treatment
- Remediation
- Green manufacturing
- Green energy

implications

- Natural nano processes
- Toxicity
- Fate, transport, and transformation
- Exposure, bioavailability, and bioaccumulation
- Industrial Ecology aspects

Applications

Sensors

improved monitoring and detection capabilities, better controls

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

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

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

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


Green Nano

Green Nanotechnology

Green nanotechnology is about doing things right in the first place—
about making green nano-products and using nano-products in support of sustainability.

Green Nanotechnology has two goals

Products

Goal 1

Produce nano-products that provide solutions to environmental challenges

involves practical use of nanoproducts in either direct or indirect applications to environmental problems.
(environmental technologies, clean energy)

Process

Goal 2

Producing nanomaterials and products without harming the environment or human health

incorporates the source reduction principles of green chemistry and engineering and focuses on the processes of making nanomaterials without emitting harmful pollutants and using nanotechnology to make current processes greener
(clean production, P2, clean tech, environmentally benign manufacturing)

How can we recognize green?

1. Regulate Claims

The Federal Trade Commission is the nation's consumer protection agency.

The FTC's Bureau of Consumer Protection works for the consumer to prevent fraud, deception, and unfair business practices in the marketplace.

- Enhances consumer confidence by enforcing federal laws that protect consumers
- Empowers consumers with free information to help them exercise their rights and spot and avoid fraud and deception

Part 260 — GUIDES FOR THE USE OF ENVIRONMENTAL MARKETING CLAIMS

Administrative interpretations of laws administered by the Federal Trade Commission

2. Add Labels

3. Develop Methodologies

Table 2 Selected 'green' metrics

Category		Units
Mass		
$\frac{\text{Total mass (kg)}}{\text{Mass of product (kg)}}$	(Mass intensity)	kg/kg
$\frac{\text{Total mass solvent (gross) (kg)}}{\text{Mass of product (kg)}}$		kg/kg
$\frac{\text{Mass of isolated product (kg)} \times 100}{\text{Total mass of reactants used in reaction (kg)}}$	(Reaction mass efficiency) RME	%
$\frac{\text{FW (g mol}^{-1}\text{) product} \times 100}{\text{FW of all reactants used in reaction}}$	(Atom economy)	% %
$\frac{\text{Mass of carbon in product (kg)} \times 100}{\text{Total mass of carbon in key reactants (kg)}}$	(Carbon efficiency)	%
Energy		
$\frac{\text{Total process energy (MJ)}}{\text{Mass of product (kg)}}$		MJ/kg
$\frac{\text{Total solvent recovery energy (MJ)}}{\text{Mass of product (kg)}}$		MJ/kg
Pollutants/toxic dispersion		
Persistent and bioaccumulative		
$\frac{\text{Total (mass persistent + bioaccumulative) (kg)}}{\text{Mass product (kg)}}$		kg/kg
Ecotoxicity		
$\frac{\text{Total (mass persistent + bioaccumulative) (kg)}}{EC_{50}{}^{a}\text{ material}/EC_{50}\text{ DDT control}}$		kg
Human health		
$\frac{\text{Total (mass of material [for all materials]) (kg)}}{\text{Permissable exposure limit (ACGIH)}^{b}\text{ (ppm)}}$		kg/ppm
POCP (photochemical ozone creation potential)		
$\frac{\text{Total [mass of solvent (kg)} \times \text{POCP value} \times \text{vapour pressure (mm)]}}{\text{mass of product (kg)} \times \text{vapour pressure [toluene]} \times \text{POCP [toluene]}}$		kg/kg (as toluene)
Greenhouse gas emissions		
$\frac{\text{Total (mass of greenhouse gas from energy [as kg } CO_2 \text{ equiv.])}}{\text{mass of product (kg)}}$		kg/kg (as CO_2)
$\frac{\text{Greenhouse gas, kg } CO_2 \text{ equivalent, ex energy for solvent recovery}}{\text{kg product}}$		kg/kg
Safety		
Thermal hazard		Highlight
Reagent hazard		Highlight
Pressure (high/low)		Highlight
Hazardous by-product formation		Highlight
Solvent		
Number of different solvents		Number
Overall estimated recovery efficiency		%
Energy for solvent recovery		MJ/kg
Mass intensity net of solvent recovery		kg/kg

[a] EC50 = the concentration at which 50% of the organisms in an acute toxicity test die during the fixed time period of the study. [b] ACGIH = American Conference of Governmental Industrial Hygienists. A standards setting organisation convened to set Threshold Limit Values (TLV) for chemical and physical hazards, usually expressed as the time weighted average (TWA) concentration permitted over an 8 h exposure period.

