NIEHS
National Institute of Environmental Health Sciences

RISKeLearning
Nanotechnology – Applications and Implications for Superfund

sbrp Superfund Basic Research Program
Balancing Scientific Excellence with Research Relevance

Session 9: November 8, 2007

"Looking Forward: Nanotechnology and Superfund"

Moderator: Heather Henry, SBRP/NIEHS

United States Environmental Protection Agency

Where Does the Nano Go?

David Rejeski

Director,
Project on Emerging Nanotechnologies,
Woodrow Wilson Center

Overview of ORD Draft Nanotechnology Research Strategy

Randy Wentsel

National Program Director, Contaminated Sites/Resource Conservation, ORD/EPA

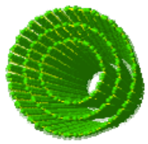
RISK*e*Learning

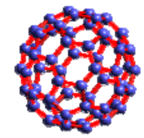
Nanotechnology: Applications and Implications

Session 1: January 18, 2007

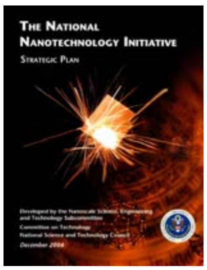
“Introduction to Nanotechnology”

Nora Savage, EPA ORD NCER
Nigel Walker, NIEHS NTP





Advantages to Nanotechnology:
- New properties
- Enable greater efficiency



- Product Use and Diversity
- Government Collaborations
- Funding Allocation
- Research Approaches
  - EPA STAR
  - NTP
  - NIEHS Grantees

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Walker

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Nanotechnology: Applications

Session 2: February 13, 2007

"Metal Remediation"

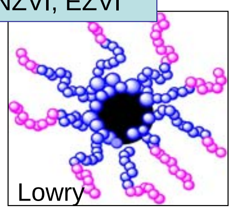
Mason Tomson, Rice University
Shas Mattigod, PNNL

Session 3: March 15, 2007

"DNAPL Remediation"

Matt Hull, Luna Innovations, Inc.
Peter Vikesland, Virginia Tech
Greg Lowry, Carnegie Mellon University

SAMMS
Nano Magnetite
NZVI, EZVI



Groundwater Remediation
Drinking Water

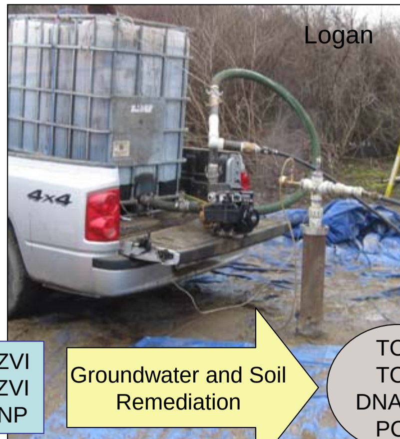
As, Cr, Hg
Actinides

TCE, CT
DNAPLs

RISKeLearning

Nanotechnology: Applications

Session 4: April 19, 2007
"Superfund Site Remediation"
Marti Otto, EPA OSRTI
Mary Logan, RPM, EPA Region 5



NZVI
EZVI
BNP

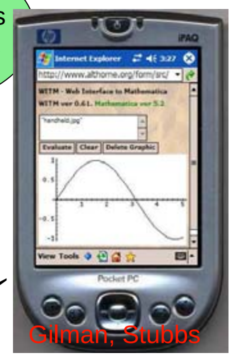
Groundwater and Soil Remediation

TCE
TCA
DNAPLs
PCE

Session 5: May 31, 2007
"Environmental Sensors"
Paul Gilman, ORCAS
Desmond Stubbs, ORCAS
Ian Kennedy, UC Davis

Dog-on-a-Chip
Exposure Monitors
Environ. Detectors
DNA Assay

Wearable
Real-Time
Qualitative
Quantifiable



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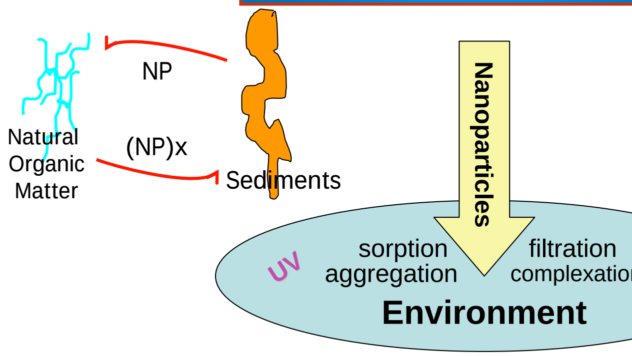
Nanotechnology: Implications

