Nanotechnology in the United States and National Science Foundation

National Science Foundation

November 6, 2008
Nanotechnology is the control and restructuring of matter at dimensions of roughly 1 to 100 nanometers where new phenomena enable new applications.
Four Generations of Products (200-2020): Timeline for beginning of industrial prototyping and nanotechnology commercialization

1st: Passive nanostructures (1st generation products)
   Ex: coatings, nanoparticles, nanostructured metals, polymers, ceramics

2nd: Active nanostructures
   Ex: 3D transistors, amplifiers, targeted drugs, actuators, adaptive structures

3rd: Systems of nanosystems
   Ex: guided assembling; 3D networking and new hierarchical architectures, robotics, evolutionary

4th: Molecular nanosystems
   Ex: molecular devices ‘by design’, atomic design, emerging functions

~ 2000
~ 2005
~ 2010
~ 2015-2020

National Nanotechnology Initiative

Collaborative, Multi-agency, Cross-cut Program Among 26 Federal agencies

Funds R&D to advance understanding and control of matter at nanoscale toward:

- National economic benefit
- National and homeland security
- Improved quality of life
A sampling of NSET Subcommittee publications for second strategic plan (2006-2010)

Supplement to the President's FY 2007 Budget

Environmental, Health, and Safety Research Needs

MC Roco, 12/12/07
**Changing national investment**

**FY 2009 NNI Budget Request - $1,527 million**

<table>
<thead>
<tr>
<th>Fiscal Year</th>
<th>NNI</th>
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<tr>
<td>2000</td>
<td>$270M</td>
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NNI / R&D ~ 1/4 of the world R&D

NNI / EHS ~ 1/2 of the world EHS R&D

EHS 2006: $38M (primary; $68M total eff.)
2007: $48M (primary; $86M total est.)
2008: $57M (primary; $102 total est.)
2009: $76M (primary - planned)
National Nanotechnology Initiative activities at NSF in FY 2008

Actual budget: $389M

- **Program solicitations**
  - Nano-EHS with EPA and DOE
  - Nanotechnology Undergraduate Education (ENG and EHR)

- **Support in the “core” program**
  with focus on single investigator & other core

  Research and education programs in all directorates
  Interdisciplinary fellowships; NSEC, STC, MRSEC and ERC centers
  Instrumentation (REG, MRI); Collaboration industry (GOALI, PFI)
  Network for Computational Nanotechnology ($3.8M/yr)
  National Nanotechnology Infrastructure Network ($14M/yr)
  Nanoscale Informal Science and Education network
  Interagency collaborations: Manufacturing, Societal Implic., EHS

- **SBIR/STTR** (additional ~ $16M/year)

MC. Roco, 12/12/05
Increased investments will be dedicated to research and education on:

- **Increased focus on complex large nanosystems.** Research on nanoscale devices and system architecture, dynamic and emerging behavior, and their respective fabrication, will be emphasized.

- **Increased focused on three-dimensional measurements of domains of engineering relevance with good time resolution.**

- **Converging science, engineering and technology from the nanoscale, by integrating nanosystems into applications** (in manufacturing, information systems, medicine, environment, etc.)

- **Expanded joint research program addressing societal implications of nanotechnology;** partner with NIOSH, EPA and FDA, USDA and NIST.

- **Earlier educational programs and teaching materials,** including for K-12, by using remote access to NSF educational networks (NU, NISE, NNIN).

- **Expand partnerships of academic researchers with industry, medical facilities and states** through two programs (GOALI, PFI), using the CBAN (Collaborative Board for Advancing Nanotechnology).
NSF – discovery, innovation and education in Nanoscale Science and Engineering (NSE)


FY 2009 Request: $397M ~1/4 of Federal and ~1/12 of World Investment

- Fundamental research - seven PCAs with new priorities
- Establishing the infrastructure - over 4,000 active projects;
  24 large centers, 2 user facilities (NNIN, NCN), multidisciplinary teams
- Training and education – over 10,000 students and teachers/yr

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Industry R&D ($6B) has exceeded national government R&D ($4.6B) in 2006

J. Nanoparticle Research, 7(6), 2005, MC. Roco
NNI Networks and User Facilities
(over 80 centers established by NNI)

- **NSF**: eight networks with national goals and service in key areas of nanoscale science and engineering
- **NIH**: four networks for medical research, cancer, metrology
- **DOE**: one network with five large facilities
- **NASA**: one network of four centers on convergence
- **DOD**: three centers on nanoscale science and technology
- **NIST**: instrumentation and manufacturing user facility
- **NIOSH**: particle characterization center
NSF Nanoscale S&E Centers

Nanoscale Science and Engineering Centers (NSEC)

- Electron Transport in Molecular Nanostructures, Columbia
- Nanoscale Systems, Cornell
- Directed Assembly of Nanostructures, RPI
- Science for Nanoscale Systems and their Device Applications, Harvard
- Institute for Nanotechnology, Northwestern
- Biological and Environmental Nanotechnology, Rice
- Scalable and Integrated Nanomanufacturing, UCLA
- Integrated Nanomechanical Systems, UC Berkeley
- High Rate Nanomanufacturing, Northeastern
- Affordable Nanoengineering, Ohio State
- Molecular Function at the Nanoscale, U Pennsylvania
- Probing the Nanoscale, Stanford
- Templated Synthesis and Assembly at the Nanoscale, U Wisconsin
- Nanotechnology in Society Network, ASU, UCSB, U South Carolina, Harvard
- Network for Hierarchical Manufacturing, U Mass-Amherst
- The Nanobiotechnology Science and Technology Center, Cornell
National Nanotechnology Infrastructure Network (NNIN)