Curzons et al *Green Chemistry*, 2001, **3**, 1–6

5. Gather scientific evidence

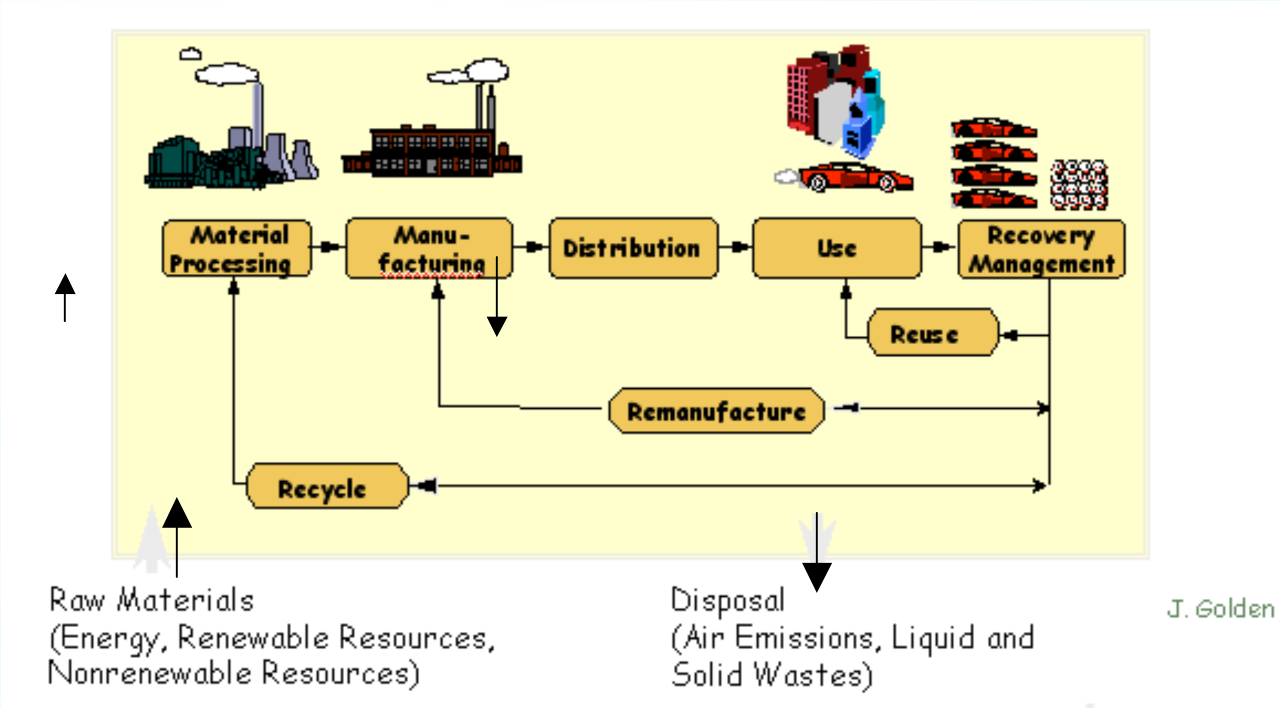
Non-toxic/hazardous materials

Low probability of exposure

Renewables

6. Treat "Green-ness" as part of a bigger picture

Pollution Prevention/Clean Production

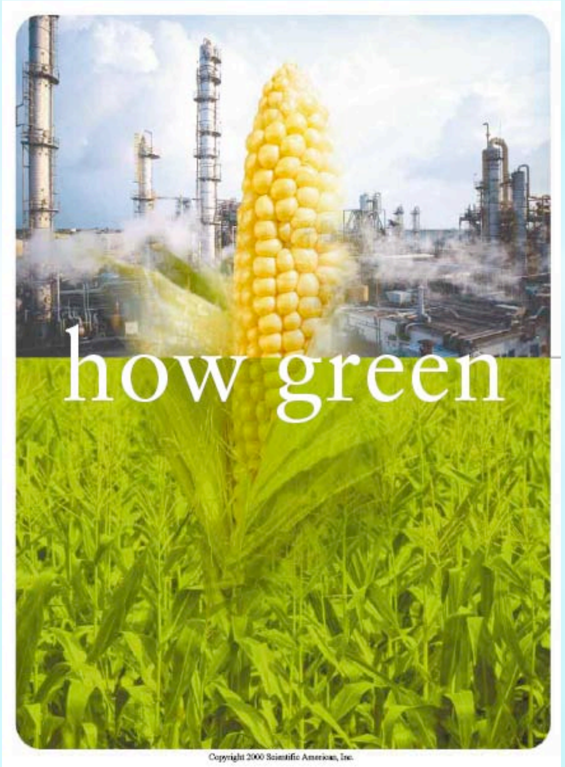


Industrial Ecology

7. Fit into Sustainability`

The concept of sustainable development – “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Bruntland, 1987) – goes well beyond manufacturing to encompass all human production and consumption activities, such as: agriculture; land, air and water resource management; human habitat management; biodiversity, *etc*.