Session 6: August 16, 2007

"Fate and Transport"

Richard Zepp, EPA, NERL/ERD
Paul Westerhoff, Arizona State University



Session 7: September 12, 2007

"Human Toxicology and Risk Assessment"

Session 8: October 18, 2007

"Nanomaterials and Ecotoxicology"

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Nanotechnology: Implications

Session 7: September 12, 2007

“Human Toxicology and Risk Assessment”

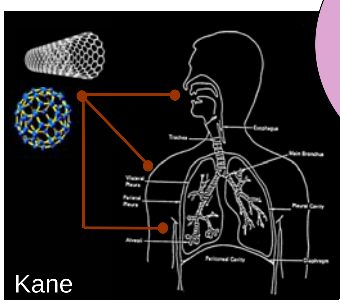
Kevin Dreher, US EPA
Agnes Kane & Robert Hurt, Brown University
Stephen Roberts, University of Florida

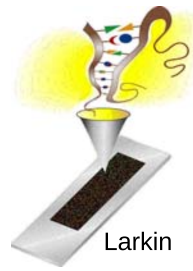
Session 8: October 18, 2007

“Nanomaterials and Ecotoxicology”

Stephen Klaine, Clemson University
Patrick Larkin, Santa Fe Comm. College

Unique “Nano-ness” could mean unique toxicities relative to bulk materials.





Larkin

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RISK*e*Learning
Nanotechnology: Applications and Implications for Superfund

- Challenges
  - – Diversity of products, rapidly evolving
    - Variability
    - Quality Control
    - Characterization
  - – Environmental interactions, which ones are critical?
- Opportunities
  - – Applications
  - – Collaborations
  - – Funding
- Future Directions
  - – Policy: David Rejeski
  - – Research: Randy Wentsel
  - – Discussion: Audience!!

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Nanotechnology: Planning Committee

THANKS!

SBRP/NIEHS

Kathy Ahlmark, Beth Anderson, David Balshaw, Heather Henry, Claudia Thompson, Sally Tinkle, William Suk

MDB, NIEHS-Contractor

Maureen Avakian, Larry Reed, Larry Whitson

EPA

Michael Gill (ORD/Reg 9), Marian Olsen (Reg 1), Marti Otto (OSWER/TIFSD), Mitch Lasat (ORD/NCER), Warren Layne (Reg 5), Charles Maurice (ORD/Reg 5), Jayne Michaud (OSWER), Nora Savage (ORD/NCER), Barbara Walton (ORD), Randy Wentsel (ORD)

CLU-IN Staff, & Jeff Heimerman (TIFSD)

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Where Does the Nano Go? End-of-Life Strategies for Nanotechnologies

David Rejeski
Director, Project on Emerging Nanotechnologies
Woodrow Wilson International Center for Scholars
Washington, DC

Woodrow Wilson International Center for Scholars

Project on Emerging Nanotechnologies at the Woodrow Wilson International Center for Scholars

Some History

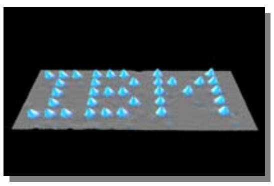
1976 Congress passes the **Resource Conservation and Recovery Act,** regulating hazardous waste from its production to its disposal.

1976 President Gerald Ford signs the **Toxic Substances Control Act** to reduce environmental and human health risks.

1977 President Jimmy Carter signs the **Clean Air Act Amendments** to strengthen air quality standards and protect human health.

