



# The National Nanotechnology Initiative: Status and Directions

NIBIB-DOE Workshop on Biomedical Applications of  
Nanotechnology

Bethesda, Maryland  
March 17, 2005

*Clayton Teague*

*Director*

*National Nanotechnology Coordination Office*

*National Science and Technology Council*

*Subcommittee on Nanoscale Science, Engineering, and Technology*



# Outline of Talk

- **What is nanotechnology?**
- **What is the National Nanotechnology Initiative (NNI)?**
- **The NNI Strategic Plan**
- **NNI efforts to address environment, health, and safety implications of nanotechnology - engineered nanomaterials**
- **Concluding remarks**



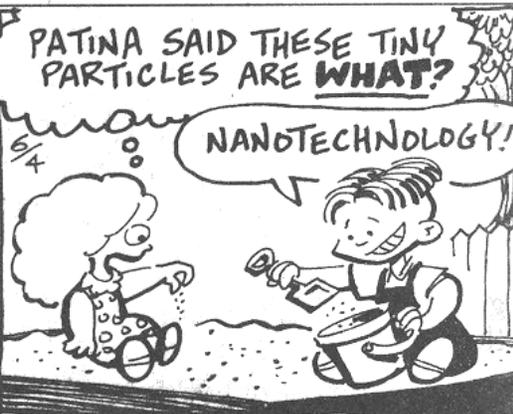
# DILBERT<sup>®</sup>

BY  
SCOTT ADAMS



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## ON THE FASTRACK BILL HOLBROOK

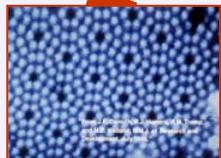


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# Nanotechnology Development

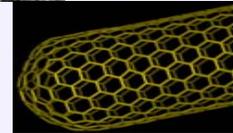
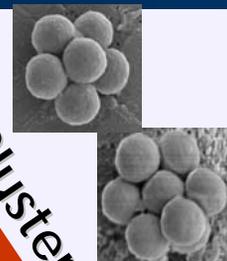


"Seeing"/Visualizing

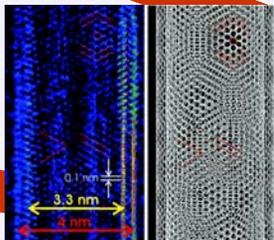
Supra Molecular Chemistry



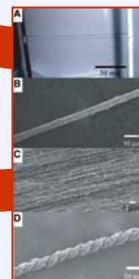
Atom Clusters S&T



Measuring



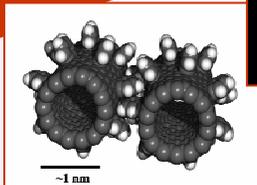
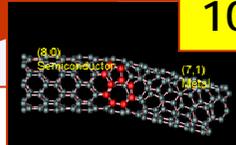
Manipulating/Controlling



Simulating/Modeling

2004 - 50,000 atoms  
100 nm long nanotube

1995 - 5000 atoms

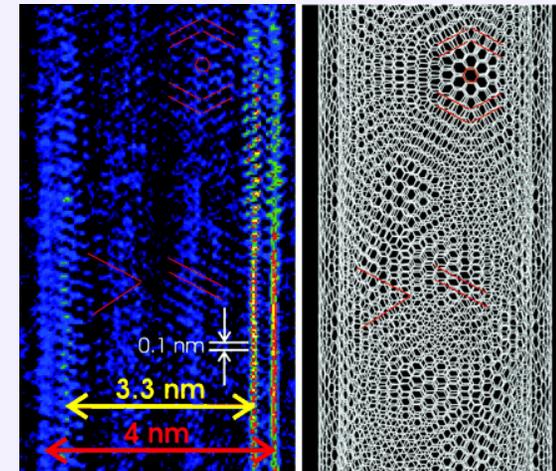


Biotechnology

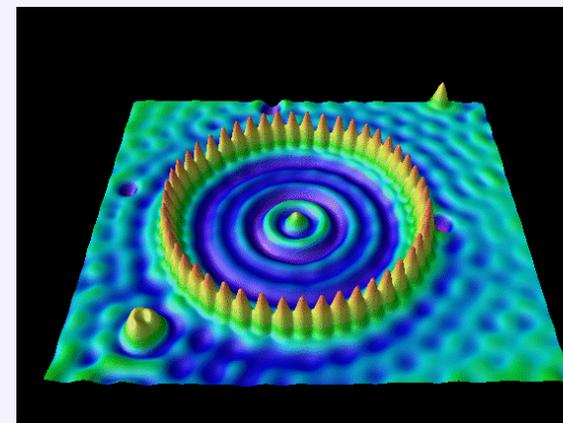
1968 - H<sub>2</sub>O

# What Is Nanotechnology?

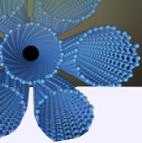
- ❖ Research and technology development aimed to understand and control matter at dimensions of approximately 1 - 100 nanometer - the nanoscale
- ❖ Ability to understand, create, and use structures, devices and systems that have fundamentally new properties and functions because of their nanoscale structure
- ❖ Ability to image, measure, model, and manipulate matter on the nanoscale to exploit those properties and functions
- ❖ Ability to integrate those properties and functions into systems spanning from nano- to macro-scopic scales



Nanoarea Electron Diffraction of DW Carbon Nanotube – Zuo, et.al



Corral of Fe Atoms – D. Eigler



# Nanotechnology is 'Now'

## Selected consumer products

### Nanoclay Composite



## Easton CNT is Real Nanotechnology

**The Buckey Ball**  
 Discovered in the eighties, the Buckey Ball derives its name from noted architect Buckminster Fuller. Sixty carbon atoms, each sharing covalent bonds with three other carbon atoms, is similar to the structure of the carbon nanotube.

**The Carbon Nanotube (CNT)**  
 A carbon nanotube is a structure one billionth of a meter

**Easton's Tiny Innovation is Huge**  
 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 1989 and has been the leading brand of composite bicycle handlebars since their introduction in 1991. Now Easton's research and development team is proud to announce a breakthrough in composite materials and manufacturing.

**The Next Frontier**  
 Nanotechnology is the next frontier in scientific research and manufacturing. Nanotechnology deals with the manipulation of matter on the atomic or molecular scale measured in billionths of a meter (nanometers). Worldwide, billions of dollars are being spent on nanotechnology research and development. Billions of dollars worldwide are spending countless man-hours and billions of dollars are being spent on nanotechnology in the areas of electronics, medicine, and structural reinforcement.

**Enhanced Resin System™**

### Carbon Nanotube Composite

**NANotex™ Fabric**

resists **SPILLS**

...if you've spilled an iced latte in your lap, but you don't mind. Spills made with NANO-TEX™ spill-resistant fabric, wipe up and roll right off.