Gallopoulos, 2006



<u>Sustainability is the bigger goal.</u>

Example Green Processes to make nanomaterials

Self-assembly

Molten Salt or Ionic Liquid Synthesis

Bottom up Manufacturing

Bio-inspired nanoscale synthesis

Use of non-toxic solvents like supercritical CO2

Microwave techniques

Photochemical synthesis

Aqueous processing

Renewable starting materials

Solvothermal/hydrothermal Processes

Templating processes

Non-toxic starting materials

Use of solid state processes

Implications

Natural Nanoprocesses

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

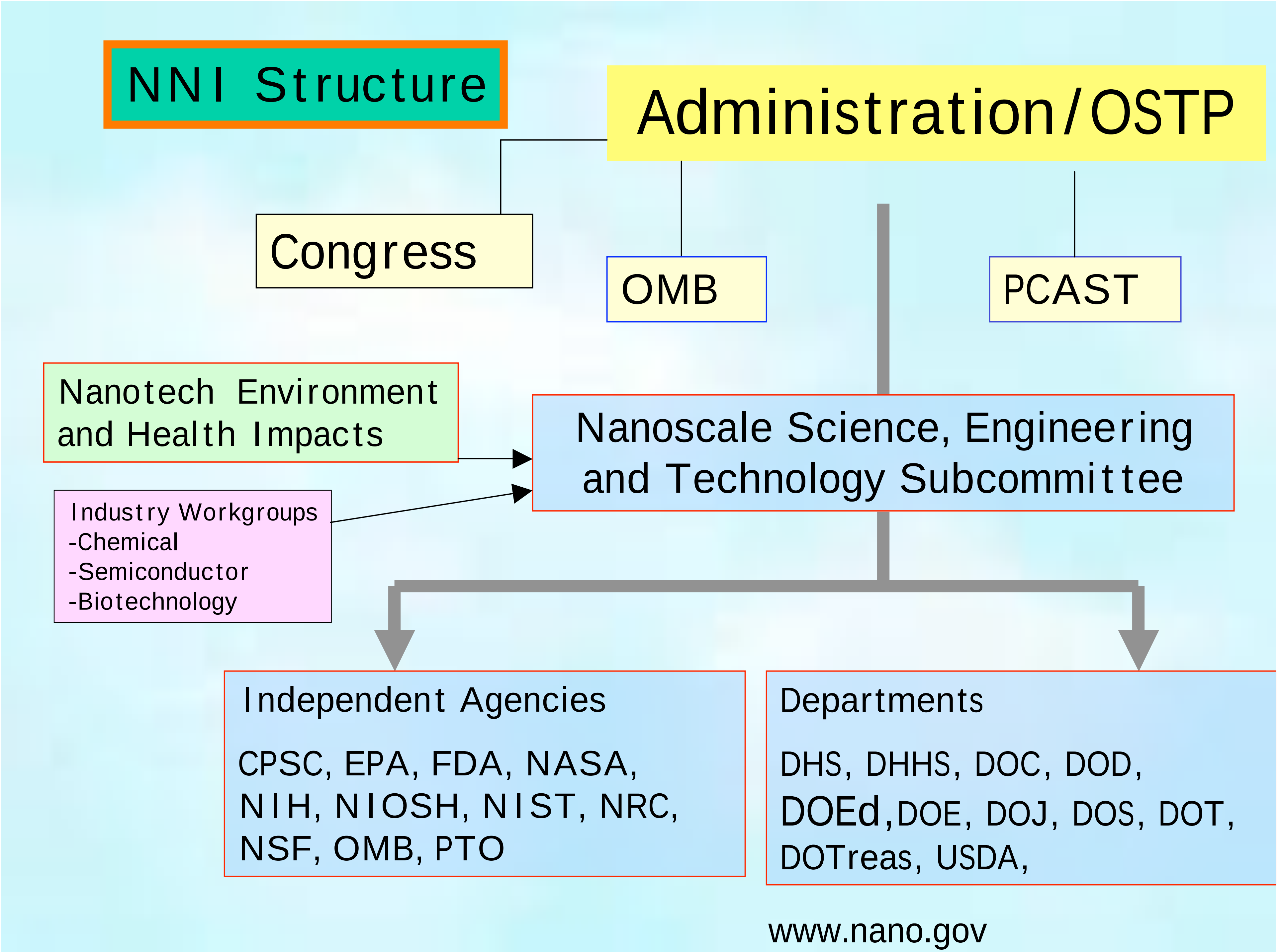
Determine exposure routes for both natural organisms in a variety of ecosystems and for humans in the environment

