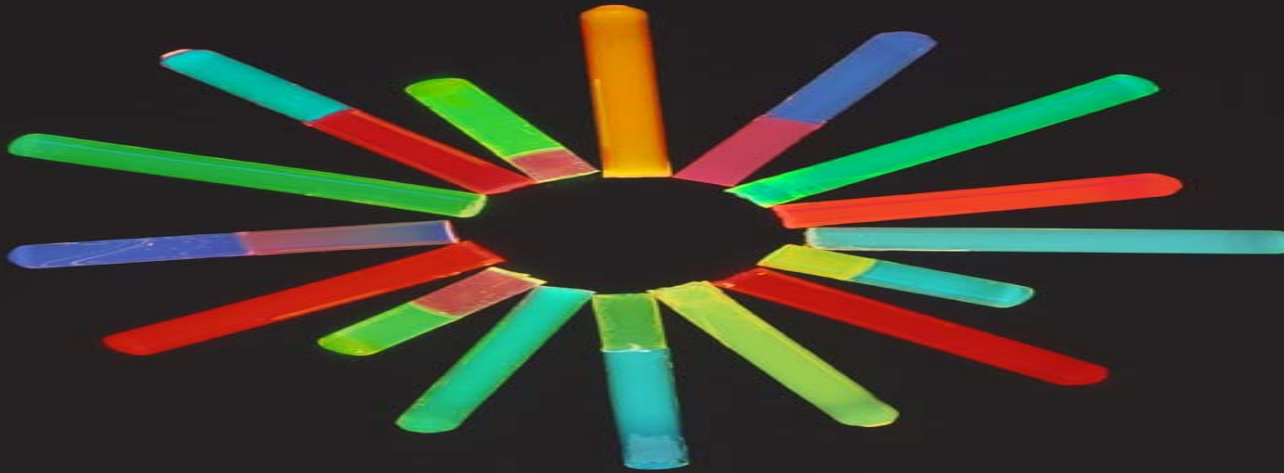


US EPA ARCHIVE DOCUMENT



F. Frankel - copyright

National Nanotechnology Initiative

Overview and environmental aspects

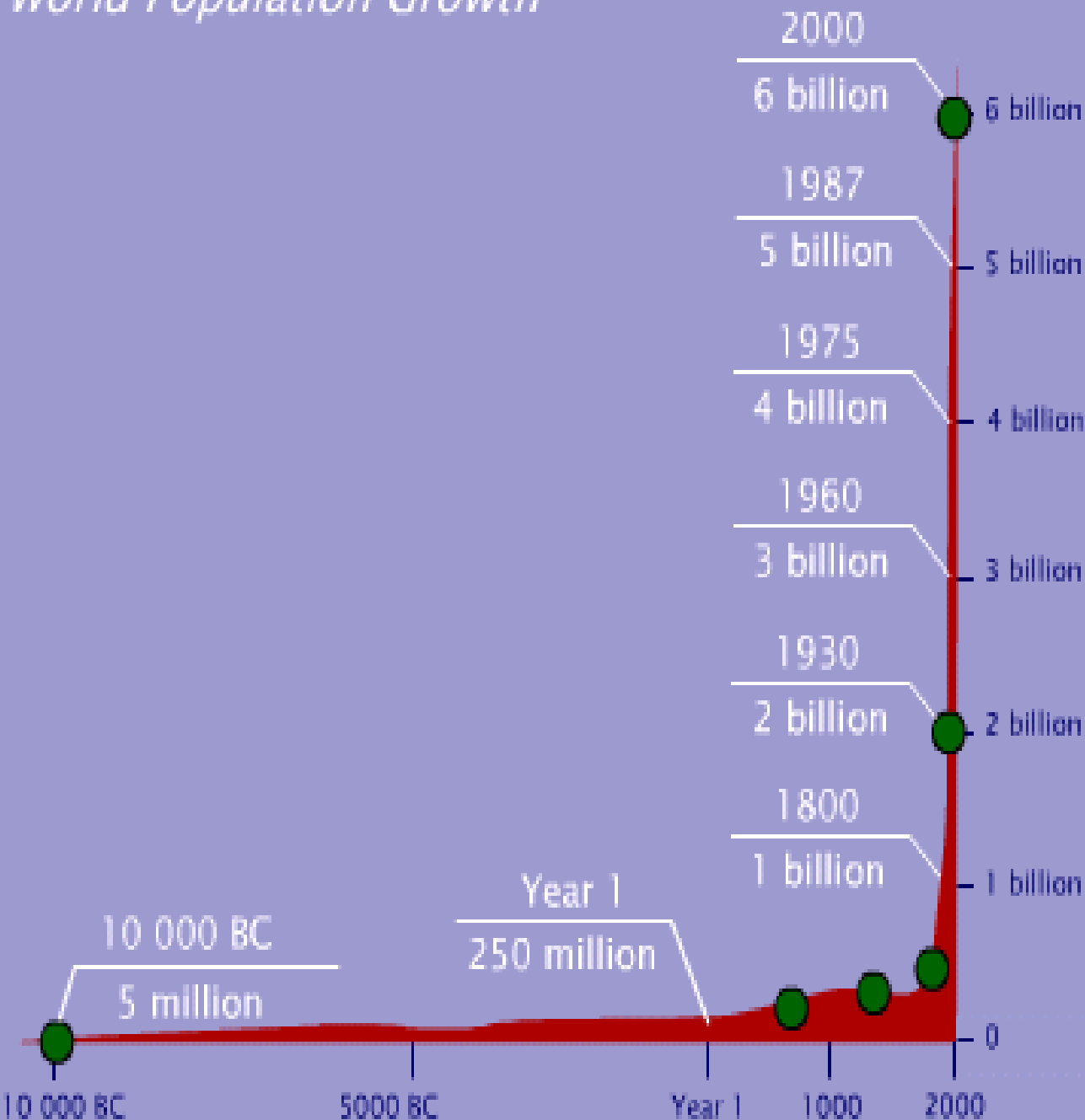
Dr. M.C. Roco

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

