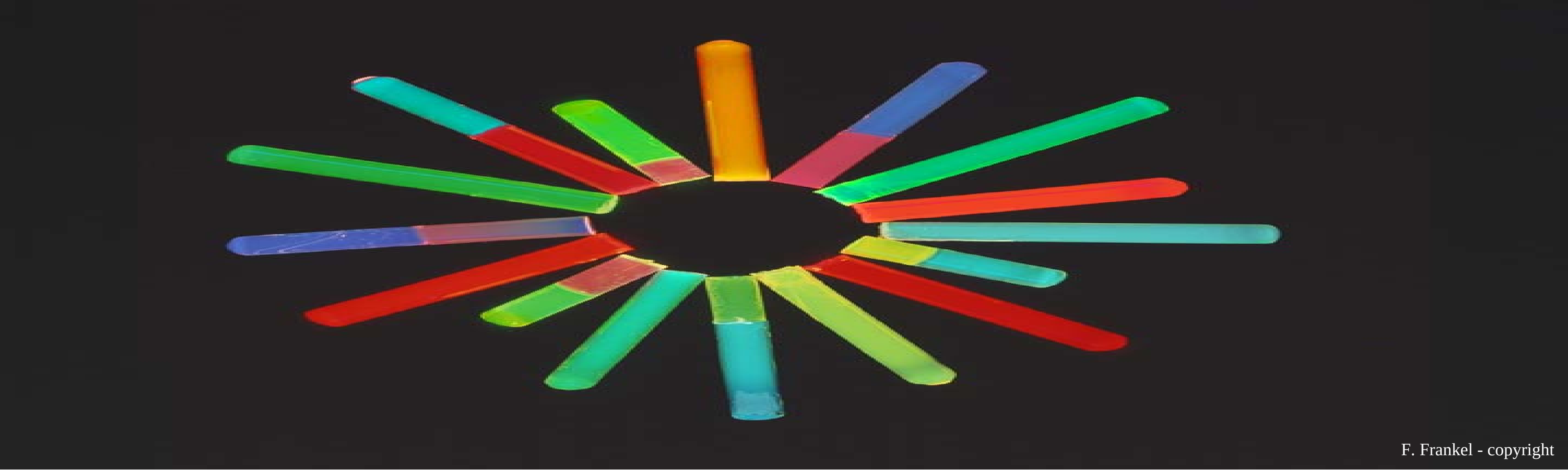


National Nanotechnology Initiative

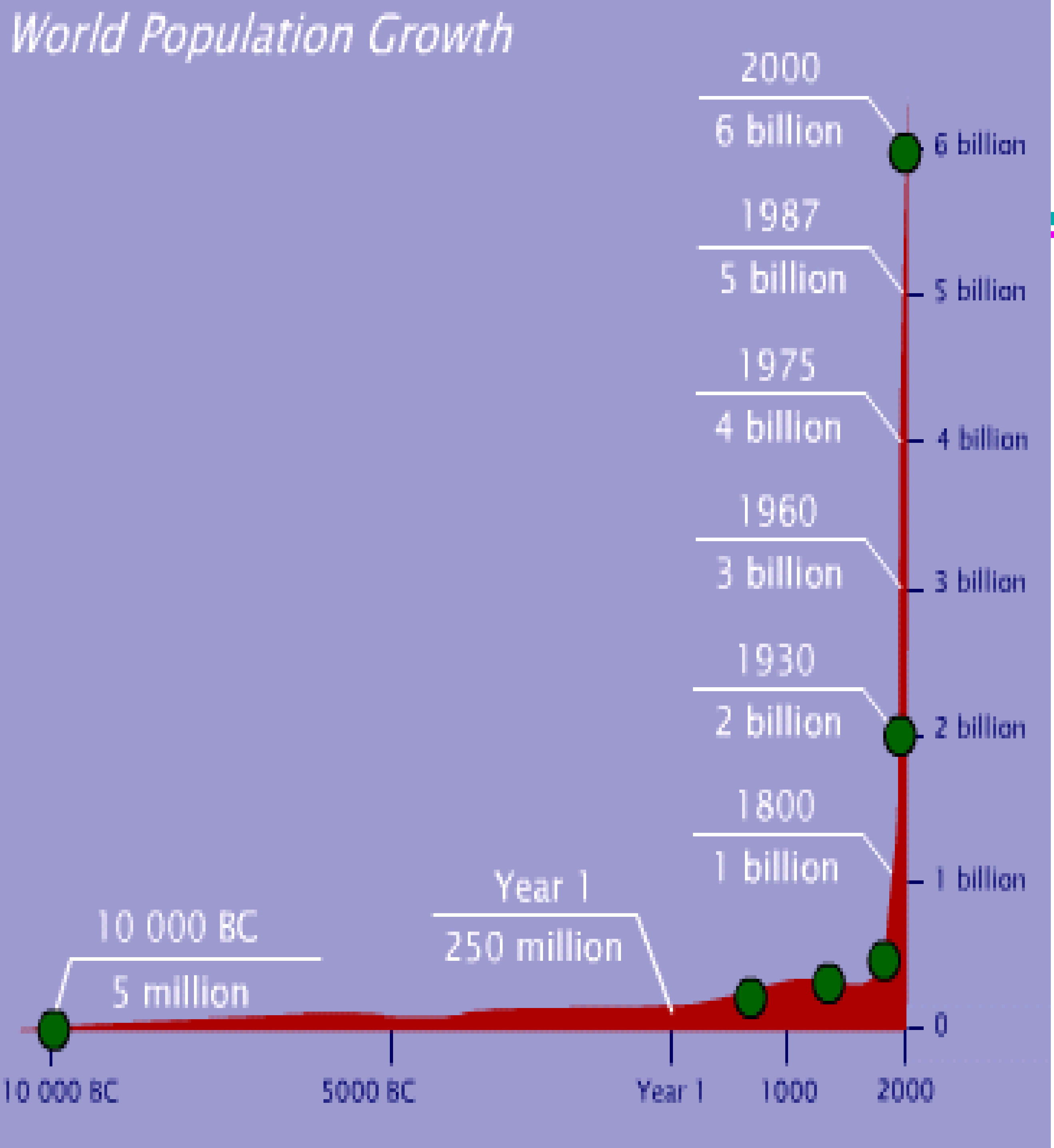
Overview and environmental aspects

Dr. M.C. Roco

Chair, Subcommittee on Nanoscience, Engineering and Technology (NSET),
National Science and Technology Council (NSTC), http://nano.gov