Exposure, Bioavailability, Bioaccumulation

Short-term and long-term effects, part of risk assessment

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


NNI Structure
Administration/OSTP
Congress
OMB
PCAST
Nanotech Environment and Health Impacts
Industry Workgroups
-Chemical
-Semiconductor
-Biotechnology
Nanoscale Science, Engineering and Technology Subcommittee
Independent Agencies
CPSC, EPA, FDA, NASA, NIH, NIOSH, NIST, NRC, NSF, OMB, PTO
Departments
DHS, DHHS, DOC, DOD, DOEd, DOE, DOJ, DOS, DOT, DOTreas, USDA,
www.nano.gov

National Nanotechnology Initiative

Vision: a future in which the ability to understand and control matter on the nanoscale leads to a revolution in technology and industry.

Goals: 1. Maintain a world-class research and development program aimed at realizing the full potential of nanotechnology

2. Facilitate transfer of new technologies into products for economic growth, jobs, and other public benefit

3. Develop educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology

4. Support responsible development of nanotechnology

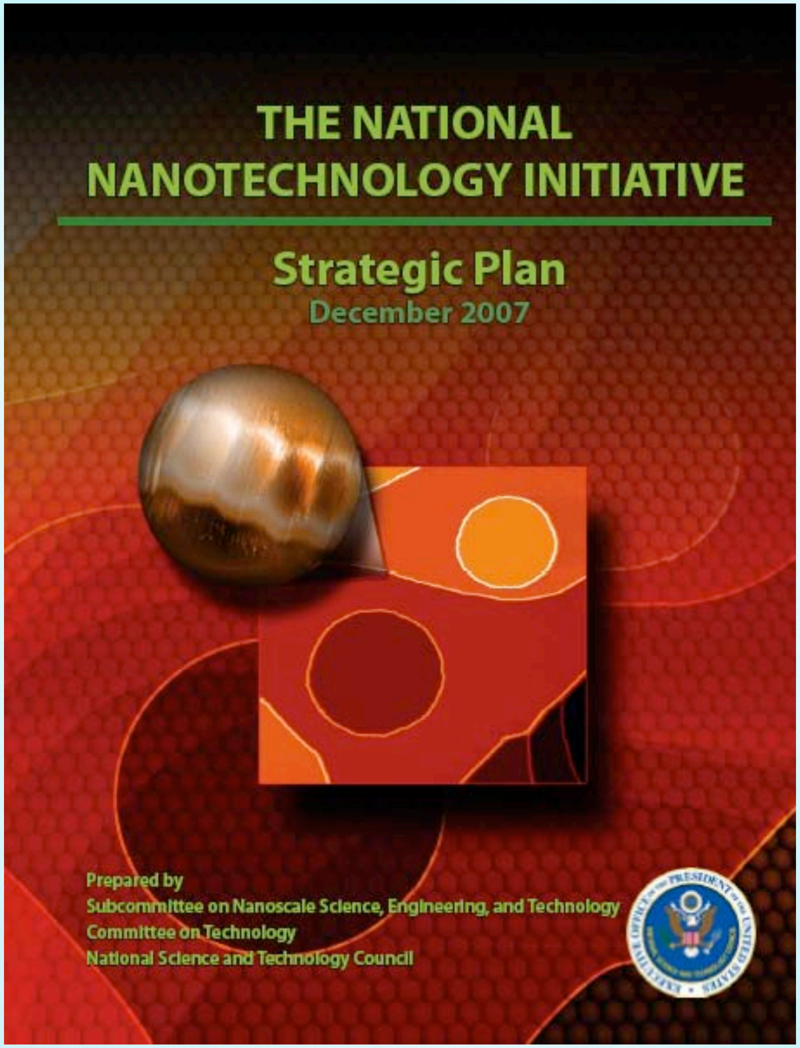
www.nano.gov

NNI: R&D Funding by Agency

NNI Budget, 2007-2009 (dollars in millions)			
	2007 Actual	2008 Estimate*	2009 Proposed
DOD	450	487	431
NSF	389	389	397
DOE**	236	251	311
DHHS (NIH)	215	226	226
DOC (NIST)	88	89	110
NASA	20	18	19
EPA	8	10	15
DHHS (NIOSH)	7	6	6
USDA (FS)	3	5	5
USDA (CSREES)	4	6	3
DOJ	2	2	2
DHS	2	1	1
DOT (FHWA)	1	1	1
TOTAL	1,425	1,491	1,527