1978 Residents discover that Love Canal, New York, is contaminated by buried leaking chemical containers.

1980 Congress creates **Superfund** to clean up hazardous waste sites.



Writing with atoms. D.M. Eigler, E.K. Schweizer. Positioning single atoms with a scanning tunneling microscope. ***Nature 344, 524-526 (1990).***

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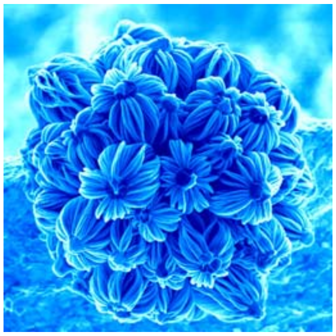
Why Address Nanotechnology End-of-Life Issues?

- Little is known about effects of nanomaterials and nanowastes on human health or the environment
- Nanomaterials may behave differently in the environment than bulk materials
- Nanomaterials are already in commerce and in the waste stream
- No law deals specifically with nanotechnology



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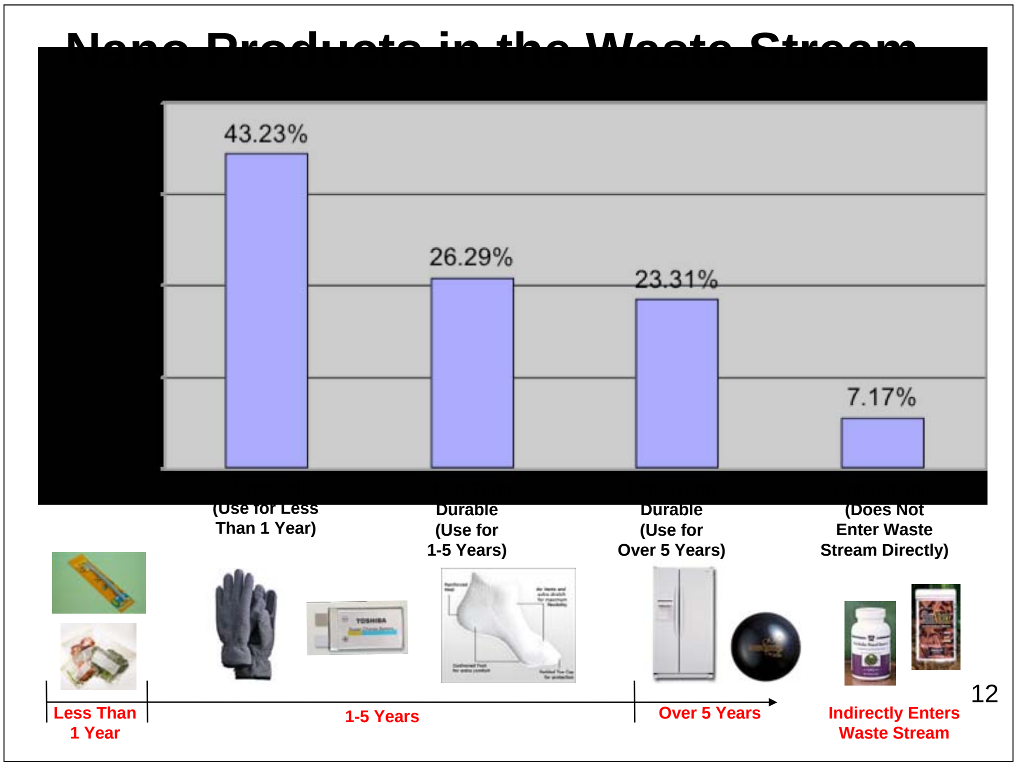
[redacted]
43.23%
26.29%
23.31%
7.17%
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Than 1 Year)
(Use for
1-5 Years)
(Use for
Over 5 Years)
Enter Waste
Stream Directly)
TOSHIBA
Less Than
1 Year
1-5 Years
Over 5 Years
Indirectly Enters
Waste Stream
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Estimated Global Production Rates for Various Nanomaterials and Devices

Application	Material/device	Estimated Production Rates (metric tons/year)		
		2004	2005-2010	2011-2020
Structural applications	Ceramics, catalysts, composites, coatings, thin films, powders, metals	10	103	10^4-10^5
Skincare products	Metal oxides (titanium dioxide, zinc oxide, iron oxide)	103	103	10^3 or less
ICT	Single wall nanotubes, nano electronics, opto-electro materials (titanium dioxide, zinc oxide, iron oxide), organic light-emitting diodes (OLEDs)	10	102	10^3 or more
Biotechnology	Nanoencapsulates, targeted drug delivery, bio-compatible, quantum dots, composites, biosensors	< 1	1	10
Instruments, sensors, characterization	MEMS, NEMS, SPM, clip-pen lithography, direct write tools	10	102	10^2-10^3
Environmental	Nanofiltration, membranes	10	102	10^3-10^4