Senior Advisor for Nanotechnology, National Science Foundation

September 15, 2003



More people

9-10 billion by 2050

- Increased consumption of water, food, energy
- Changing environment
- Changing society
- Maintaining peace

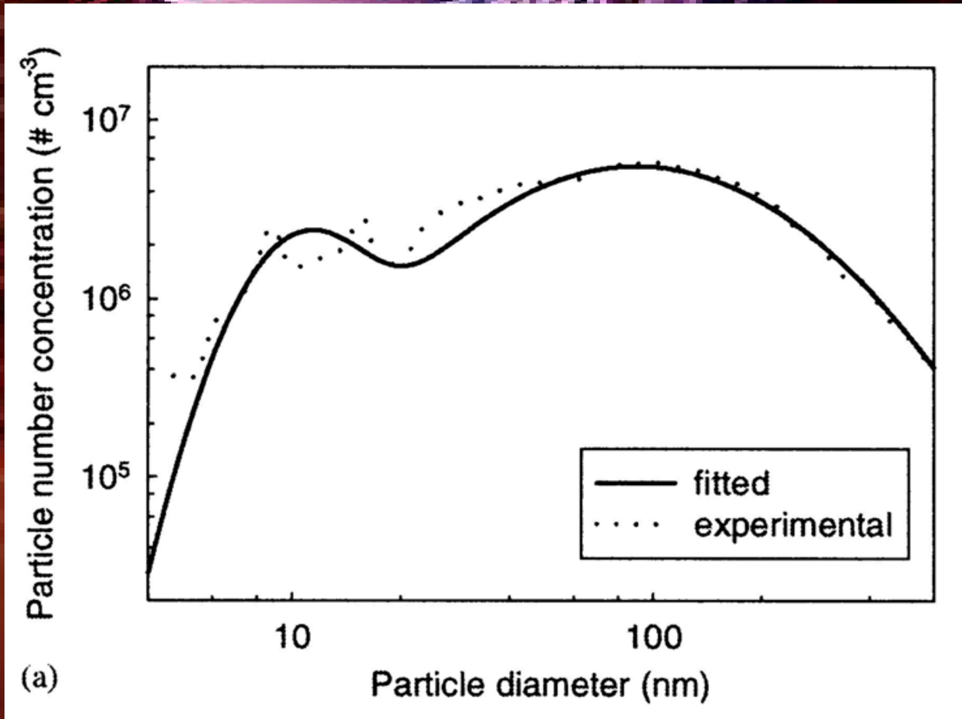
NEED OF RADICALLY NEW TECHNOLOGIES

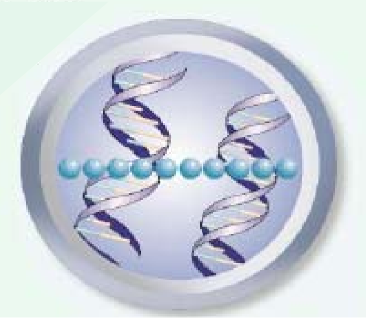
MC. Roco, 9/15/03

Environmental issues related to nanotechnology include:

- **Sustainable development, life-cycle of products, measurement and mitigation, clean-up techniques, global effects**
- **Combustion, welding, water/air filtration, cell behavior**

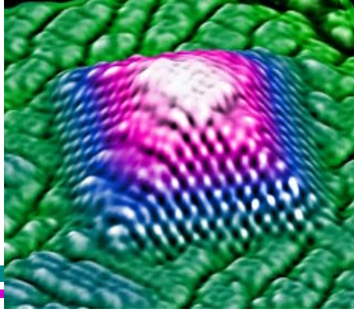
Zimmer et al., 2002





Nanotechnology

Definition on http://nano.gov/omb_nifty50.htm **(2000)**



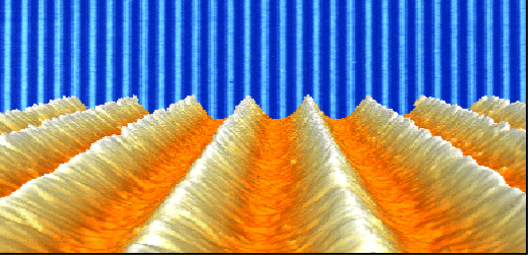
- Working at the atomic, molecular and supramolecular levels, in the length scale of approximately 1 – 100 nm range, in order to understand and create materials, devices and systems with fundamentally new properties and functions because of their small structure

- **NNI definition encourages new contributions that were not possible before.**

  - novel phenomena, properties and functions at nanoscale, which are nonscalable outside of the nm domain

  - the ability to measure/ control / manipulate matter at the nanoscale in order to change those properties and functions

  - integration along length scales, and fields of application



Why moving into the nanoworld ?
A. Intellectual drive

- Miniaturization is of interest

More important, radical improvements:

- Novel properties/ phenomena/ processes
- Unity and generality of all natural/man-made things
- Most efficient length scale for manufacturing
- Transcendent effects: at the confluence of steams