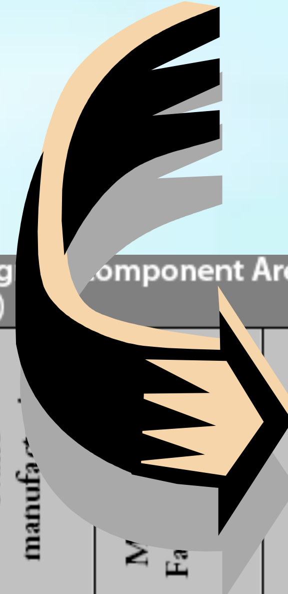
2009 budget for R& D: $1,527M

NNI Program Component Areas:



- ➢Fundamental nanoscale phenomena and processes
- ➢Nanomaterials
- ➢Nanoscale devices and systems
- ➢Instrumentation research, metrology, and standards for nanotechnology
- ➢Nanomanufacturing
- ➢Major research facilities and instrumentation acquisition.
- ➢ Environment, health, and safety
- ➢ Education and societal dimensions

Funding by program component areas



Actual 2007 Agency Investments by Prog… …omponent Area (dollars in millions)									
	Fundamental Phenomena & Processes	Nanomaterials	Nanoscale Devices & Systems	Instrument Research, Metrology, & Standards	Nano- manufa…	M… Fa…	Environment, Health, and Safety	Education & Societal Dimensions	NNI Total
DOD	210.1	86.0	120.0	4.3	7.5	22.3			450.2
NSF	145.2	58.4	52.4	14.9	26.6	30.0	26.9	34.4	388.8
DOE	52.6	68.5	9.7	11.3	0.5	92.9		0.5	236.0
DHHS (NIH)	45.7	25.4	125.7	5.9	0.8		7.7	4.2	215.4
DOC (NIST)	24.2	7.5	22.9	14.2	12.4	5.5	0.9		87.6
NASA	0.8	9.9	9.1						19.8
EPA	0.2	0.2	0.1				7.1		7.6
DHHS (NIOSH)						1.7	5.6		7.3
USDA (FS)	0.4	1.3	0.7	0.3	0.2				2.9
USDA (CSREES)	0.5	1.0	2.1		0.1		0.1	0.1	3.9
DOJ		0.1		1.6					1.7
DHS			2.0						2.0
DOT (FHWA)	0.9								0.9
TOTAL	480.6	258.3	344.7	52.5	48.1	152.4	48.3	39.2	1,424.1

EHS from 3.4% in 2007 to 5% proposed in 2009

Interagency Working Group on Nanotechnology Environmental and Health Implications (NEHI)

Members: Environmental Protection Agency, Food and Drug Administration, Consumer Product Safety Commission, Occupational Safety and Health Administration, National Institute for Occupational Safety and Health, and the Department of Agriculture and other agencies

Purpose:

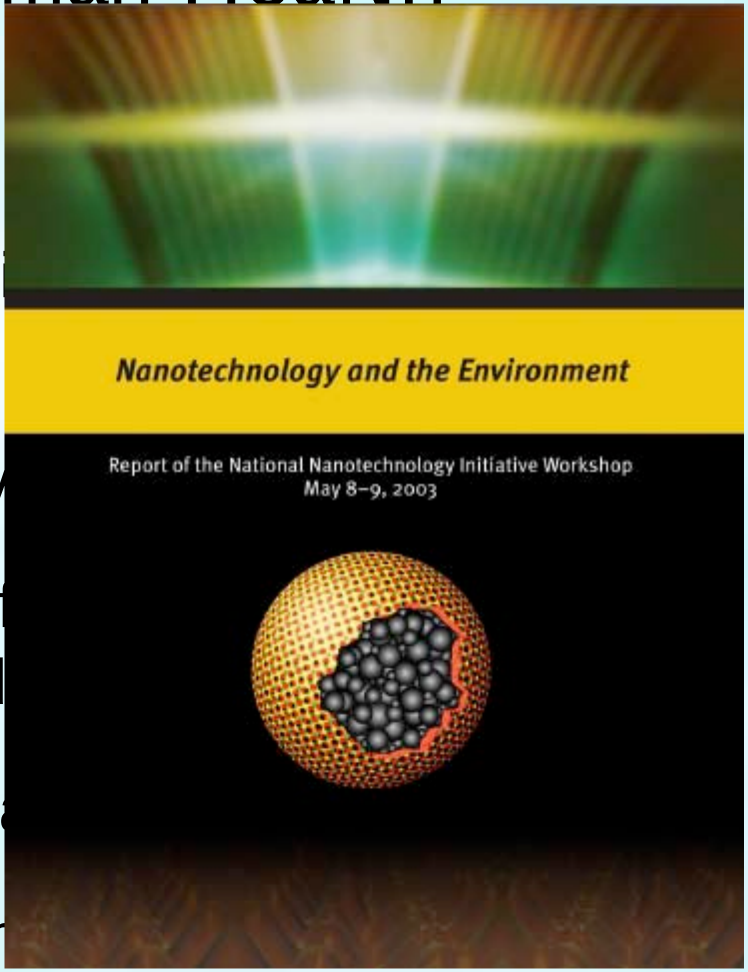
- provide for exchange of information among agencies that support nanotechnology research and those responsible for regulation and guidelines related to nanoproducts (defined as engineered nanoscale materials, nanostructured materials or nanotechnology-based devices, and their byproducts);