...like conventional fabric, NANO-TEX™ fabric has never been seen before. NANO-TEX™ fabric builds on the strength of the very fibers that make it so soft, and it's what they should be.

...fabric, you're looking good. NANO-TEX™ fabric applications roll away like water. Experience the breakthrough and be the next.

### Filtek™ Supreme Universal Restorative

Say goodbye to microfills and hybrids with our revolutionary new nanocomposite based restorative.

**It's good to be king!**

**3M ESPE**

### Nanosilica Composite

### Nano fibers



# What is the NNI?

- ❖ The National Nanotechnology Initiative coordinates research and development activities in nanoscale science, engineering, and technology – or nanotechnology – across the Federal Government.
- ❖ When the NNI was established in 2001, six agencies were investing in nanotechnology R&D. The total Federal investment was \$464 million.
- ❖ For FY 2005, estimated R&D funding totals over \$1 billion across 11 agencies; 12 additional participating agencies
- ❖ The organization and strategy laid out in FY 2001 has effectively shaped and guided the initiative over its first four years. A new strategic plan has just been released which will guide the agencies through the next five to ten years.

# How is the Government Investing \$1B NNI Funding?

\$1,082 Million is FY2005 Estimated NNI Funding



NSF - 338

DOD - 257

DOE - 210

HHS - 146

NIST - 75

NASA - 45

EPA - 5

USDA - 3

DOJ - 2

DHS - 1

Academia

~65 %

Single and Multiple  
Investigators

Centers and User  
Facilities

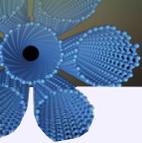
Government  
Intramural

~25%

NRL, AFRL, ARL NIH,  
NASA, NIST, EPA, FDA,  
DOE Nat Labs

Industry ~10%

SBIR, STTR, ATP,  
DOD Contracts

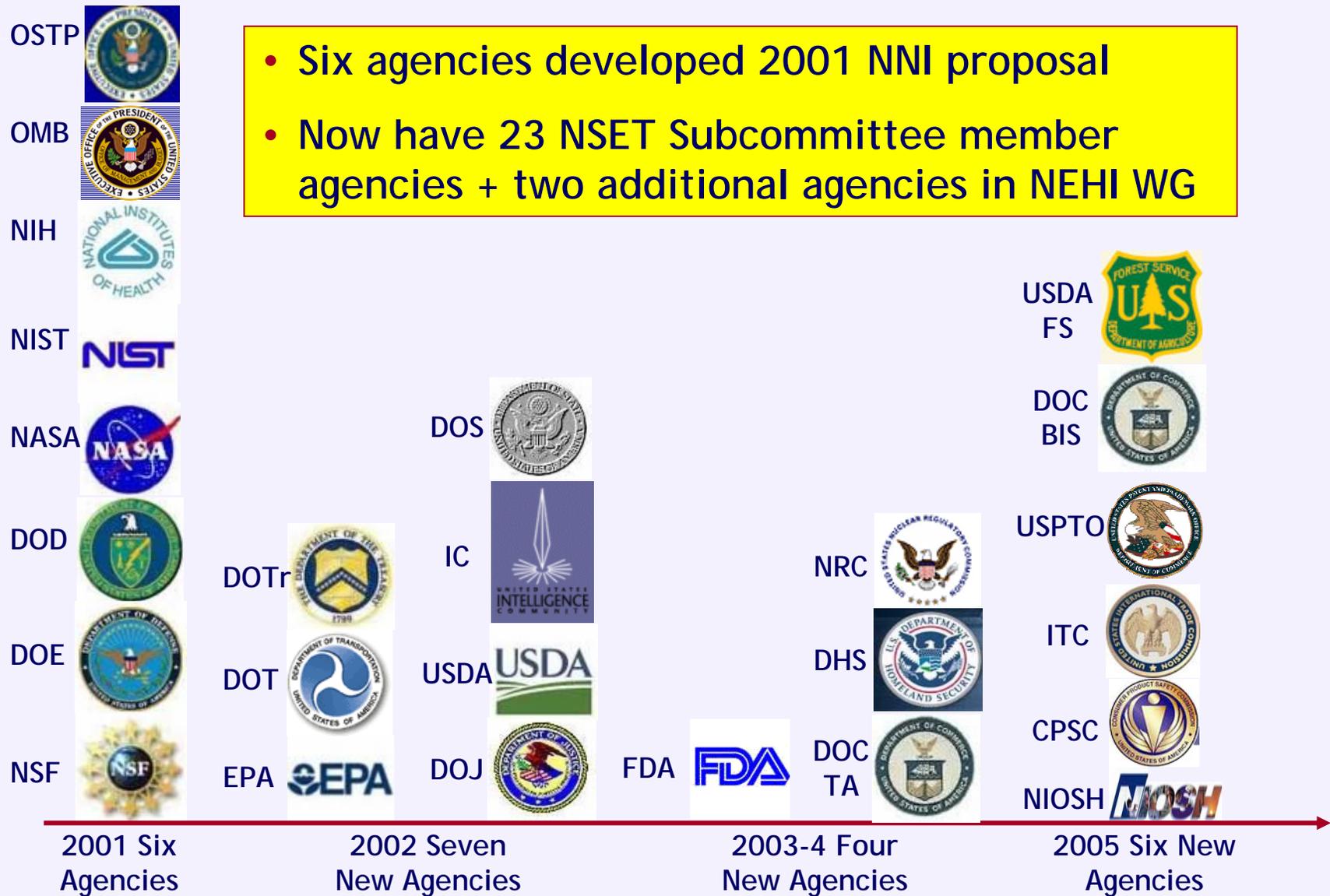


# Organization & Management of the NNI

- ❖ The National Science and Technology Council (NSTC) is a cabinet-level council which coordinates science, space, and technology policies across the Federal Government on behalf of the President.
- ❖ Planning, coordination, and implementation of the National Nanotechnology Initiative is the responsibility of the Nanoscale Science, Engineering, and Technology Subcommittee (NSET) of the NSTC's Committee on Technology.
- ❖ The National Nanotechnology Coordination Office (NNCO) supports the interagency coordination activities of the NSET. The NNCO provides technical and administrative support to the NSET Subcommittee. The NNCO is also chartered to serve as the point of contact on Federal nanotechnology activities, conduct public outreach, and promote transfer of the results of Federal nanotechnology R&D for commercial use and public benefit.