Source: RS/RAE. 2004. *Nanoscience and nanotechnologies: Opportunities and uncertainties*, The Royal Society and The Royal Academy of Engineering, London, UK. Table 4.1. Available at: http://www.nanotec.org.uk/finalReport.htm

Note: Estimated global production rates for various nanomaterials and devices are based on international chemical journals and reviews and market research.

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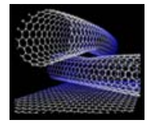
The Case of Carbon Nanotubes



Uses: sporting goods, conductive composites, batteries, fuel cells, solar cells, field emission displays, biomedical uses, fibers/fabrics, sensors.

27 firms producing carbon nanotubes globally. Production concentrated in the U.S. and Japan but shifting to Korea and China.

108 metric tons produced in year 2004
>1000 metric tons annual production estimated within five years

End-of-life issues (incineration, land-filling, recycling) unresolved

From: "Analysis of Nanotechnology from an Industrial Ecology Perspective," Deanna Lekas, Yale School of Forestry and Environmental Studies, 2005.

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Carbon Nanotube Production Inputs

Inputs for Chemical Vapor Deposition (CVD) Production Process	**Approx. Quantities to Produce 1 kg CNT/yr**
Process gases:	
Acetylene	708 L
Ammonia	708 L
Methane	708 L
Hydrogen	708 L
Ceramic catalyst support particles	170 g
Iron, cobalt, and nickel compounds	80 g
Acid bath (e.g., hydrochloric, nitric, hydrofluoric)	0.67 L

Note: Inputs from one CNT manufacturer using the CVD production process.

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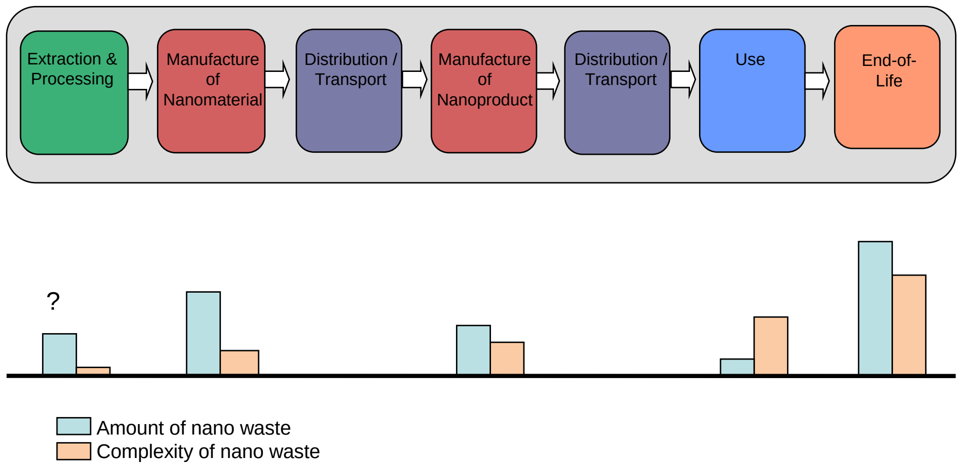
Waste and the Nanotech Life Cycle



"The potential benefits of nanotechnologies should be assessed in terms of life cycle assessment (LCA)." UK Royal Society (2004), *Nanoscience and nanotechnologies: opportunities and uncertainties.*

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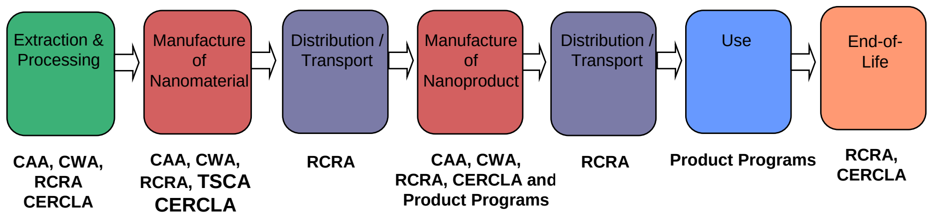
Add photos

Regulations Across the Life Cycle



CAA = Clean Air Act
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act
CWA = Clean Water Act
FIFRA = Federal Insecticide, Fungicide, and Rodenticide Act
RCRA = Resource, Conservation and Recovery Act
TSCA = Toxic Substances Control Act
Product Programs in this context refer to FIFRA, TSCA, and CAA §211.