- facilitate the identification, prioritization, and implementation of research and other activities required for the responsible research and development, utilization, and oversight of nanotechnology, including research methods of life-cycle analysis;

- promote communication of information related to research on environmental and health implications of nanotechnology to other Government agencies and non-Government parties.

Efforts of NNI on Nanotechnology – Environment and Human Health

- Interagency Report on EHS
- EPA Research Grants in Envi and Implications
- NSF Research Grants in Env
- NIH Research on Effects of Body-Adjunct to Cancer and
- NIOSH Research on Nanom
- National Toxicology Program
- NSF, DOE, DOD Research Centers



EHS Research Plans

EPA

White Paper

Nanomaterial Research Strategy

NEHI

Strategy for Nanotechnology-Related Environmental, Health, and Safety Research

Purpose of EPA Strategy

- Guides the nanotechnology research program within EPA's Office of Research and Development (ORD)

- Describes initiation of ORD in-house research program

- Builds upon research needs identified in the Agency Nanotechnology White Paper and the NNI

- Describes key research questions under four themes and seven primary research questions

Four Research Themes

- Sources, Fate, Transport, and Exposure
- Human Health and Ecological Research to Inform Risk Assessment and Test Methods
- Risk Assessment Methods and Case Studies
- Preventing and Mitigating Risks

"Special attention is given to EPA's role among Federal Agencies in addressing data needs for hazard assessment, risk assessment, and risk management relevant to the EPA mission and regulatory responsibilities ."

Epa.gov/ncer/nano

5 Categories of NNI EHS Research Strategy

Instrumentation, Metrology, Analytical Methods

Nanomaterials and Human Health

Nanomaterials and the Environment

Health and Environmental Exposure Assessment

Risk Management Methods

See Nano.gov

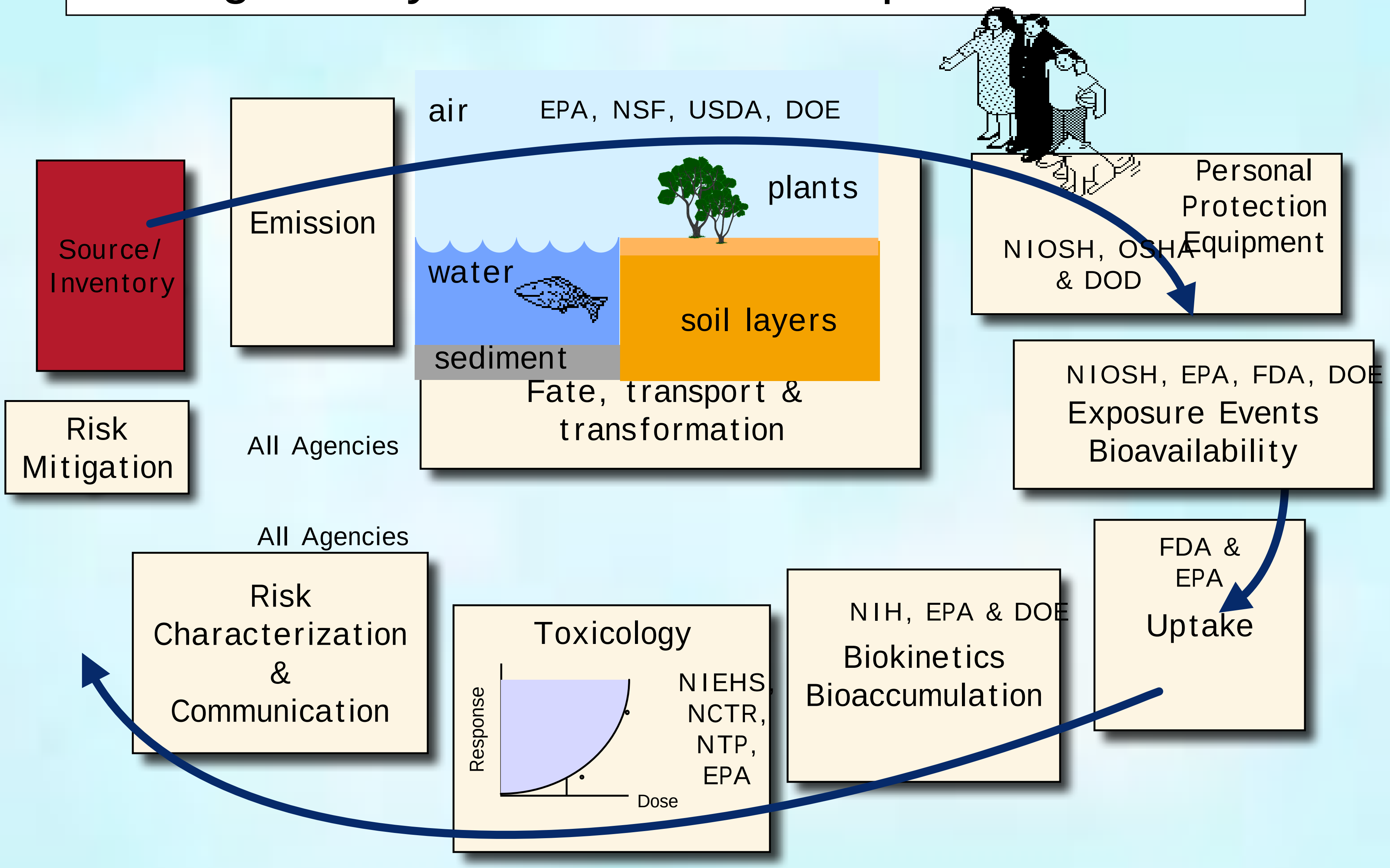
1. Knowledge-gathering approaches:
Research and Development