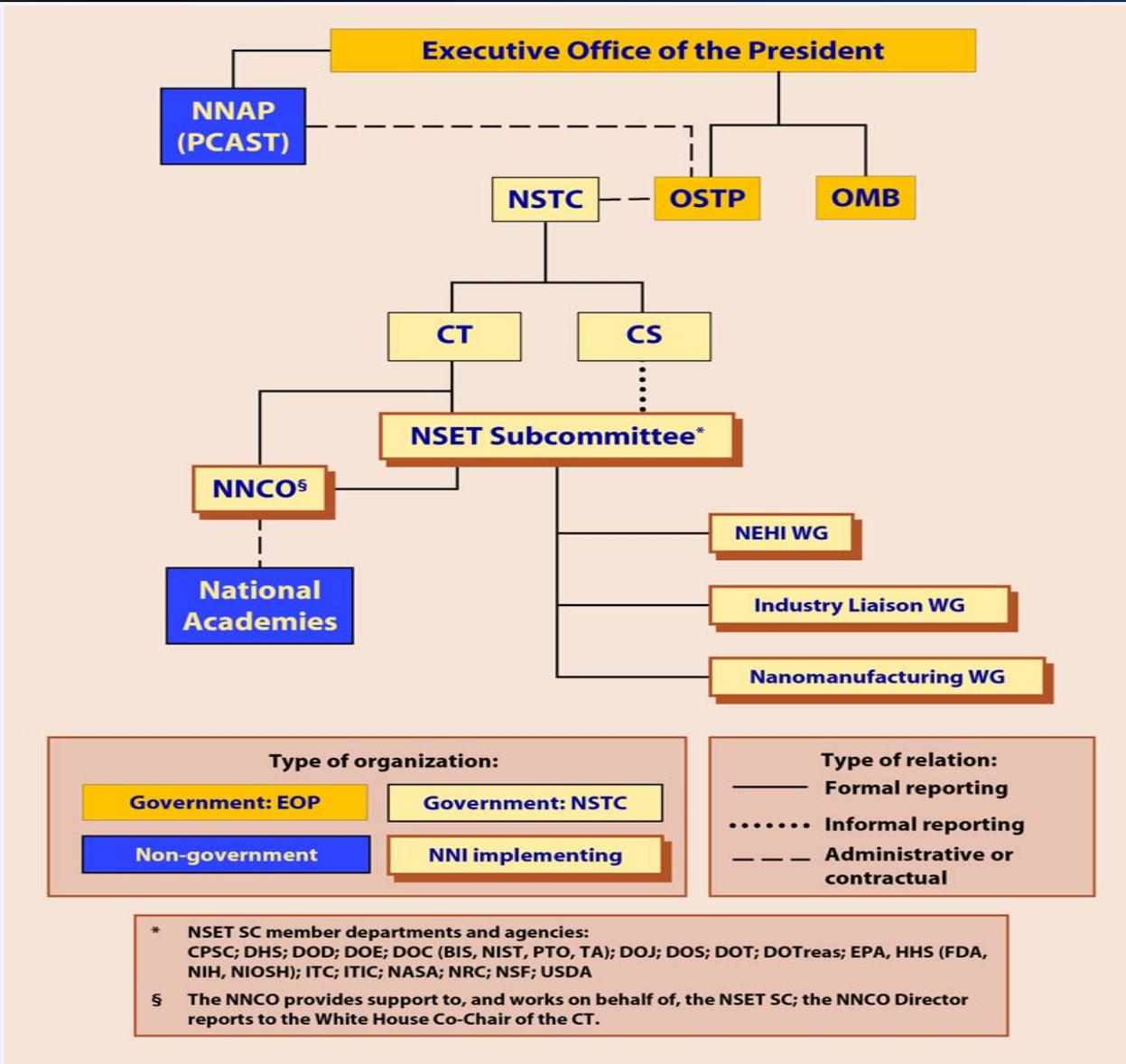
# Growth of NSET Subcommittee

- Six agencies developed 2001 NNI proposal
- Now have 23 NSET Subcommittee member agencies + two additional agencies in NEHI WG





# NNI Organization



**Type of organization:**

Government: EOP

Government: NSTC

Non-government

NNI implementing

**Type of relation:**

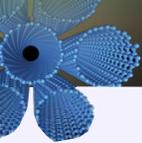
—— Formal reporting

..... Informal reporting

--- Administrative or contractual

\* NSET SC member departments and agencies:  
CPSC; DHS; DOD; DOE; DOC (BIS, NIST, PTO, TA); DOJ; DOS; DOT; DOTreas; EPA, HHS (FDA, NIH, NIOSH); ITC; ITIC; NASA; NRC; NSF; USDA

§ The NNCO provides support to, and works on behalf of, the NSET SC; the NNCO Director reports to the White House Co-Chair of the CT.



# The NNI Vision: A Revolution in Technology & Industry

*The vision of the National Nanotechnology Initiative is a future in which the ability to understand and control matter on the nanoscale leads to a revolution in technology and industry.*

*Toward this vision, the NNI will expedite the discovery, development, and deployment of nanotechnology in order:*

*to achieve responsible and sustainable economic benefit,  
to enhance the quality of life, and  
to promote national security.*

*In the process, the NNI:*

*will support the missions of the participating agencies,  
will ensure continuing leadership by the United States in  
nanoscale science, engineering, and technology, and  
will contribute to the nation's economic competitiveness*

# Four Goals of the NNI

**Maintain a world-class research and development program aimed at realizing the full potential of nanotechnology**

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

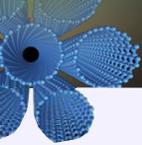
**Develop educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology**

**Support responsible development of nanotechnology**

# NNI Program Component Areas

The 21<sup>st</sup> Century Nanotechnology Research and Development Act, passed by Congress and signed by the President in December 2003, requires that the participating NNI agencies report their nanotechnology activities by major subject areas. The December 2004 NNI Strategic Plan defines seven Program Component Areas, each an area where federal investment is essential to achieving the goals of the NNI

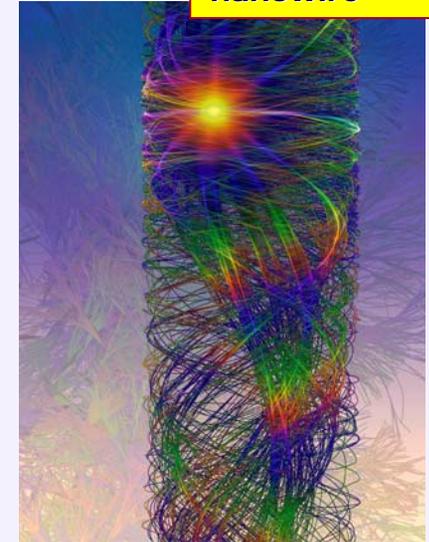
- 1) Fundamental Nanoscale Phenomena and Processes
- 2) Nanomaterials
- 3) Nanoscale Devices and Systems
- 4) Instrumentation Research, Metrology, and Standards for Nanotechnology
- 5) Nanomanufacturing
- 6) Major Research Facilities and Instrumentation Acquisition
- 7) Societal Dimensions



