Nanotechnology

Opportunities and Challenges in a Changing World

Andrew D. Maynard
Chief Science Advisor

The Pew Charitable Trusts
Nanotechnology
Science Fiction or Science Fact?

Imagine…

A material where strength is governed by atomic bonds…

… that can be woven into super-strong strands and ropes…

… and used to build an elevator to space!

Nanotechnology is turning fiction to reality…

www.liftport.com

Countdown to Lift: April 12, 2018
4891 days, 10 hours, 33 minutes, 42 seconds

Single Walled Carbon nanotubes
Nanotechnology

- **Definition**
  - Development/engineering of new devices and materials which demonstrate unique properties associated with structures on a nanometer length-scale
  - Nanometer scale: less than ~100 nm

- **Includes:**
  - Engineered nano-scale surface layers
  - Engineered nano-scale structures (discrete or heterogeneous)
  - Engineered nano-scale devices
Nanotechnology in context

Nanomaterials
- Nanoscale structures in unprocessed form
  - Carbon Nanotubes

Nanointermediates
- Intermediate products with nanoscale features
  - Multifunctional nanoparticles

Nano-enabled products
- Finished goods incorporating nanotechnology
  - Nanocomposite parts

Nanotools
- Capital equipment and software used to visualize, manipulate and model matter at the nanoscale
  - Electron Microscopy
Nanotechnology development and implementation

1st Generation
- Passive Nanostructures
  - Nanoparticles
  - Nanotubes
  - Nano-composites
  - Nano-coatings
  - Nanostructured materials

2nd Generation
- Active Nanostructures
  - Electronics
  - Sensors
  - Targeted drugs
  - Adaptive structures

3rd Generation
- Systems of nanosystems
  - Guided molecular assembly
  - 3D networking
  - Robotics
  - Supra-molecules

4th Generation
- Molecular nanosystems
  - Molecules ‘by design’
  - Hierarchical functions
  - Evolutionary systems

Adapted from Roco, MC (2004) AIChE J. 50 (5)
Nanotechnology Investment and Impact
Global R&D Investment in 2004

Nanotechnology Investment and Impact
Global forecast of products sold incorporating nanotechnology

Nanotechnology is ‘Now’
Selected consumer products

- **Nanosilica Composite**
- **Carbon Nanotube Composite**
- **Nanoclay Composite**

**Easton CNT is Real Nanotechnology**

Easton has an eighty-three year history of leading the market by developing new materials and innovative products. Easton has been manufacturing sporting goods using carbon-fiber composites since 1980 and has been the leading brand of composite bicycle frames since their introduction in 1985.

New Easton’s research and development team is proud to present a revolutionary breakthrough in composite materials and manufacturing.

**The Next Frontier**

Nanotechnology is the next frontier in scientific research and advanced manufacturing. Nanotechnology deals with the manipulation of materials on an atomic or molecular scale measured in billions of a meter (nanometer). Scientists worldwide are spending countless man-hours and billions of dollars researching uses for nanotechnology in the areas of electronics, medicine, robotics and structural reinforcement.

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It’s good to be king!

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Woodrow Wilson Center, Project on Emerging Nanotechnologies
Sustainability
Nanotechnology and risk

• Nanotechnology - The Motivation
  • Purposely engineered nanostructured materials and devices demonstrate new, unique and non-scalable properties and behavior

• Sustainable Nanotechnology - The Challenge
  • Does the nature of engineered nanostructured materials and devices present new health and environmental risks?
  • How can the benefits of nanotechnology be realized while proactively minimizing the potential risk?
  • How can public trust in the technology be maintained?
Nanotechnology in Poplar Culture

Over 20 science fiction novels since 1982, including Michael Crichton’s *Prey*

Variety of films including Spiderman II

Product branding

Public protests

Console video games

Nanobreaker for PSII

iPod Nano
Public Perceptions
Macoubrie, September 2005

- 80 - 85% of public has heard “little” or “nothing” about nanotechnology
- Perceived benefits outweigh risks
- Top perceived potential benefits include:
  - Disease detection and treatment
  - Environmental remediation
  - National Security
  - Improved human abilities
  - Cheaper, longer lasting consumer products
- Top concerns include:
  - Military uses
  - Long term health effects
  - Environmental impacts
  - Loss of freedom and privacy
- Low trust in both government and industry to manage risk

From: Macoubrie, J. “Nanotechnology: Public Concerns, Reasoning, and Trust in Government”
Potential Impact of Nanotechnology
Concerns

Industry and government regulators maintain that the unique size and properties of nanoscale materials do not warrant a closer look at the potential health, safety and environmental impacts. In this Occasional Paper, ETC Group explains why size matters!