2. Government approaches:
Agencies, Laws, Regulations

3. Private sector approaches:
NGOs, Academia, Industry

4. Philosophical approaches

Regulatory and Research Topics for EHS



DOE Molecular Foundry—Lawrence Berkeley National Laboratory

Mark Alper, sl. modified

Government approaches address:

Products containing nanomaterials

Consumer Product Safety Commission (CPSC)

- Recalls, Safety

Federal Trade Commission (FTC)

- Safety of some products mainly by fairness

Nanomaterials themselves

US Department of Agriculture (USDA)

- Packaging, additives

Food and Drug Administration (FDA)

- Drugs and devices

Environmental Protection Agency (EPA)

Some EPA Laws that apply to nanomaterials:

Pre-approval:

- TSCA- currently voluntary under pre-manufacturing Notices (PMN)
- FIFRA-nanomaterials as biocides

Protection:

- Clean Air Act (ultrafines, preapproval additives)
- Clean Water Act
- RCRA, CERCLA, EPCRA (hazardous substances)
- NEPA

Other Government EHS Activities

Federal Science Advisor (Director, OSTP) and the CEQ Chairman

Memorandum to heads of executive department & Agencies on “Principles for Nanotechnology EHS Oversight”
Gives “regulatory path forward” Nov. 8, 2007

State Efforts

Wisconsin looking into nano regulations

Local Efforts:

Berkeley, California
Researchers and manufacturers must report what nanotechnology materials they are working with and how they are handling them.

Cambridge, Massachusetts studying Berkeley’s law

International Risk Governance Council

Recommendations:

- Improve the knowledge base.
- Strengthen risk management structures and processes.
- Promote stakeholder communication and participation.
- Ensure social benefits and acceptance.
- Collaboration between stakeholders and nations.

IRGC Nanotechnology Risk Governance Policy Brief, 2007

1. Knowledge-gathering approaches:
Research and Development

2. Government approaches:
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4. Philosophical approaches

Non-Governmental Organizations (NGOs)

Woodrow Wilson International Center for Scholars
Project on Emerging Nanotechnologies

Consumer Union

Environmental Defense Fund

Standards organizations: ASTM, ISO

International Council on Nanotechnology (ICON)

Academic efforts:

NSF centers

ELSI and EHS projects in other centers

Industry efforts:

ACC, Responsible Care

Nano Business Alliance

Dupont research, risk with Environmental Defense

Industry/NNI Consultative Boards

Industry Research Needs

- Terminology
  - Standard nomenclature for nanomaterials; include biologically significant descriptors.
- Metrology
  - Develop exposure monitoring techniques and instrumentation
- Exposure management
  - Voluntary standard of care for handling nanomaterials
  - Establishment of exposure limits
- Worker Protection
  - PPE protocols; engineering controls
- Emission Controls
  - Develop control methodologies for environmental emissions

1. Knowledge-gathering approaches:
Research and Development

2. Government approaches:
Agencies, Laws, Regulations

3. Private sector approaches:
NGOs, Industry, Academia

4. Philosophical approaches

Ethics: The moral principles governing or influencing conduct.
The branch of knowledge concerned with moral principles.