B. Broad societal implications

(examples of societal implications;
worldwide estimations made in 2000, NSF)

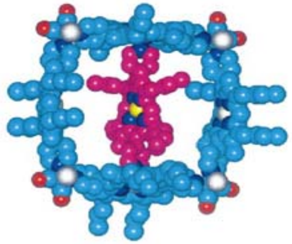
- **Knowledge base**: better comprehension of nature, life
- **New technologies and products**: **~ $1 trillion / year by 2015**
  (With input from industry US, Japan, Europe 1997-2000, access to leading experts)

  Materials beyond chemistry: $340B/y
  Pharmaceuticals: $180 B/y
  Aerospace about $70B/y
  Electronics: over $300B/y
  Chemicals (catalysts): $100B/y
  Tools ~ $22 B/y

  Est. in 2000 (NSF) : about $40B for catalysts, GMR, materials, etc.
  Est. in 2002 (DB) : about $116B for materials, pharmaceuticals and chemicals

  Would require worldwide ~ 2 million nanotech workers

- **Improved healthcare**: extend life-span, its quality, physical capabilities
- **Sustainability**: agriculture, food, water, energy, materials, environment; ex: lighting energy reduction ~ 10% or **$100B/y**



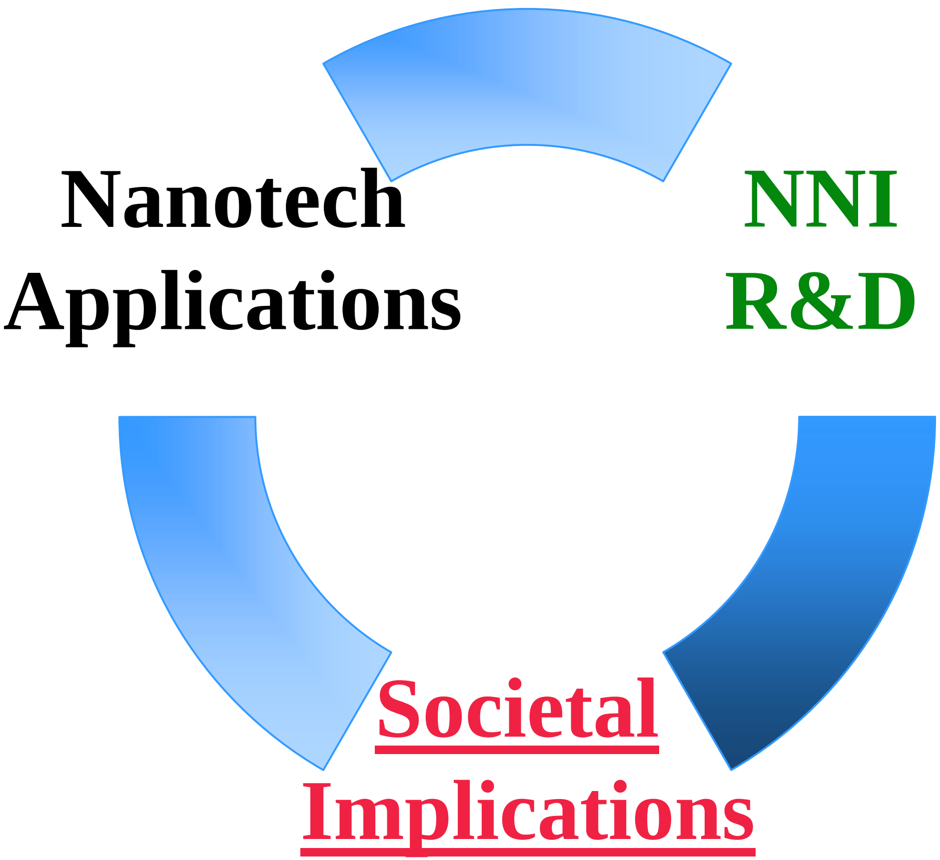
C. Timeline for beginning of industrial prototyping and commercialization

Accidental nanotechnology: since **1000s yr** (carbon black)

Isolated applications (catalysts, composites, others) since **1990**

- **First Generation: passive nanostructures**
  in coatings, nanoparticles, bulk materials (nanostructured metals, polymers, ceramics):
  ~ 2001 –
- **Second Generation: active nanostructures**
  such as transistors, amplifiers, targeted drugs and chemicals, actuators, adaptive structures:
  ~ 2005 –
- **Third Generation: 3D nanosystems**
  with heterogeneous nanocomponents and various assembling techniques; bio-assembling; networking at the nanoscale and new architectures
  ~ 2010 –
- **Fourth Generation: molecular nanosystems**
  with heterogeneous molecules, based on biomimetics and new designs
  ~ 2020 (?) -