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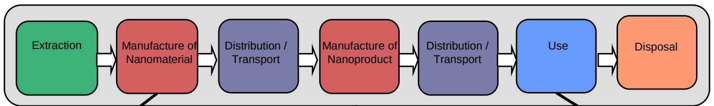
NGO Activities



Protest at Molecular Foundry opening, Lawrence Berkeley National Lab

NANO Risk Framework

Environmental Defense

(with DuPont)

http://www.nanoriskframework.org

NRDC: Supermodel Angela Lindvall talks nanotechnology

http://www.itsyournature.org/video/Tips/183

THONG: Protesting Nanotex outside Bauer,

http://www.treehugger.com/files/2005/05/nano

ETC Group: Nano-Hazard Symbol Competition

http://www.etcgroup.org/en/materials/publications.html?pub_id=604

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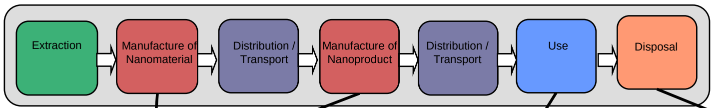
Public Perception Concerns



"What is going to be the long-term effect?

"Industry can deliver better products, like better paints. But what about the guy who is making the paint, or spraying it?"

"We're gonna be killed or cured."

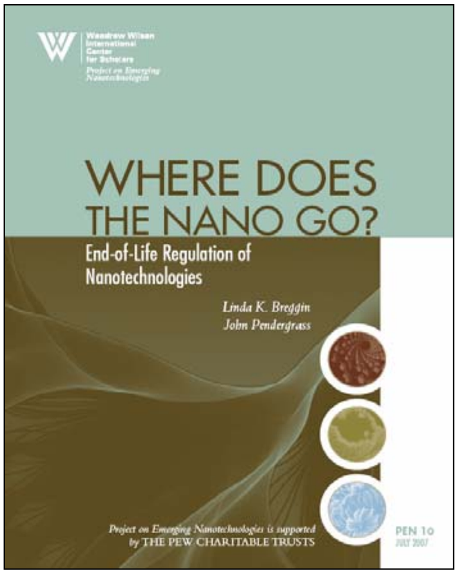
"Are there labels?"

"It's so small, it can wind up in places you don't expect it… that's a worry – it getting in unintended places and having unintended consequences."

"What happens if they don't break down? How do we get rid of them?"

"It's like nuclear power. It's a great concept, but what do you do with the waste products?"

Quotes from: Macoubrie, Jane. (2005) "Informed Public Perceptions of Nanotechnology and Trust in Government," January.
and Francesconi, Robert. (2005) "Facilitator's Report of Findings: Nanotechnology Experimental Issue Groups," July.



Available at: http://www.nanotechproject.org/132/where-does-the-nano-go-new-report-on-end-of-life-regulation-of-nanotechnologies

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CERCLA

Key objectives:

• Clean up inactive and abandoned hazardous waste sites;

• Create incentives for proper future handling of hazardous substances.

• Addresses contamination the system failed to address prospectively.

Could the Superfund Statute Apply to Nanomaterials?

Four Key Questions

- Is there a **hazardous substance** (or pollutant or contaminant)?
- Is there a **release** or substantial threat of release?
- Is the release from a **facility**?
- Is the release into the **environment**?

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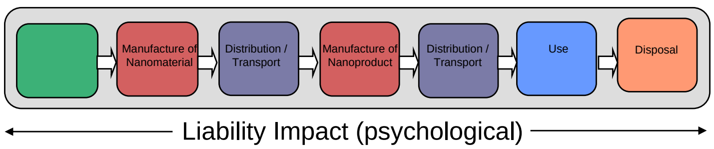
Nanomaterials and CERCLA Liability

Liability is **retroactive, strict, and joint and several** for wide range of parties, including:

- site owners/operators, generators, and transporters; and
- covers federal facilities.