World Population Growth



More people

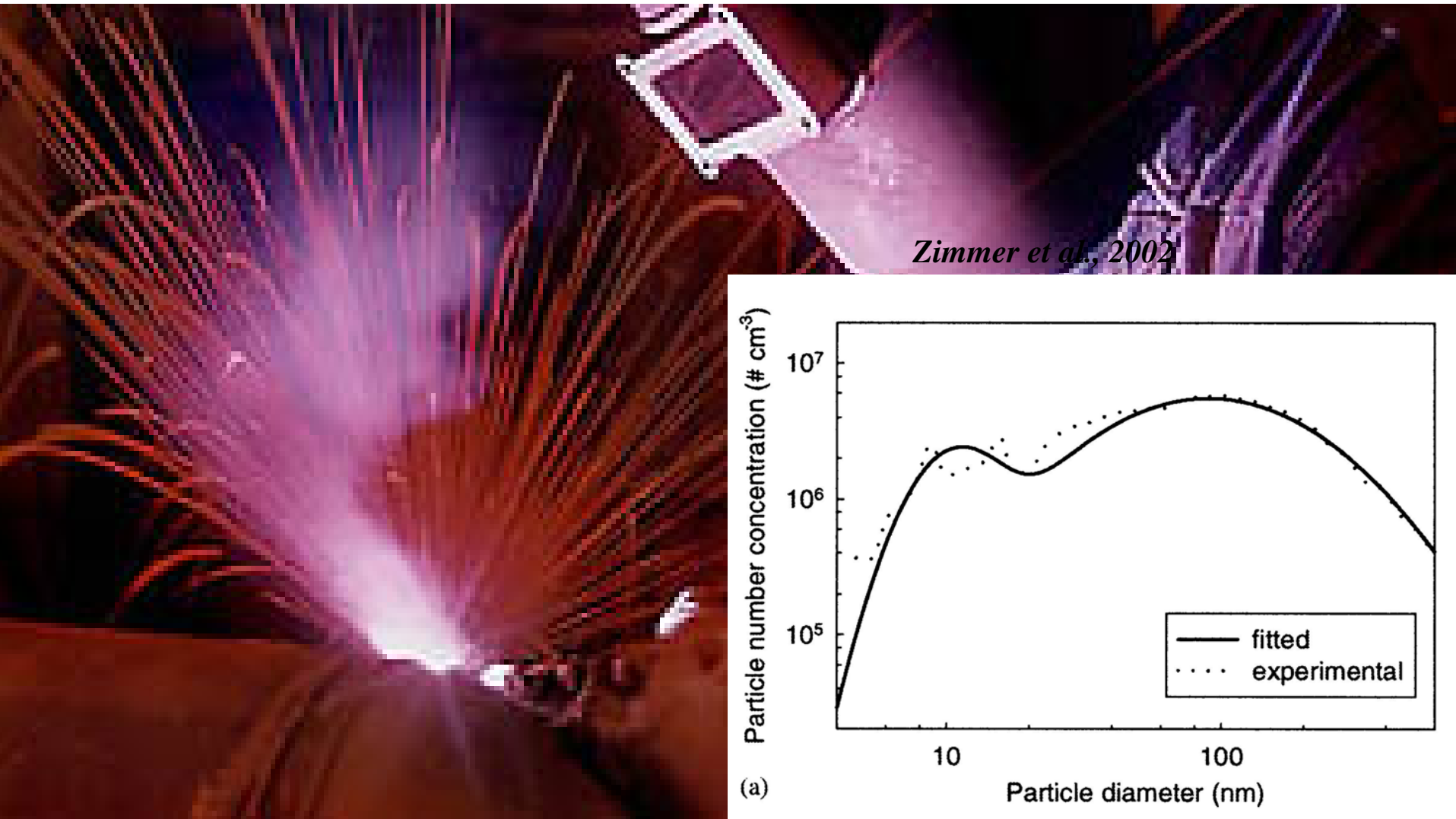
9-10 billion by 2050

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

**NEED OF
RADICALLY
NEW
TECHNOLOGIES**

Environmental issues related to nanotechnology include:

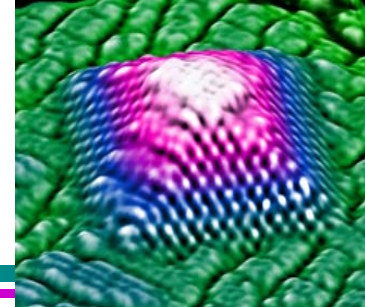
- Sustainable development, life-cycle of products, measurement and mitigation, clean-up techniques, global effects
- Combustion, welding, water/air filtration, cell behavior