NNI R&D - closed loop with societal implications



Defining the vision

National Nanotechnology Initiative

1999:
10-year
vision

Government
plan

Worldwide
benchmark

Reports

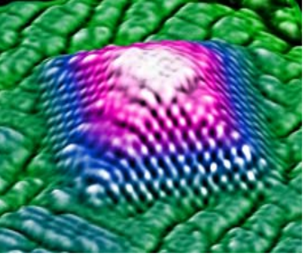
Brochure for
public

Societal
implications

June 2002: "Review of NNI" by U.S. Academies for WH/OSTP

April 2003: "FY 2004 NNI and Its Implementation Plan", NSET

In preparation: Topical reports; new 2004: 10 year vision



Planning for the future: expanding the frontiers of nanotechnology

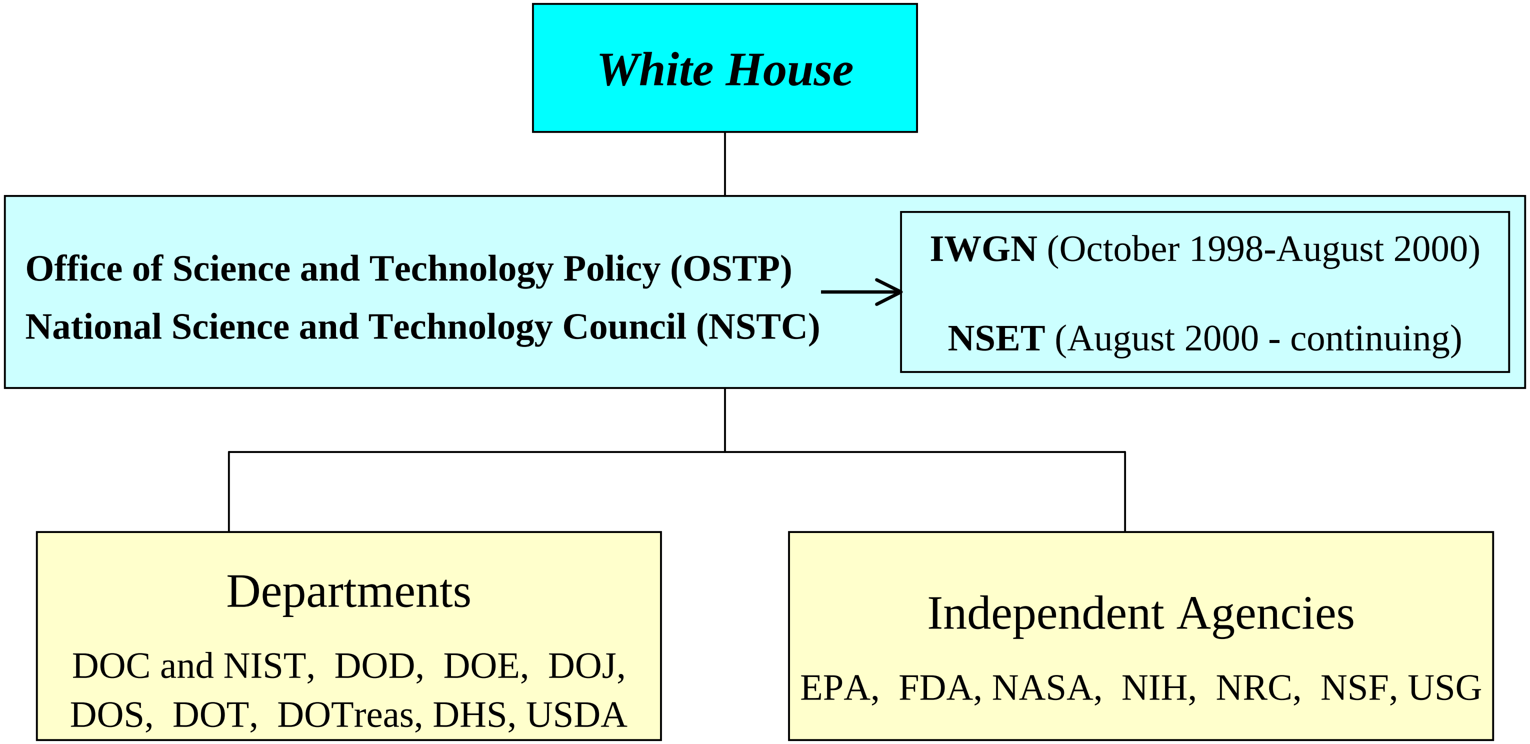
Workshops for receiving input from the community (examples):

- Nanostructured materials "by design" - Workshops on 10/02, 06/03
- Nanoelectronics, optoelectronics and magnetics - Workshops 11/02, Fall 03
- CBRE protection and detection (revised in 2002) - Workshop 05/02
  Report: Nanotechnology Innovations for CBRE
- Advanced healthcare, therapeutics, diagnostics - Workshops 06/00
- Nano-biology and medicine – Workshop Fall 03
- Environmental improvement - Workshops 06/02, 08/02, Spring 03
- Efficient energy conversion and storage - Workshops 10/02, 01/03
- Microcraft space exploration and industrialization - Workshop Fall 03
- Manufacturing processes - Workshops 01/02, 05/02
- Agriculture and food systems – Workshop 11/02
- Societal implications (II) - Workshop Fall 03