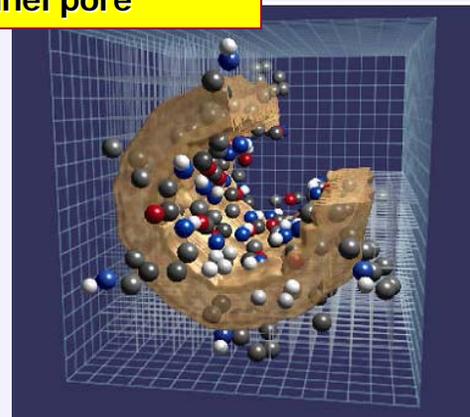
# Fundamental Nanoscale Phenomena & Processes

- Electron transport, magnetism, optical properties, thermal properties, ....
- Theory, modeling, and simulation
- Self-assembly
- Organic/Inorganic interface (wet/dry)
- Biosystems

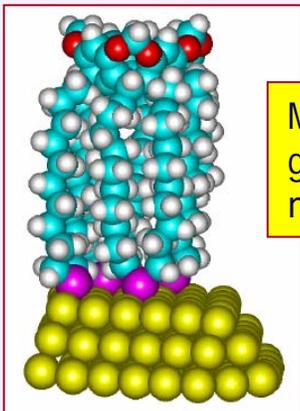
Electron flow in nanowire



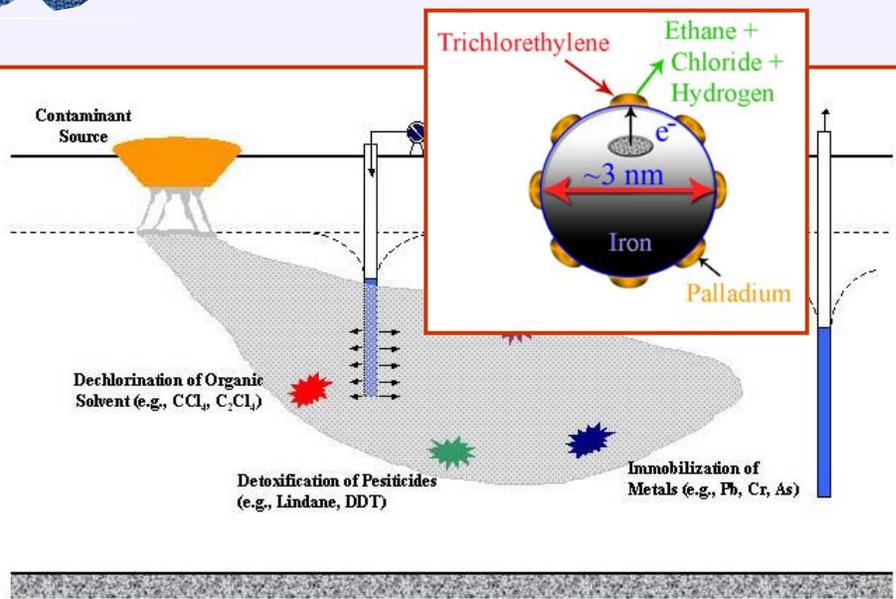
Simulation of biological ion-channel pore



Macromolecule on gold substrate for molecular recognition

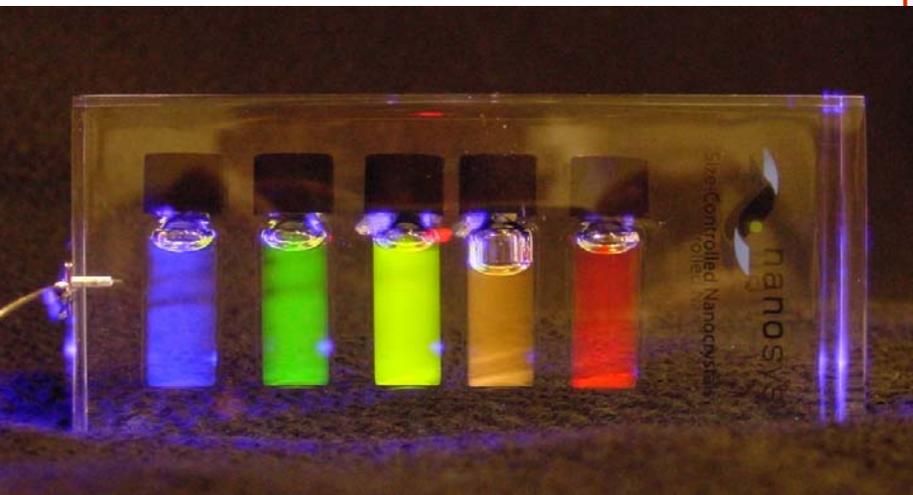


# Nanomaterials



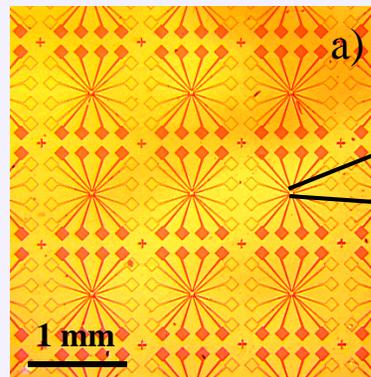
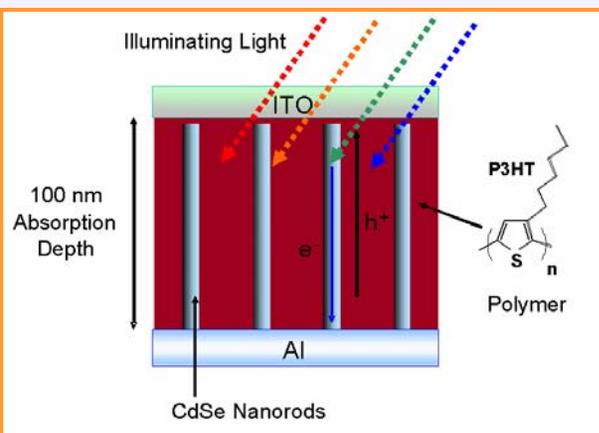
Small size  $\rightarrow$  high ratio of surface area to volume.