Statutory liability approach could:

- provide authority to require cleanups, if nanomaterials are determined at a later date to be hazardous substances;
- may influence firm behavior today with respect to handling and disposal of nanomaterials.



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Conclusions

- Virtually all of the Superfund **statutory** authorities are broad enough in theory to cover nanomaterials.
- Key threshold issue is whether any nanomaterials are or will constitute hazardous substances.
- Highlights importance of how EPA assesses and designates nanomaterials under CERCLA and other statutes.
- Emphasizes critical need for EPA to invest in and encourage human health and eco- toxicity data collection and development.

Inclusion of Nanomaterials in Tox Testing

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Agency for Toxic Substances and Disease Registry [ATSDR–235]
Proposed Substances To Be Evaluated for Set 22 Toxicological Profiles

		CAS Number
68	TRICHLOROETHANE	025323–89–1
69	HEXACHLOROCYCLOPENTADIENE	000077–47–4
70	1,2-DIPHENYLHYDRAZINE	000122–66–7
71	**NANOMATERIALS**	**????**
72	VANADIUM	007440–62–2
73	FORMALDEHYDE	000050–00–0

Federal Register / Vol. 72, No. 206 / Thursday, October 25, 2007 / Notices

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Minimize Risks with LCA and DfE

Large Potential Benefits, Minimal Downsides

Dark Green: Nanotechnology is applied directly to solve environmental problems.

Light Green: Nanotechnology provides environmental benefits for other applications.

Right Green: Nano-based processes and products are designed to be environmentally low-impact.

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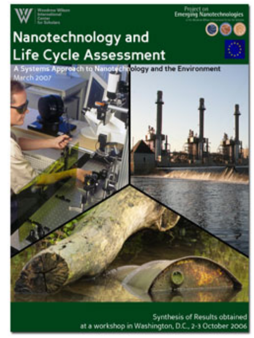
Nano LCA



- Convened in **October 2006** by:
- The European Commission's Nano & Converging Science and Technologies Unit
- EPA's Office of Research & Development, and
- The Project on Emerging Nanotechnologies
- Involved international LCA and nano experts
- **Purpose:** determine whether existing LCA tools and methods are adequate to use on a new technology
- **Key Conclusions:**
- **Use a case-study approach**
- **Do not wait to have near-perfect data (won't exist anyway).**
- **Be modest and open about uncertainties.**
- **Use a critical and independent review to ensure credibility.**
- **Build the knowledge base with an international inventory of evolving nano LCA's.**
- **Use the LCA results to improve the design of products and processes.**
- **Promote best practices and successes.**

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For More Information

www.nanotechproject.org

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Email: david.rejeski@wilsoncenter.org

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Overview of ORD Draft Nanotechnology Research Strategy (NRS)

Office of Research and Development

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OUTLINE

- Briefing Purpose
- Nanotechnology Research Strategy (NRS)
  - Background
  - Rationale
  - Key Themes and Questions
  - Anticipated results
- Path Forward – Next Steps
- Writing Team

Briefing Purpose

- Explain EPA Office of Research and Development (ORD) draft NRS (relationship to the EPA White Paper and the Nanotechnology Environmental and Health Implications Workgroup Report (under NNI)

- Stimulate discussion on increased collaboration and linkage of research products

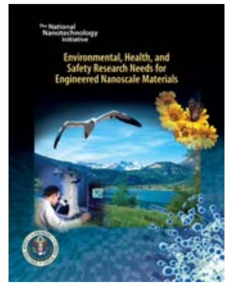
United States Environmental Protection Agency

Purpose of 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

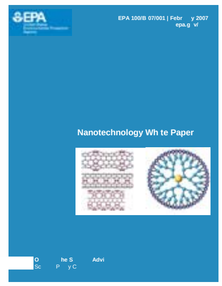
Rationale

Nanotechnology Environmental and Health Implications (NEHI) Interagency Working Group of NSET, (NSTC, 2006)



http://www.nano.gov/NNI_EHS_research_needs.pdf

EPA White Paper on Nanotechnology (EPA, 2007)



http://www.epa.gov/OSA/pdfs/nanotech/epa-nanotechnology-whitepaper-0207.pdf

National Collaboration Activities

- Joint RFAs – DOE, NIEHS/NIH, NIOSH, and NSF
- Research project collaborations with NTP
- National research strategy collaborations with CPSC, FDA, NIEHS
- International research strategy collaborations with EC, Singapore