"Nanotechnology Research Directions (II)" - January 2004

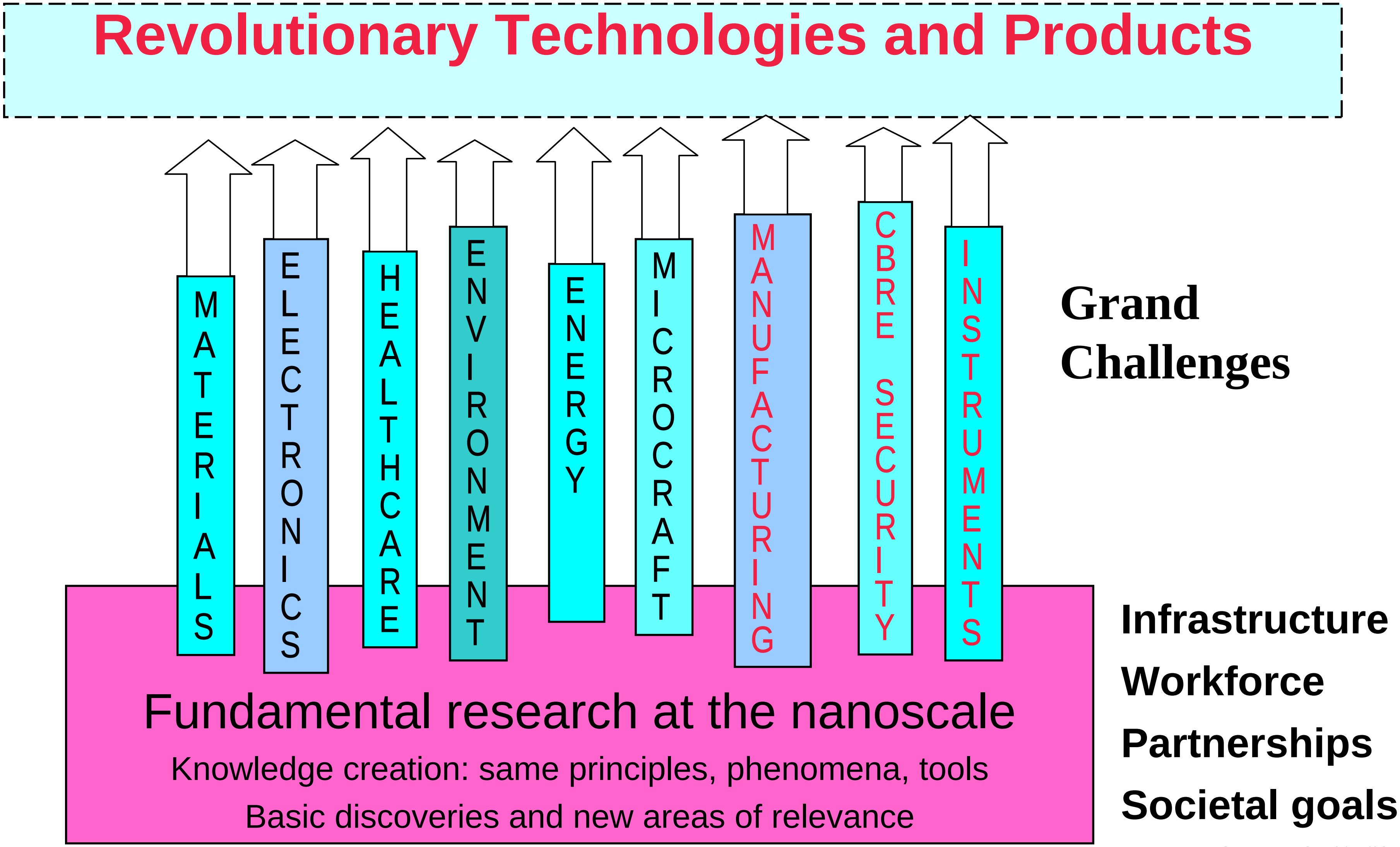
Revisit the NNI long-term vision formulated in January 1999

Organizations that have prepared and contribute to the National Nanotechnology Initiative



Estimation:	Federal Government R&D funding	NNI (~ $700M in 02)
	Industry (private sectors)	~ NNI funding
	State and local (universities, foundations)	~ 1/2 NNI funding

Interdisciplinary "horizontal" knowledge creation vs. "vertical" transition from basic concepts to Grand Challenges



M.C. Roco, NSF, 9/15/03

NNI: Key Investment Strategies

- Focus on fundamental research ('horizontal')
  + transition to technological innovation ("vertical')
- Address broad humanity goals and other societal aspects
- Long-term vision, part of coherent S&T evolution
- Prepare the nanotechnology workforce
- Policy of inclusion and partnerships
  Interdisciplinary, Interagency collaboration
- Transforming strategy; bio-inspired approach;
  consider the full architecture and interactions

NNI: R&D Funding by Agency

Fiscal year (all in million $)	*2000*	*2001* Enacted/actual	*2002* Enacted/actual	*2003*	2004 Request
National Science Foundation	97	150 /150	199 /204	221	249
Department of Defense	70	110 /125	180 /224	243	222
Department of Energy	58	93 /88	91.1 /89	133	197
National Institutes of Health	32	39 /39.6	40.8 /59	65	70
NASA	5	20 /22/	35 /35	33	31
NIST	8	10 /33.4	37.6 /77	66	62
Environmental Protection Agency	-	/5.8	5 /6	5	5
Homeland Security (TSA)	-		2 /2	2	2
Department of Agriculture	-	/1.5	1.5 /0	1	10
Department of Justice	-	/1.4	1.4 /1	1.4	1.4
TOTAL	270.0	422.0 /464.7	~ 600 /697	~ 770	~ 849

Other NNI (NSET) participants are:
OSTP, NSTC, OMB, DOC, DOS, DOT, DOTreas, FDA, NRC, DHS, IC

Grand Challenges (NNI, FY 2002)

- Nanostructured materials "by design" (NSF lead) ~ 22%
- Nanoelectronics, optoelectronics and magnetics (DOD lead) **39%**
- Advanced healthcare, therapeutics, diagnostics (NIH lead) 8%
- Environmental improvement (lead EPA and NSF) 4%
- Efficient energy conversion and storage (DOE) 5%
- Microcraft space exploration and industrialization (NASA lead) 3%
- CBRE Protection and Detection (revised in 2002) (DOD lead) 7%
- Instrumentation and metrology 9NIST and NSF lead) 6%
- Manufacturing processes (NSF and NIST lead) 5%

(details in the NNI Implementation Plan, http://nano.gov)

Centers and networks

Overall: 22 new large centers and networks supported by NNI since 2001 (with environmental research components)

- 10 NSF (8 NSECs, 2 networks)
- 5 DOE (including 6 national labs) – large R&D facilities
- 3 DOD (including Soldier Nanotech at MIT in 2002)
- 4 NASA (at universities in 2002)