For example, 5 ccs of material divided into 1 nanometer cubes and spread in a single layer can cover a football field

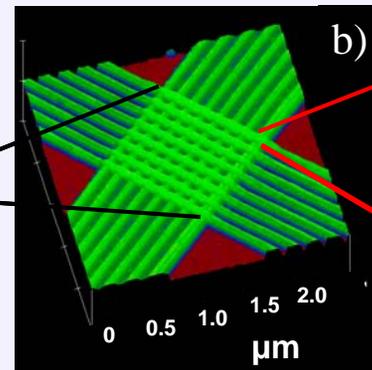


# Nanoscale Devices and Systems

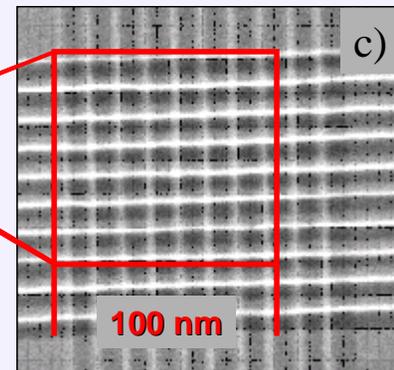
Produce high efficiency, inexpensive solar cells. Layers of cells with nanorods tuned to absorb different colors of solar spectrum



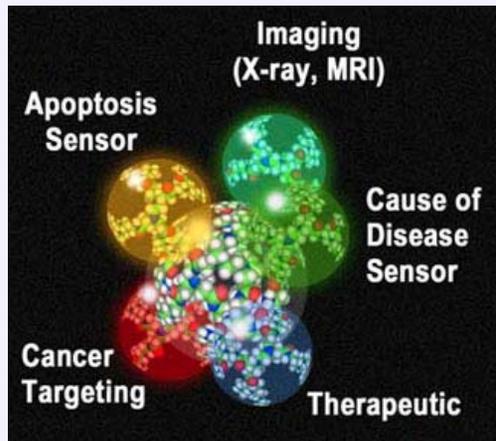
Optical micrograph of an array of 64-bit molecular electronic circuits (courtesy J. Heath, Caltech; partner HP)



Atomic force micrograph revealing a single 64 bit circuit ( $7 \times 10^9$  bits/cm<sup>2</sup>) used for simultaneous logic and memory operations



Electron micrograph of a 100 bit circuit at  $5 \times 10^{11}$  bits/cm<sup>2</sup>. The highlighted 64 bits of this ultra-dense circuit fits inside a single bit of the circuit shown left



Artist's rendition of "smart therapeutic biomedical device" - Tecto-dendrimer

UMich Center for Biologic Nanotechnology

# Instrumentation, Metrology, and Standards

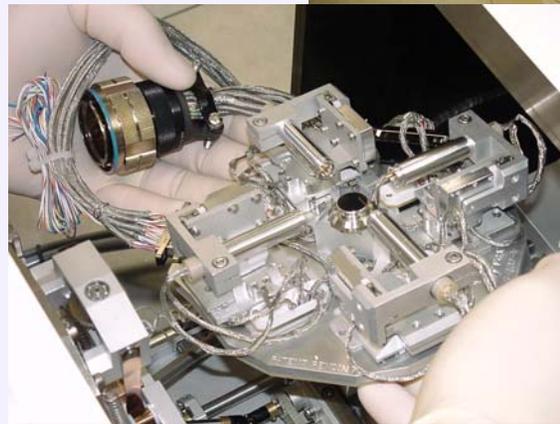
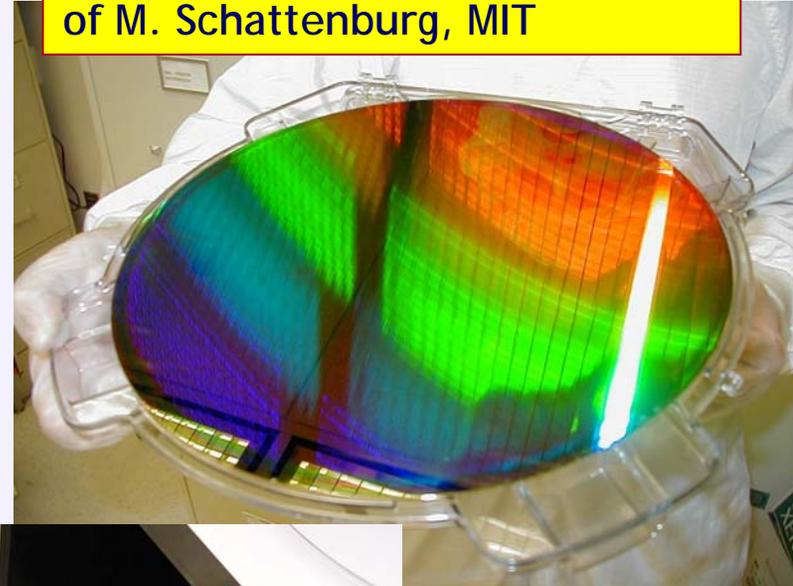
Nanotechnology Standards Panel of the American National Standards Institute (ANSI-NSP) Releases Priority Recommendations Related to Nanotechnology Standardization Needs

- General terminology and nomenclature - definition of the term "nano," to particle size and shape,
- Metrology and characterization
- Environment, health, and safety

The ANSI-NSP serves as the cross-sector coordinating body for standards in the area of nanotechnology and provides the forum within which stakeholders can work cooperatively to promote, accelerate, and coordinate the timely development of useful voluntary consensus standards.



UV diffraction grating - courtesy of M. Schattenburg, MIT

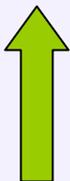
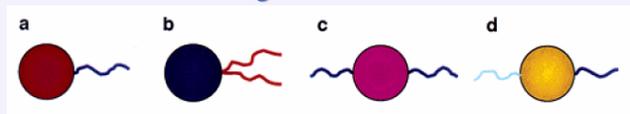


Nanomanipulator - Courtesy of Zyvex Corporation

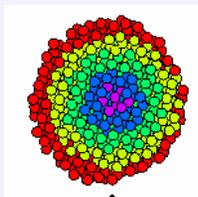


# Nanomanufacturing

## A possible route to self-assembly based manufacturing



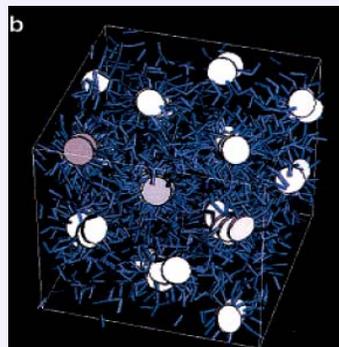
Attach oligomeric, polymeric, or biomolecular tethers



Form nanospheres, nanorods, ...