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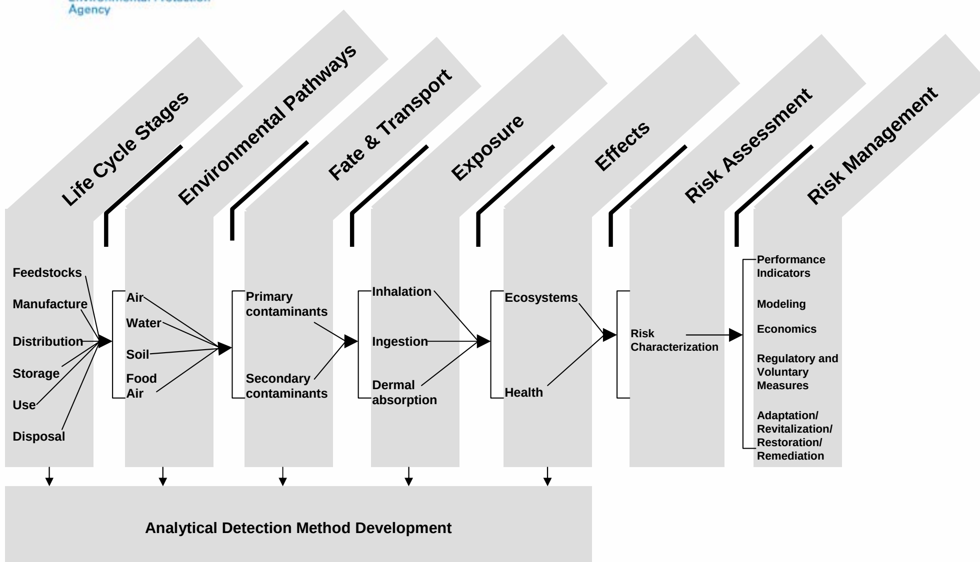
International Collaboration Activities

- Organisation for Economic Cooperation and Development (OECD), Chemicals Committee – Working Party on Manufactured Nanomaterials (WPMN)
- International Meetings – Applications & Implications (Region 5)
- International research strategy collaborations with EC, Singapore
- ANSI, ISO & ASTM participation

Document Organization

- Introduction
- Background
- Research Strategy Overview
- Research Themes – for each science question:
  - Background/Program Relevance
  - Research Activities
  - Anticipated Outcomes
- Implementation and Research Linkages
- Appendix A – side by side table of White Paper research needs versus ORD research plans
- Appendix B – ORD Description



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Office of Research and Development

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

Theme 1: Sources, Fate, Transport, and Exposure

Key Science Questions (Two of Four)

- Which nanomaterials have a high potential for release from a life-cycle perspective?
- What technologies exist, can be modified, or must be developed to detect and quantify engineered materials in environmental media and biological samples?

United States Environmental Protection Agency

Life Cycle Anticipated Outcomes

- Collaborative effort to identify industries, processes, and products which have relatively high potential to release engineered nanomaterials into the environment
- Determine the industries of importance and identify where gaps in information preclude a full assessment of emission/release points of concern
- Produce a systematic assessment of the production, use, and ultimate fate of nanomaterials to understand the potential for emissions/releases into the environment
- Understand which industries pose the greatest potential to emit/release nanomaterials of concern and to inform decision-makers about the overall impact of engineered nanomaterials
- Conduct assessments for the highest priority industry categories, results of which will be used to guide industry and nanomaterial selection for assessment.
- Produce comparative assessments to inform decision-makers at what stage in the lifecycle of engineered nanomaterials interventions could be used to avoid future environmental impacts.

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Detection – Anticipated Outcomes

- Establishment of research partnerships with NIST, NCI and/or DOE for the purpose of characterizing nanomaterials for laboratory studies
- Development of analytical methods for the detection of carbon-based nanomaterials in environmental matrices
- Development of analytical methods for the detection of non-carbon-based nanomaterials in environmental matrices
- In cooperation with other federal agencies develop standardized reference materials in a variety of representative environmental matrices.