Revolutionary technologies, products and services

- **Growing area**
  - **Materials, including bulk, coating, dispersed systems**
  - **Chemicals, including catalysts**
  - **Pharmaceuticals**
  - **Electronics**
- **Emerging areas**
  - **Nanomedicine**
  - **Energy conversion and storage**
  - **Agriculture and food systems**
  - **Molecular architectures**
  - **Realistic multiphenomena/multiscale simulations**
  - **Environmental implications**
  - **Converging technologies**

Nanoparticles and Environmental Aspects

- timeline at NSF -

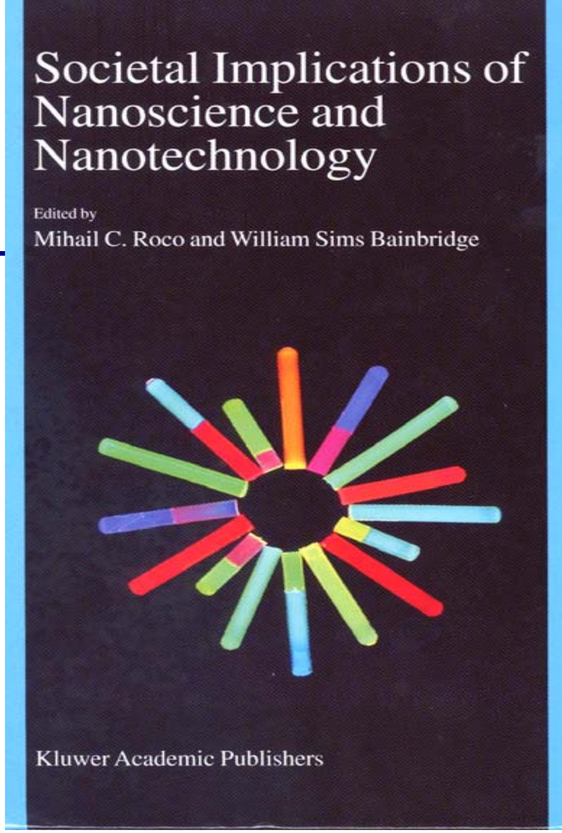
- **Series of workshops on nanoparticles**
  Safety section in Nov. 1990, before the first call for proposals on “Synthesis and processing of nanoparticles”

  - Nov. 1990 (NSF): Risk from combustion processes

  - 1994 (NSF and NIST): A focus on instrumentation

  - 1997 (NSF and NIST): A focus on integration of synthesis and processing (without intermediate handling of nanoparticles)

Societal Implications: Follow-up of the September 2000 report



http://nano.gov

- Make support for social, ethical, and economic research studies a priority:
  (a) New theme in the NSF program solicitations (2000-);
  (b) Centers with societal implications programs;
  (c) Initiative on the impact of technology, NBIC, HSD
- NNCO (2001-) – communicate with the public and address unexpected consequences
- Basic reference for the interaction with the public
- Taking faster advantage of the benefits
- Converging technologies from the nanoscale
- International workshop with EC (2001); links to Asia

Research and education themes program announcements

Programs with a focus on nanotechnology and environment:

- **NSF**: Nanoscale Science and Engineering have included the theme "**Nanoscale processes in the environment" since July 2000** (5 program announcements: NSF 00-119 July 2000; NSF 01-157 July 2001; NSF 02-148 July 2002; NSF 03-043 and 03-044 July 2003)
- **EPA: STAR program included nanotechnology since May 2002** (2 program announcements; focus in 2003: nanoparticles implications)

Increased investment in societal (ethical, economic, etc.), educational and environmental implications

Increased NNI investments are planned, because of (a) creation of new nanostructures and advancing knowledge; (b) nanotechnology products move to the market; and (c) growth of interdisciplinary societal implication research

a. For societal and educational implications

(Cross-cutting, including contributions from fellowships).

FY 2002	**~ $30M**:	NSF ($21M), DOD ($3M), NIH, NIST, EPA (est.)
FY 2003	**~ $35M**	of which $3M ethical, economical, societal implic.
FY 2004	**~ $40M**	(est.)

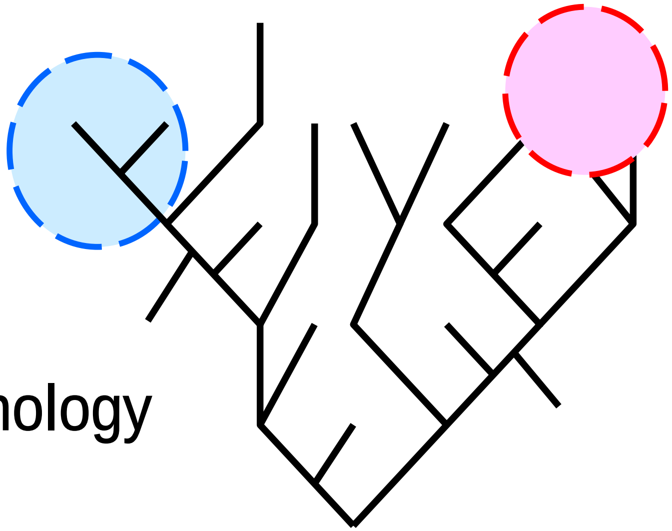
b. For nanoscale R&D with relevance to environment

(Crosscutting, including env. processes, benign nano-manufacturing, implications)

FY 2002:	**~ $50M**:	NSF ($30M), DOE (~$10M), EPA (~$6M), NIH, USDA, NASA, NIST and FDA programs (est.)
FY 2003	**~ $55M**	(est.)
FY 2004	**~ $60M**	(est.)