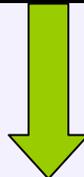


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Li	Be											B	C	N	O	F	Ne																														
Na	Mg											Al	Si	P	S	Cl	Ar																														
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr																														
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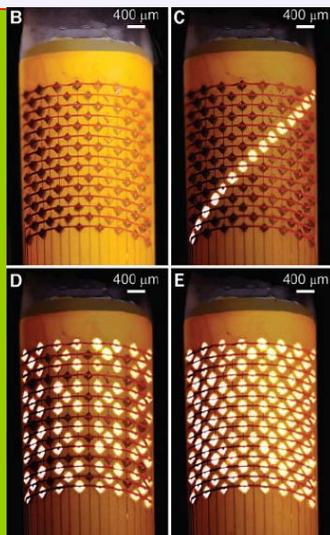
Directed self-assembly of building blocks

From S. Glotzer group at U. of Michigan



Scaffolds and structures for:

- Catalysis
- Hydrogen storage
- Fuel cells
- Tissue engineering
- Drug delivery
- Electronics



Increasing scale of self-assembly of building blocks directed by:

- Electric fields
- Structured light
- Patterned substrates
- Free-energy minimization

H.O. Jacobs, A. R. Tao, A.Schwartz, D. H. Gracias, G. M. Whitesides

# Major Research Facilities & Instrumentation

## NNI Centers and User Facilities

- Electron Transport in Molecular Nanostructures – *Columbia*
- Nanoscale Systems in Info. Technologies – *Cornell*
- Nanoscience in Biological & Environmental Engineering – *Rice*
- Integrated Nanopatterning & Detection – *Northwestern*
- Nanoscale Systems & Their

NSF – 17 Centers  
2 Networks  
DOD – 3 Centers  
DOE – 5 NSRCs  
NASA – 4 Centers

Extreme Ultraviolet Science and Technology – *Colorado State*  
Scalable & Integrated

- Templated Synthesis & Assembly at the Nanoscale – *U Wisconsin-Madison*
- Molecular Function at NanoBio Interface – *U Pennsylvania*
- High-Rate Nanomanufacturing – *Northeastern*
- Affordable Nanoengineering of Polymer Biomedical Devices – *Ohio State*
- Integrated Nanomechanical Systems – *UC-Berkeley*
- Probing the Nanoscale – *Stanford*
- Learning & Teaching in Nano S&E – *Northwestern*

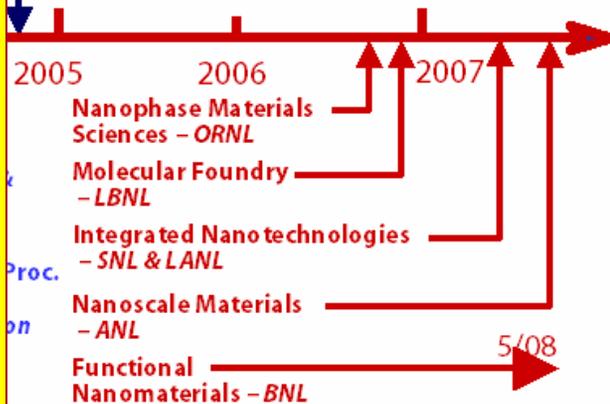
### More coming soon!

NSF has 2005 solicitations for centers in nanomanufacturing, nano and society, informal nano education

NIH has 2005 solicitations for nanomedicine development centers at NHLBI, and centers for cancer nanotechnology excellence at NCI

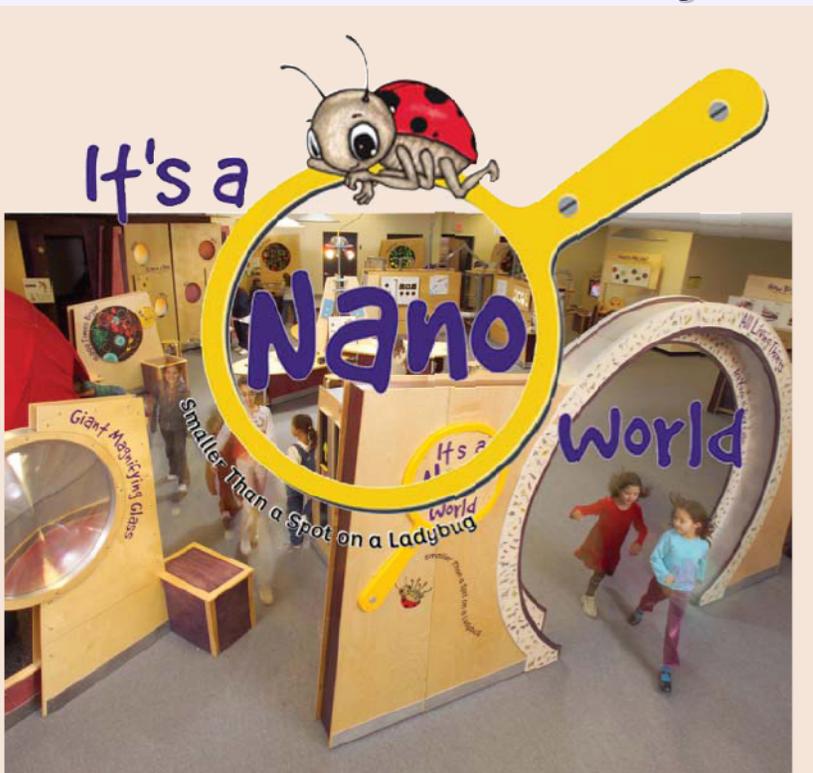
NIOSH is establishing a center of excellence for nanotechnology research

NIST bringing into operation National Nanomanufacturing and Nanofabrication Facility



# Societal Dimensions

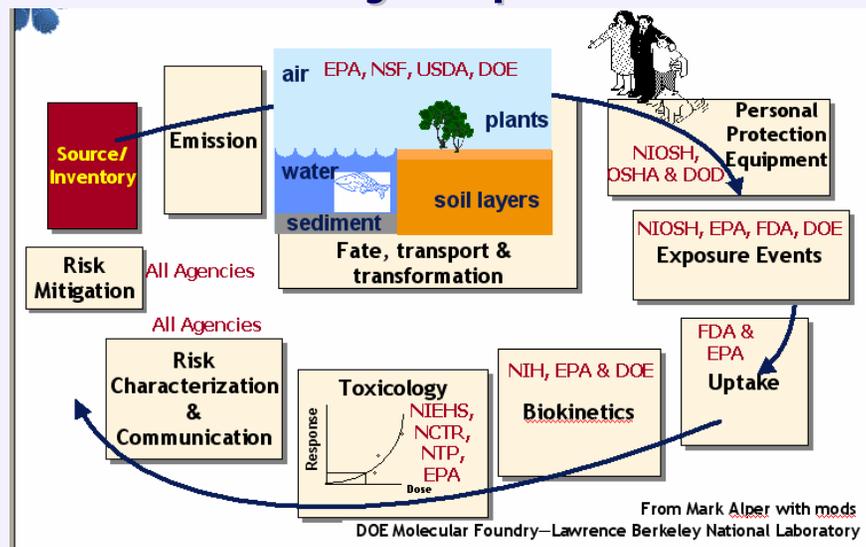
## Education, K to Gray



Courtesy Cornell University

- Ethical, Legal, and Social Issues

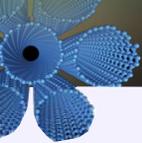
## Environmental, Health, and Safety Implications



- Economic Impacts

U.S. Dept. of Energy estimated in 2002 that nanotechnology-based solid-state lighting could cut the electricity used for illumination up to 50 percent





# Unique Properties of Nanoscale Materials

- Chemical reactivity of nanoscale materials greatly different from more macroscopic form, e.g., gold
- Vastly increased surface area per unit mass, e.g., upwards of 100 m<sup>2</sup> per gram
- Quantum effects influence mechanical, electronic, and magnetic properties of nanoscale materials
- New chemical forms of common chemical elements, e.g., fullerenes, nanotubes of carbon, titanium oxide, zinc oxide, other layered compounds

**TWO-Edged SWORD**

# Administration R&D Budget Priorities

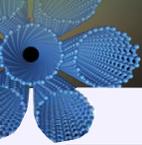
“In order to ensure that nanotechnology research leads to the **responsible development** of beneficial applications, agencies should support research on the various societal implications of the nascent technology.