Compact Oxford English Dictionary

Nanoethics

"concerns ethical and social issues associated with developments in nanotechnology"

Wikipedia, accessed 1-29-08

Ethical issues of nanotechnology

Health, Safety - life cycle issues, worker protection, risk management, military uses, privacy, toxicity, exposure

Legal - intellectual property, regulations/laws for e.g. environment, drugs, food, consumer products

Social concerns - who benefits, north-south, rich-poor

Economic displacements - ”rust” belts, education of workforce, patent benefits, infrastructure, transportation

Governance - the role of the public, laws/regulations, non-government organizations, think tanks, academia, research funding, bringing up a new technology wisely

Environment – Pollution, sustainability, green nano, energy

Transhumanists - changing human nature itself

Some Nanoethics Activities

ELSI, NBIC, etc. conferences

International activities—UN, Meridian, Dialogue on Responsible Nanotechnology, International Risk Governance Council

University centers – e.g.,UC Santa Barbara, University of Arizona

Nanoethics Journal   Numerous journal articles

Organizations – ETC, Foresight, Nanoethics

Web sites / blogs

Book, book chapters-e.g. *Nanoethics: The Ethical and Social Implications of Nanotechnology*

Declarations, Principles

Principles encompass values, ideology, morality, ethics

Green Chemistry Principles applied to Nanoscience

Green Chemistry Principles		Designing Greener Nanomaterial and Nanomaterial Production Methods		Practicing Green Nanoscience
P1.	Prevent waste	Design of safer nanomaterials (P4,P12)	→	Determine the biological impacts of nanoparticle size, surface area, surface functionality; utilize this knowledge to design effective safer materials that possess desired physical properties; avoid incorporation of toxic elements in nanoparticle compositions
P2.	Atom economy			
P3.	Less hazardous chemical synthesis	Design for reduced environmental impact (P7,P10)	→	Study nanomaterial degradation and fate in the environment; design material to degrade to harmless subunits or products. An important approach involves avoiding the use of hazardous elements in nanoparticle formulation; the use of hazardless, bio-based nanoparticle feedstocks may be a key.
P4.	Designing safer chemicals			
P5.	Safer solvents/reaction media	Design for waste reduction (P1,P5,P8)	→	Eliminate solvent-intensive purifications by utilizing selective nanosyntheses - resulting in greater purity and monodispersity; develop new purification methods, e.g. nanofiltration, that minimize solvent use; utilize bottom-up approaches to enhance materials efficiency and eliminate steps
P6.	Design for energy efficiency			
P7.	Renewable feedstocks	Design for process safety (P3,P5,P7,P12)	→	Design and develop advanced syntheses that utilize more benign reagents and solvents than used in "discovery" preparations; utilize more benign feedstocks, derived from renewable sources, if possible; identify replacements for highly toxic and pyrophoric reagents
P8.	Reduce derivatives			
P9.	Catalysis	Design for materials efficiency (P2,P5,P9,P11)	→	Develop new, compact synthetic strategies; optimize incorporation raw material in products through bottom-up approaches, use alternative reaction media and catalysis to enhance reaction selectivity; develop real-time monitoring to guide process control in complex nanoparticle syntheses
P10.	Design for degradation/Design for end of life			
P11.	Real-time monitoring and process control	Design for energy efficiency (P6,P9,P11)	→	Pursue efficient synthetic pathways that can be carried out at ambient temperature rather than elevated temperatures; utilize non-covalent and bottom-up assembly method near ambient temperature, utilize real-time monitoring to optimize reaction chemistry and minimize energy costs
P12.	Inherently safer chemistry			

Dahl et al Greener Nano Synthesis, Chem. Rev. 2007 107:2228.

Principles for Nanotechnologies and Nanomaterials Oversight

Released September, 2007

Precautionary Principle

Mandatory Nano-specific Regulations

Health and safety of the public and workers

Environmental sustainability

Transparency

Public Participation

Inclusion of broader impacts

Manufacturer liability

46 signatories as of October-07

International Center for Technology Assessment

Nanotechnologies Industry Association

Nanoethics…takes as its subject a science still aborning; many of the ethical and social ills it seeks to address are mere speculations about the hypothetical ramifications of theoretical technologies that may prove technically impossible. It is fair to say that no scientific field or technological innovation has ever faced such intense scrutiny so prematurely.

Adam Keiper, 2007

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Stay tuned.

The future should be exciting!

Questions

?

"It is not who is right, but what is right that is of importance."

T. Huxley

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