Note: FY 2002 NNI investment of $80M is ~ 11% of $700M

Societal implications: examples



- Social and ethical dimensions of nanotechnology
  M. Gorman, U. VA.
- Philosophical and social dimensions of nanoscale research: developing a rational approach to an emerging S&T
  D. Baird, USC
- Ethics and belief inside the development of nanotechnology
  R.W. Berne, U. VA. (CAREER)
- Scanning Probe Microscope: The genesis and practices
  M.L. Lynch, Cornell U., Dissertation Research
- Courses on societal implications for public
  Columbia U. (NSEC)

Environment: Nanotechnology holds major implications

- **Nanoscale manufacturing will provide the means for sustainable development**: less material, less water, less energy and less waste for manufacturing, and new methods to convert energy, filter water, etc. - **"Exact manufacturing"**

- **Means to address current health and environmental issues, and "unexpected consequences" of NT**. Novel molecular processes can be used to remove existing pollutants that cannot be separated otherwise. Nanoscale sensors to better monitor the environment.

- **Ex. research activities in US**: nanoparticles in the air, soils and water; nanoscale processes in bio-environmental systems; new tools; and green manufacturing. A list of 100 examples of awards on the website.

The risk of not doing R&D in nanotechnology would be high

Examples of nano-environmental projects: understanding the implications

- Nanoparticles in the environment

    A. Novrotski, UC Davis (IGERT); U. Kortshagen U Minnesota (IGERT)

- Nano-colloids (metals, actinides) in aquatic systems

    P. Santschi, TAMU (NIRT); JB Fein, Env Molecular Science Institute, UND

- Surface reactivity of nanostructures in environment

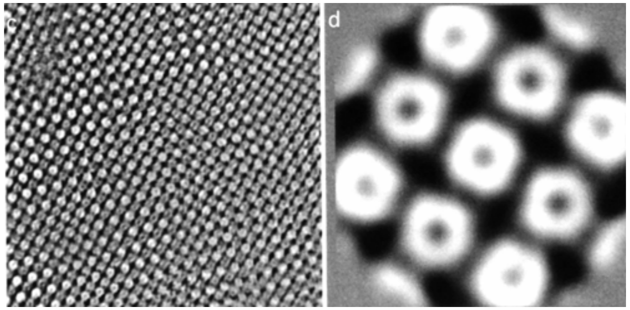
    JF Banfiled, UCB; PT Cummins, UVB; MK Ridley, TX Tech Univ (NIRT)

- Application of quantum dots to environment and cell biology,

    AK Sengupta, Lehigh U.

- Molecular Minerals- Microbial interactions in the environment

    M. Nanny, U. Okla., (NIRT); MF Hochella, U. VA.



Protein layers of 11 nm diameter by bacteria

- Biological and environmental nanotechnology

    V. Colvin, Rice U. (NSEC)

Nanoscale Processes in the Environment

J. Banfield, UCB, Wet nanoparticles

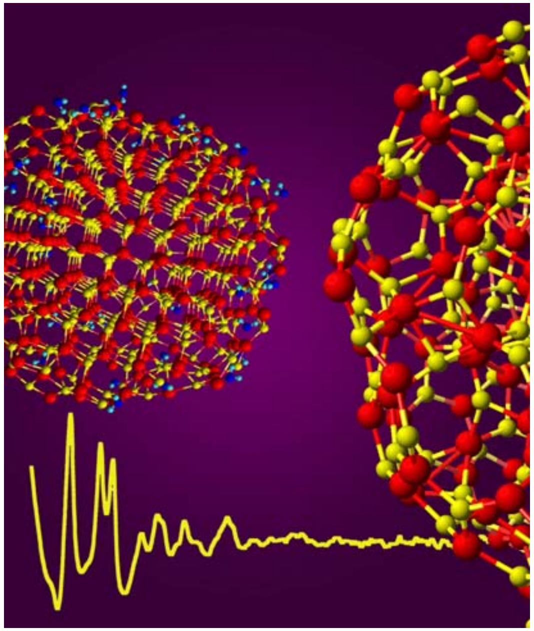


Illustration by Zhang, Gilbert, Huang, & Banfield (University of California, Berkeley)

Published in NATURE (August 28, 2003)

Well-ordered structure of ZnS **nanoparticle** (far left) when exposed to water molecules (shown in blue at surface of particle).

In the absence of water, the outer shell of the particle is severely distorted (particle at right).

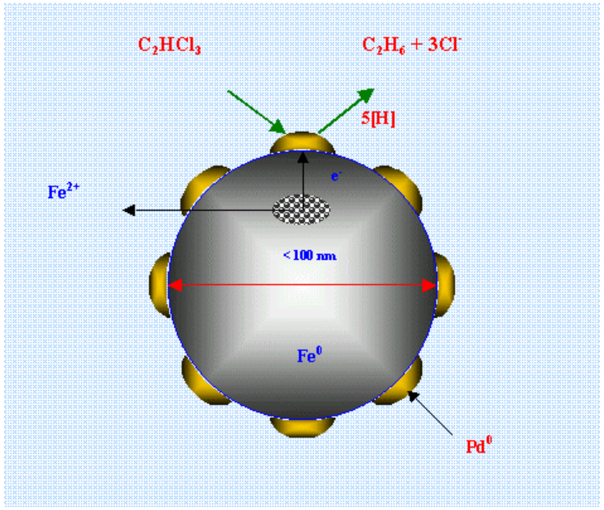
Wide-angle x-ray scattering spectra and molecular dynamics simulations (yellow curve) predict a change from a more distorted to a more periodic structure accompanying binding of water molecules to this nanoparticle surface.