In particular, agencies should **place a high priority** on research on **human health and environmental issues** related to **nanotechnology** and develop, where applicable, cross-agency approaches to the funding and execution of this research.”

*John Marburger III, Dir. OSTP*

*Joshua Bolten, Dir. OMB*

*Memorandum for Heads of Executive Departments and Agencies  
August 12, 2004*



# NNI Strategic Plan

## THE NATIONAL NANOTECHNOLOGY INITIATIVE

STRATEGIC PLAN

Developed by the Nanoscale Science, Engineering  
and Technology Subcommittee  
Committee on Technology  
National Science and Technology Council  
*December 2004*



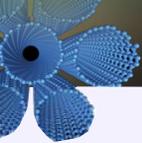
Goal 4: Support responsible development of nanotechnology:

- Environmental, health and safety implications
- Ethical, legal and other societal issues

Program Component Area 7:  
Societal Dimensions

- Environmental, health and safety research
- Education
- Broad societal implications

[www.nano.gov](http://www.nano.gov)



# Nanotechnology, Environment, Health and Safety: The Challenge

## Nanostructured materials and devices demonstrate new and unique properties and behavior

- The Environmental, Health and Safety challenge:
  - Do these properties lead to new and unique health risks ...?
  - Are current procedures, guidelines and regulations sufficiently robust to protect human health & the environment?
  
- Consequences of inaction:
  - Potential acute and chronic health and environmental impact
  - Loss of public confidence
  - Societal and economic benefits not realized



# Remarks: EHS Implications of Nanomaterials

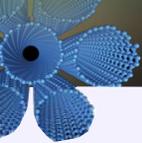
- The NNI has recognized the importance of and invested in EHS R&D since its inception
- By its nature nanotechnology EHS R&D will lag the discovery of new material properties
- NNI investment in nanotechnology EHS R&D has grown along with the investments to advance the technology
- Existing Federal regulatory mechanisms are in place for assessing and regulating workplace, environmental, and health risks of new technology materials
- Active efforts are underway to ensure that these regulatory mechanisms or appropriately amended ones provide proper coverage of nanotechnology-based materials
- Research in Federal laboratories, private industry, and academia is now in progress to determine how the nanotechnology-based materials may differ from conventional ones in their implications for public health and the environment



# Group Organized to Coordinate Nano ESH

- NSET Working Group on Nanotechnology Environment and Health Implications (NEHI WG)
- Membership from all relevant regulatory and research agencies, OSTP, and OMB
- Goals of Working Group:
  - Provide for exchange of information among agencies that support nanotechnology research and those responsible for regulation related to nanoscale materials and nanotechnology-based products
  - Identify/prioritize research needed to support regulatory decision-making and communicate those needs to the research agencies
- Convened in August 2003 by NNCO in coordination with OSTP; meeting monthly since February 2004





# Topics Being Addressed by NEHI WG

- **Nomenclature for identifying and delineating nanomaterials**
  - ANSI-Nanotechnology Standards Panel formed
  - Supporting establishment of ISO Technical Committee
  - EHS standards for nanotechnology a priority
- **Documentation of “recommended practices” for working with the nanomaterials**
  - Documentation being developed by NIOSH & OSHA
  - Q&As and “Current Intelligence Bulletin” to be forthcoming
- **Data on potential toxicity of nanomaterials**
  - National Toxicology Program under DHHS began study of TiO<sub>2</sub>, nanotubes, and quantum dots in October 2003
- **Strategic plan for guiding research -**
  - Under development with input from regulatory and research agencies



# Status of NTP Project for Nanomaterials

- NIH / NIEHS - support of the new National Toxicology Program, multi-year project initiated in October 2003
- Funding for these studies to be ramped up to \$5M/yr by FY08
  - Evaluate physical and toxicological properties of major classes of nanomaterials representing a cross section of size, surface coatings and physicochemical properties and use these as model systems to study how nanomaterials interact with biological systems
  - Determine appropriate methods of detection, characterization and quantification of nanoscale materials in tissues and study how materials are absorbed, distributed, taken up and eliminated by cells and organelles
  - Studies to evaluate immunotoxicity of fullerenes and quantum dots
  - Studies of inhalation toxicology of fullerenes in laboratory animals

# Environmental, Health, and Safety:

## Recent Research by NSET Subcommittee member agencies

### New NSF Centers

- Center on Molecular Function at the Nano/Bio Interface  
U Pennsylvania -  
Basic complex biological and physiological processes
- Center for High Rate Nanomanufacturing Northeastern U,  
U Mass Lowell; U of NH; and Michigan State U  
Assess the environmental impact of nanomanufacturing during  
process development.

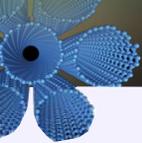
### EPA - Impacts of manufactured nanomaterials on human health and the environment

Toxicology of manufactured nanomaterials

Fate, transport, and transformation of manufactured  
nanomaterials

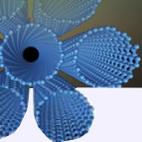
Human exposure and bioavailability

### DOD - MURI: models for toxicity of generic classes nanomaterials



# Recent & Planned EHS Related Actions by Regulatory Agencies

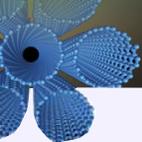
- FDA has developed a new nanotechnology website: [www.fda.gov/nanotechnology](http://www.fda.gov/nanotechnology) - position statement
  - Expects existing pharmotoxicity tests to be adequate for most nanotechnology products
  - As new toxicological risks are identified, new tests will be required
- EPA plans to initiate the process for instituting a voluntary reporting program under TSCA for nanoengineered materials
- NIOSH, EPA, and OSHA are developing statements by relevant offices of their agencies on positions wrt their regulatory authorities for nanotechnology products