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Theme 1: Sources, Fate, Transport, and Exposure

- What are the major processes that govern the environmental fate of engineered nanomaterials, and how are these related to physical and chemical properties of those materials?
- What are the indicators of exposure that will result from releases of engineered nanomaterials?

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Environmental Fate and Transport – Anticipated Outcomes

- Develop a scientific understanding of the processes that govern the fate and transport of engineered nanomaterials.
- Develop a scientific understanding and measure the chemical and physical properties of engineered nanomaterials and how they influence and impact the fate and transport processes.
- Identify the exposure pathways associated with production, end-use and disposal in differing environmental matrices of engineered nanomaterials.
- Improve the scientific understanding of detection methodologies for quantifying engineered nanomaterials.
- Develop multiple predictive models for understanding and measuring the transport of engineered nanomaterials

EPA United States Environmental Protection Agency

Exposure – Anticipated Results

- Identification of the dominant exposure pathways to ecological receptors of interest
- An assessment of the applicability of the Agency's current exposure models to nanomaterials
- Identification of the physicochemical properties required to inform exposure
- Identification of indicators of exposure through the application of genomics, proteomics and metabolomics.

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Office of Research and Development

United States Environmental Protection Agency

Theme 2: Human Health and Ecological Research to Inform Risk Assessment and Test Methods

Key Science Question

- What are the effects of engineered nanomaterials on human and ecological receptors, and how can those effects be best quantified and predicted?

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Human and Ecological Effects

- Characterization of NM health and ecological effects; identification of physicochemical properties and factors that regulate NM dosimetry, fate, and toxicity
- Identification of testing methods/approaches to predict *in vivo* toxicity of NMs; characterizing molecular expression profiles that may provide biomarkers of NM exposure and/or toxicity
- Provide the necessary expertise for review of premanufacture notice applications and assess the adequacy of harmonized test guidelines from NMs to OPPTS and internationally to OECD.
- Health and ecological research will address the gap in our knowledge regarding the toxicity of nanomaterials which has impeded the ability to conduct accurate life cycle analysis.

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Office of Research and Development

Theme 3: Risk Assessment Methods and Case Studies

Key Science Question

- How do Agency risk assessment and regulatory approaches need to be amended to incorporate the special characteristics of engineered nanomaterials?

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Risk Assessment – Anticipated Outcomes

- CEA approach will be used for case studies of selected nanomaterials
- Three case studies incorporating peer consultation input will be developed in FY07 for evaluation in a workshop.
- A summary report of the workshop identifying and prioritizing research needed to support comprehensive assessment of selected nanomaterials will be developed in FY08
- Identification of special properties of nanomaterials in developing data and carrying out risk assessments.

EPA United States Environmental Protection Agency

Theme 4: Preventing and Mitigating Risks

Key Science Question

- What technologies or practices can be applied to minimize risks of engineered nanomaterials throughout their life cycle, and to use nanotechnology to minimize other risks?

EPA United States Environmental Protection Agency

Risk Mitigation – Anticipated Results

- An evaluation of the efficacy of existing pollution control approaches and technologies to manage releases of engineered nanomaterials to all media during their production.
- ORD will collaborate with industry and academia to report on opportunities to reduce the environmental implications of nanomaterial production by employing greener synthesis approaches
- ORD will identify design production processes that are sustainable, minimize or eliminate any emissions/releases, and reduce energy consumption during the manufacturing of nanomaterials and products
- ORD will report on the viability and performance on the use of nanotechnology for the abatement and remediation of conventional toxic pollution.

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Anticipated Outcomes and Next Steps

- Focused research projects to address risk assessment and management needs for nanomaterials in support of the various environmental statues for which the EPA is responsible
- Currently undergoing Agency-wide review
- Planned Federal agency (NSET) review
- External peer review – December 2007

United States Environmental Protection Agency

Writing Team

Nora Savage, Co-Lead
Randy Wentsel, Co-lead

Michele Aston, NERL
J. Michael Davis, NCEA
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Kevin Dreher, NHEERL
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