Implications for:

- semiconductor devices
- environmental sensors (less invasive)
- understanding extraterrestrial materials

Examples of nano-environmental research: improving the implications

- Sequestration of volatile organic nanocompounds in environment
  EJ Leboeuf, U. Venderbild (CAREER)
- Nanoscale photocathalyst for destruction of environmental pollutants
  JC Crttenden, MTU (NER)
- Environmental friendly processing of metal oxide suspensions
  RM Davis, VPI
- Nanoscale metal particles: remediation in groundwater
  W. Zhang, Lehigh U. (CAREER)



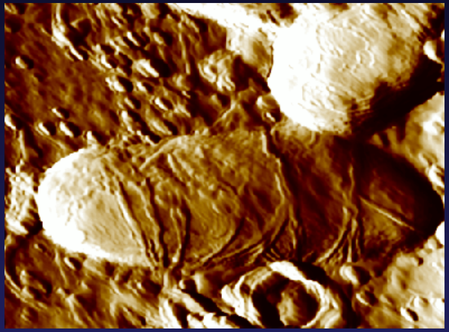
- Nanobiosensor using dynamic AFM
  JW Schneider, CMU (NER)
- Magnetic separation for environmentally benign processing
  JA Ritter, USC Columbia

NSF environmental centers and interdisciplinary groups with research and education at the nanoscale

Center	Institution
Fundamental Studies of Nanoparticles Formation in Air Pollution	Worcester Polytechnic Institute
Center for Advanced Materials for Water Purification	University of Illinois at Urbana
Center for Environmentally Responsible Solvents and Processes	University of North Carolina at Chapel Hill
Nanoscience in Biological and Environmental Engineering (Nanoscale Science and Engineering Center – NSEC) (estimated 50% in environment)	Rice University
Environmental Molecular Science Institute	University of Notre Dame
NIRT: Investigating Nano-carbon Particles in the Atmosphere: Formation and Transformation	University of Utah
NIRT: Nanoscale Processes in the Environment - Atmospheric Nanoparticles	Harvard University
NIRT: Nanoscale Sensing Device for Measuring the Supply of Iron to Phytoplankton in Marine Systems	University of Maine

Environmental Molecular Science Institute

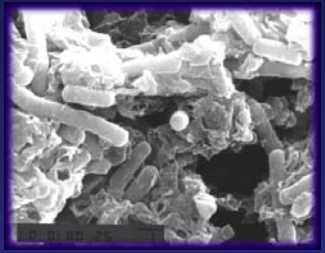
Jeremy Fein, University of Notre Dame



Science/Engineering Projects

Mission**:** Determine the effects of nano- and micro-particles on heavy metal and radionuclide transport in geologic systems.

-Bacteria
-Natural Organic Matter
-Nanoscale Mineral Aggregates



Education/Outreach Projects

- REU Summer Program
- High School Student Internships
- Active Recruitment of Under-represented Groups with G.E.M.
- National Lab/Industry Internships

National Lab/Industry Partnerships

- Argonne (APS; Actinide Facility)
- Sandia (molecular dynamics modeling)
- Oak Ridge (geomicrobiology)
- DuPont Engineering Technologies

Workshops/conferences on nano-environmental research: examples

- NSF, 6/2002: "Nanoparticles and the environment" (grantees meeting, book)
- EPA, 11/2003: "Nanotechnology and the environment applications and implications" (grantees meeting, brochure)
- ACS, 3/2003: Symposium on nanotechnology implications in the environment, New Orleans
- NNI, 5/2003: Vision for environmental implications and improvement (interagency, report)
- NSET/NNCO, 8/2003: Review of Federal Regulations
- NNI, 9/2003: Interagency grantees meeting (report)

Regional alliances

- Nanotechnology Alliance in Southern California **www.larta.org/Nano**
- Nanotechnology Franklin Institute, Pennsylvania

  www.sep.benfranklin.org/resources/nanotech.html
- Texas Nanotechnology Initiative **www.texasnano.org**
- Virginia Nanotechnology Initiative **www.INanoVA.org**
- Denver Nano Hub **www.nanobusiness.org/denver.html**
- Silicon Valley, San Diego and Michigan Nano Hubs **May 2002**
- Massachusetts Nanotech Initiative (MNI) **Jan. 2003**
- Connecticut Nanotechnology Initiative (CNI) **Feb. 2003**

NSET/NNCO sponsors series of regional research providers / industry / business meetings for networking, **www.nano.gov**

State participation

Illustrations from 20 states

CA	California NanoSystem Institute	$100M/ 4 yrs
NY	Center of Excellence in Nanoelectronics; Albany Center	$50M, $400M/ 5 yrs
IL	Nanoscience Center (NU, U Ill, ANL)	$63M
PA	Nanotechnology Center	$37M
GA	Center at Georgia Tech	$25M
IN	Nanotechnology Center	$5M
TX	Nanotechnology Center	$0.5M over 2 yrs
SC	NanoCenter	$1M
AZ	Nanobio research	$5M for 20 years
NM	Consortium University of NM and National labs	
NJ	Support at NJIT and future nanophotonics consortium	
FL	Center at the University of South Florida	
OK	Nano-Net (~$3M/yr for 5 years)	

- OH (support Center $27M in Columbus), TN ($24M), Louisiana, CT, MA, VA, AZ

NNI key issues to be addressed in 2003 and beyond

Need for coherent 5-10 year programs:

- *draft Bill in Senate 189 "21st Century Nanotechnology R&D Act"*
  5-year "National Nanotechnology Program"; (NSF $350M in 2004)
- *similar draft bill in House of Representatives H.R.766 (2004-2008)*

Horizontal versus vertical S&T development:

0.5% in 2001 (on basics) versus 5% (plus precompetitive R&D) of US R&D budget

Long-term and short-term results

R&D vision:

- *Fundamental research, infrastructure, education **and societal implications***
- *Exploratory research in nanobiomedicine, molecular nanosystems,*
  *energy conversion, agriculture and food, realistic simulations, **environment***
- *Manufacturing science and **life cycle analysis***
- *International collaboration and competition, including **responsible nanotechnology***