# How Not to Handle Nanotubes



**Unprocessed single walled nanotube material**

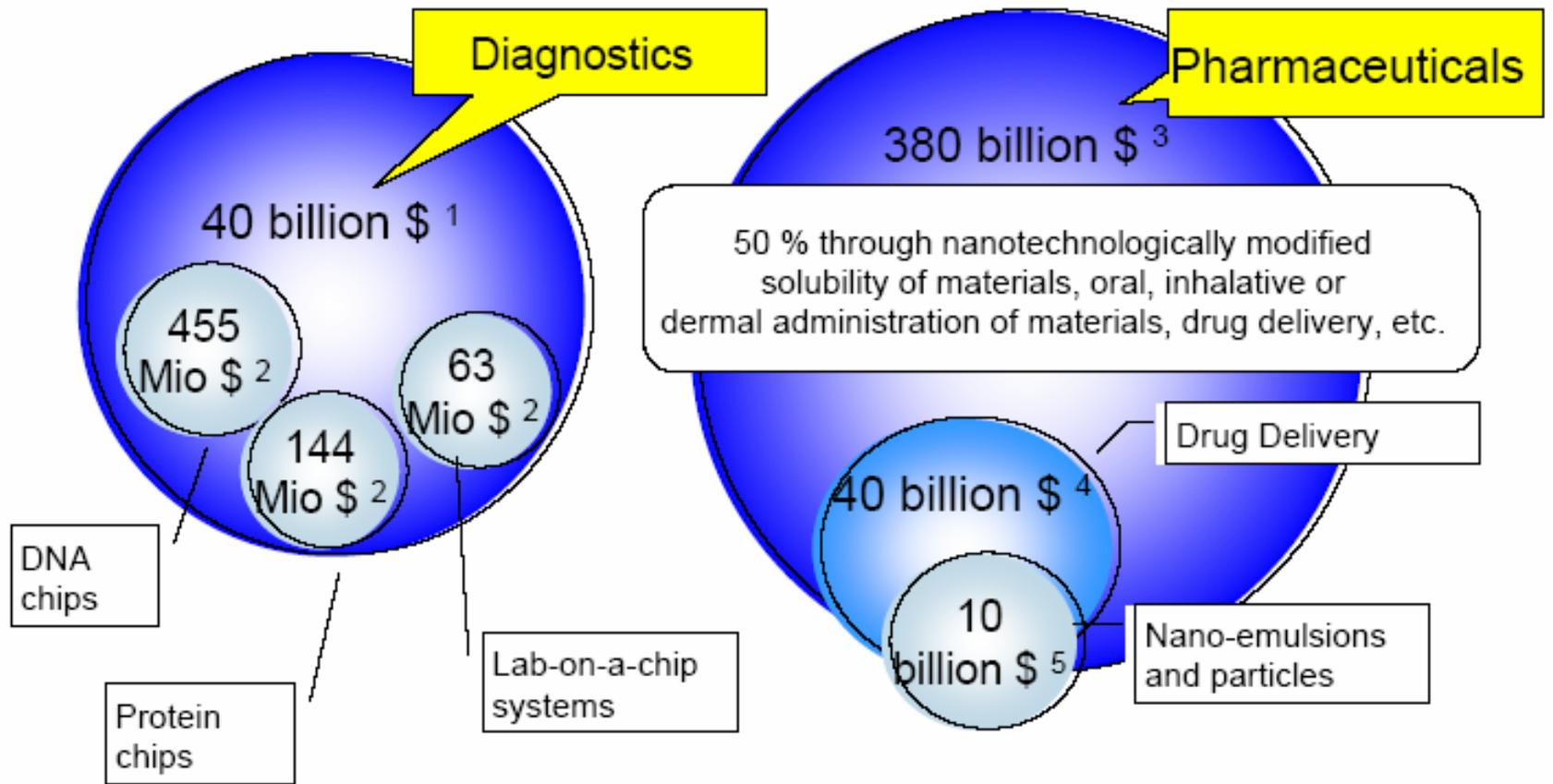


# Recommendations for Working With Nanomaterials

- Current data are insufficient to provide definitive strategies for working safely with engineered nanomaterials, they do point toward the need to approach these materials with caution.
- Methods to control airborne nanostructured particle exposure have not been well characterized at small particle diameters
- Theory and limited experimental data indicate that conventional ventilation, engineering control and filtration approaches should be applicable to particles a few nanometers in diameter and larger in many cases.

A.D. Maynard & E.D. Kuempel -  
submitted for publication

# Markets for Nanotechnology: Medicine



1: World market 2005 source: Uni Ulm; 2: World market 2005 source : Line Strategic Management; 3: World market 2000 source NNI Study;  
4: World market 2000 source Market Letter; 5: World market 2005 source : SkyePharma

Study by German Federal Ministry of Education and Research

... if you want to know more about the NNI

Point your  
browser to:

[www.nano.gov](http://www.nano.gov)

[http://www.nano.gov/NNI\\_Strategic\\_Plan\\_2004.pdf](http://www.nano.gov/NNI_Strategic_Plan_2004.pdf)

The screenshot shows a web browser window displaying the National Nanotechnology Initiative (NNI) website. The browser's address bar shows the URL <http://www.nano.gov/>. The website header includes navigation links for "Site Map", "Search", and "Contact Us". The main content area features the NNI logo and a descriptive paragraph: "The National Nanotechnology Initiative (NNI) provides a multi-agency framework to ensure U.S. leadership in nanotechnology that will be essential to improved human health, economic well being and national security. The NNI invests in fundamental research to further understanding of nanoscale phenomena and facilitates technology transfer." Below this is a banner for "Supporting the Next Industrial Revolution". The main content is divided into two columns. The left column contains a navigation menu with links: "About the NNI", "Nanotech Facts", "Government Dept/Agencies Research", "Funding Opportunities", "Nanotechnology Centers", "Newsroom", "Education Center", and "Resources". The right column features two news items. The first is "EPA Awards 12 Grants on Environmental Impacts", with a sub-headline "The U.S. Environmental Protection Agency's National Center for Environmental Research (NCER) has recently made grants to twelve universities worth a total of \$4-million to investigate potential health and environmental impacts of nanomaterials. Six of the NCER grants will investigate health effects or environmental impacts of manufactured nanomaterials. The other six grants will examine the fate and transport of nanomaterials in the environment." and a link to "Read complete story.". The second news item is "NSET Releases Strategic Plan", with a sub-headline "The Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the National Science and Technology Council's Committee on Technology has released its 2004 Strategic Plan for the Federal R&D program in nanotechnology. This report, which was developed with the support of the National Nanotechnology Coordination Office, updates the original strategic plan of the National Nanotechnology Initiative (NNI) for the next 5 to 10 years." and a link to "The document contains the vision, goals and plans for specific activities".