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Nanomaterial safety - challenging assumptions

Handling unprocessed single walled nanotube material
Potential Health Impact
What makes ‘nano’ different?
Unanticipated exposure routes…
Translocation to the brain following inhalation in rodents

![Graph showing translocation of nanoparticles to various organs](image)

- **Cerebellum**
- **Cerebrum**
- **Lung**
- **Olfactory bulb**

**Significant data point**


Woodrow Wilson Center, Project on Emerging Nanotechnologies
Nanomaterials in the environment
Routes of exposure, uptake, distribution and degradation

Oberdörster et al. (2005) EHP. 113(7):823-839
Life Cycle Assessment
Taking a systems approach to environmental protection
National Nanotechnology Initiative
Strategic Plan

- Goal 4: Support responsible development of nanotechnology:
  - Environmental, health and safety implications
  - Ethical, legal and all other societal issues

- Program Component Area 7: Societal Dimensions
  - Environmental, health and safety research
  - Education
  - Broad societal implications

www.nano.gov
Interagency Coordination of Activities
Nanotechnology, Environment and Health Working Group (NEHI)

- Working group of the Nanoscale Science, Engineering and Technology subcommittee (NSET)

- Membership from all relevant regulatory and research agencies, Office of Science and Technology Policy, and Office of Management and Budget

- Goals of Working Group:
  - Provide for exchange of information among agencies
  - Facilitate the identification/prioritization of research and other activities required for responsible nanotechnology
  - Promote communication of information related to the environmental and health implications of nanotechnology
# 2006 National Nanotechnology Initiative Investment

## Societal Implications

### Estimates of 2006 NNI Investments within Societal Dimensions Program Component Area

<table>
<thead>
<tr>
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<th>Environmental, Health, and Safety R&amp;D</th>
<th>Education and Ethical, Legal, and other Societal Issues</th>
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<td>NSF</td>
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<td><strong>TOTAL</strong>*</td>
<td><strong>$38.5 million</strong></td>
<td><strong>$42.6 million</strong></td>
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* Indicates total investment.
National Institute for Occupational Safety and Health
Integrated research into the health impact of carbon nanotubes

Exposure routes → Exposure → Dose → Risk → Control → Reduced risk/impact

Characterization

Health Effects

Toxicity

Exposure

Risk

Control

Shvedova, Baron, Maynard

Woodrow Wilson Center, Project on Emerging Nanotechnologies
Environmental Protection Agency

- **Focus on Nanotechnology:**
  - Potential for environmental improvement
  - Possibility for harmful effects on human health/environment
  - EPA’s regulatory responsibilities
    - Toxic Substances Control Act, Clean Air Act, Clean Water Act, Comprehensive Environmental Response, Compensation and Liability Act/Superfund

- **Science to Achieve Results program (STAR)**
  - 2004 Program: Environmental and Human Health Effects of nanomaterials
    - $7 million, joint with NSF and NIOSH
    - 18 Grants Awarded – 14 EPA, 2 – NSF, 2 – NIOSH, To be announced
  - 2005 Program: Environmental and Human Health Effects of nanomaterials. Announcement expected Fall 2005
National Science Foundation
Center for Biological and Environmental Nanotechnology - Rice University

- **Highlights:**
  - $12.4 million from NSF, $5.3 million from Rice, over 5 years
  - > 200 invited “center” presentations; > 200 accepted publications
  - Research, education, knowledge transfer, commercialization
  - First observation of carbon nanotube emission and its first application to biological imaging.
  - Near-infrared nanoparticles demonstrated to shrink tumors using photothermal therapy.
  - First publications in the area of nanotechnology and environmental impact.

![Nanotube fluorescence](image1)

![Nanoshell-heated cancer tissue](image2)

Ecotoxicology and nanocarbons
Correlating Physico-Chemical and Toxicological Properties of Nanoparticles

- Nanoparticle
  - (physico-chemical characterization: size, external surface area, BET surface area [porosity], crystallinity, chemical composition, surface charge)

- In vitro assays
  - acellular assays
  - subcellular assays
  - cellular assays
  - model testing
  - in vivo assays

- Results for model inputs
  - biocompatible

- Surface modification
  - solubility
  - protein binding
  - cytoskeletal function
  - metabolic effects
  - oxidative stress
  - cytotoxicity

Oberdörster, Pui and Biswas
University of Rochester, University of Minnesota, Washington University St. Louis
Sustainable Nanotechnology
Global initiatives

- Europe
- Asia
- USA

Partnerships
- Academia
- Industry
- Non-Government Organizations
Project on Emerging Nanotechnologies
About the Woodrow Wilson International Center for Scholars

• Living memorial to Former President Wilson established by Congress in 1968
• Non-partisan institution, supported by public and private funds
• A lively, neutral, domestic and international forum for free and informed dialogue
• Integrated into the Smithsonian Institute
• 200 staff, fellows, and scholars
• Annual budget of $30m
• Directed by Former US Congressman Lee Hamilton
Project on Emerging Nanotechnologies

- **Goal**
  - Ensure government and private sector address the risks as well as the benefits of nanotechnology

- **Budget**
  - $3 million over 2 years

- **Programs**
  - Meetings, research, polling, outreach

Created in partnership with the Pew Charitable Trusts
Project on Emerging Nanotechnologies
Current activities include…

- Database of federally funded research on environmental, safety and health implications
  - Providing an overview of research focuses and gaps

- Review of airborne nanomaterial exposure measurement requirements
  - Evaluating current capabilities and research/development needs

- Use of gene arrays in ecotoxicity screening
  - Developing rapid, cost-effective screening assays for early detection of potential issues

- Facilitating domestic and international partnerships
Looking to the Future
Successful implementation of sustainable nanotechnologies

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Summary

- Nanotechnology is a revolutionary technology
- Significant societal and economic benefits are anticipated
- Conventional risk management models are being challenged
- Successful development and implementation of nanotechnology will require an integrated approach to risk
- Global, interdisciplinary and cross-sector partnerships are essential to developing sustainable nanotechnologies
Contact Information

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