An integrated national network of user facilities
providing researchers open access to resources, instrumentation and expertise in all domains of nanoscale science, engineering and technology

http://www.NNIN.org; Est. 4,000 users in 2006, NSF 3,500/ user

MC Roco, 12/12/07
Network for Computational Nanotechnology

A national resource for research, education and user-facility to accelerate the transformation of nanoscience to nanotechnology through theory, modeling, and simulation and collaboration enabled by cyberinfrastructure

Focus: “from atoms to systems”; “same equations for various applications”

http://www.nanoHUB.org

Est. 12,000 users / 2006; NSF $350 / user
National Nanomanufacturing Network

- Four NSECs (NSF)
  - Center for Scalable and Integrated Nanomanufacturing, UCLA (2004-)
  - Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems, University of Illinois at Urbana-Champagne (2005-)
  - Center for High Rate Nanomanufacturing, Northeastern University (2005-)
  - Network for Hierarchical Manufacturing U. Mass. - Amherst (2006-) (Main Node)

- DOD, MURI centers
- NIST, Laboratory for Nanoscale Science and Technology
Nanotechnology Informal Science Education Network

Center for Public Engagement
Museum of Science
Boston

Center for Exhibits & Programs
Science Museum of Minnesota

Center for NISE Research
Exploratorium
San Francisco

• Visualization Lab
• Resource Center
• Research and Evaluation
• Professional Development
• Public Website

• Network Media
• Forums
• Network Administration

• Exhibit and Program Packages

To create 100 science museum sites in U.S. by 2010
NSEC: Nanotechnology in Society

Four nodes established in September 2005:
- 2 centers and
- 2 small-groups

Arizona State University

University of South Carolina:
- visualization methods

Harvard University:
- database for ELSI

University of California Santa Barbara

To address Ethical, Legal and other Social Issues related to Nanotechnology
DOE: Construction is complete and initial operations are underway at four NSRCs

Center for Nanoscale Materials (Argonne National Laboratory)

Center for Functional Nanomaterials (Brookhaven National Laboratory)

Center for Nanophase Materials Sciences (Oak Ridge National Laboratory)

Molecular Foundry (Lawrence Berkeley National Laboratory)

Center for Integrated Nanotechnologies (Sandia & Los Alamos National Labs)
Cancer Centers of Nanotechnology Excellence (8 established in October 2005)

- Carolina Center of Cancer Nanotechnology Excellence, University of North Carolina, Chapel Hill, N.C.
- Nanosystems Biology Cancer Center, California Institute of Technology, Pasadena, Calif.
- Center of Nanotechnology for Treatment, Understanding, and Monitoring of Cancer, University of California, San Diego, Calif.
- Nanomaterials for Cancer Diagnostics and Therapeutics, Northwestern University, Evanston, Ill.
- The Siteman Center of Cancer Nanotechnology Excellence at Washington University, St. Louis, Mo.
- Emory-Georgia Tech Nanotechnology Center for Personalized and Predictive Oncology, Atlanta, Ga.
- Carolina Center of Cancer Nanotechnology Excellence, University of North Carolina, Chapel Hill, N.C.

MC Roco, 12/12/07
Several NNI Accomplishments

• **Developed foundational knowledge** for control of matter at the nanoscale: over 4,000 active projects in > 500 universities, private sector institutions and gov. labs in all 50 states

• “Created an **interdisciplinary nanotechnology community**” ¹

• **R&D / Innovation Results**: With ~25% of global government investments, the U.S. accounts worldwide for
  
  ~ 50% of highly cited papers,
  
  ~ 60% of USPTO patents², and
  
  ~70% of startups³ in nanotech.

  Over 2,000 companies with nanotechnology products in 2006 (U.S.)

• **Infrastructure**:

  80 new large nanotechnology research centers, networks and user facilities; about 30,000 users in 2 academic-based networks

¹ NSF Committee of Visitors, 2004; ² Journal of Nanoparticle Research, 2004; ³ NanoBusiness Alliance, 2004
U.S. International partnerships for Nanotechnology

- Nanotechnology included in bilateral (e.g. U.S.-Japan, EU, India, etc.), and international organizations (e.g. OECD, APEC, etc.) S&T agreements

- Typical NSF activities
  - Bottom-up by individual partnerships in research
  - Periodical NanoForums (annual); other workshops
  - Using networks: NNIN / NCN and partner networks / facilities
  - Young scientists exchange programs

- Areas and modes of increased collaboration:
  - fundamental knowledge (precompetitive) - by twinning and networking
  - education - by visits, int. courses, books, int. accreditation, study institutes
  - broad societal implications: health, environment, energy, water filtration, ethics - exchanges
  - contribute to international S&T “grand challenges”
  - industry partnerships, precompetitive nanotechnology platforms

MC Roco, 12/12/07
www.nsf.gov/nano
or link www.nano.gov

NSF National Nanotechnology Initiative (NNI)

Search for NSF awards by keywords
(go to the "Full text search", and complete the box with your keywords; Examples of keywords are nano*, selfassemb* and nanoparticle)

NSF press releases on Nanotechnology Research since January 2004

NSF press releases on Nanotechnology Research from 2003 to 2001

SOLICITATIONS AND OUTCOMES IN FY 2005

NSF Announcement 05-543: Nanoscale Science and Engineering Education (NSEE)
"Preparation workshop: Public Engagement in Nanoscale Science and Engineering" (PDF, 776KB)

NSF Announcement 04-043: Nanoscale Science and Engineering (NSE)
NSEC on "Nanotechnology in Society" workshop

Joint EPA-NSF-NIOSH solicitation for research in Environmental and Human Health Effects of Manufactured Nanomaterials