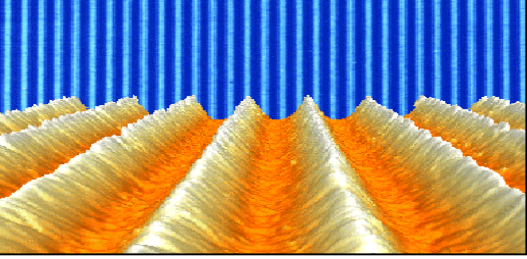


Nanotechnology

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

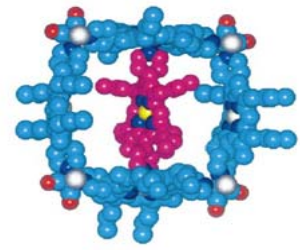
Tools ~ \$22 B/y

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



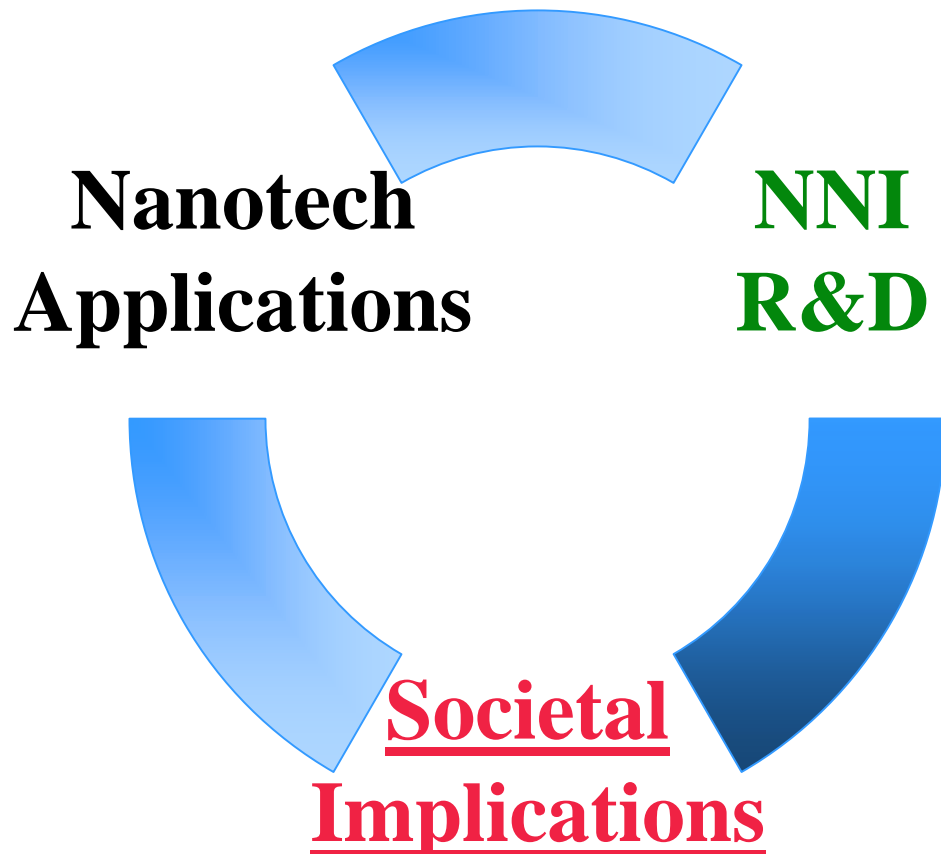
C. Timeline for beginning of industrial prototyping and commercialization

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 (?) -

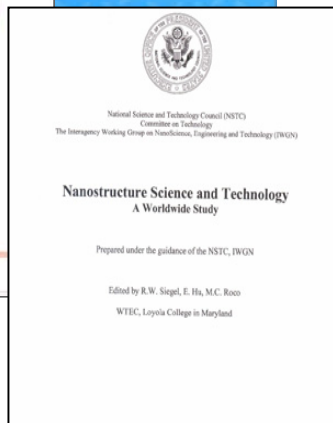
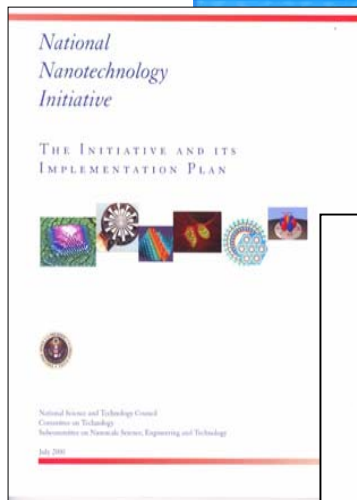
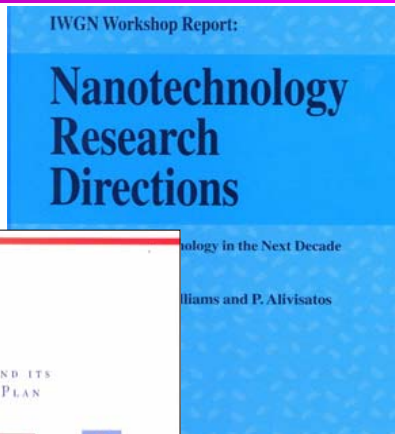
NNI R&D - closed loop with societal implications



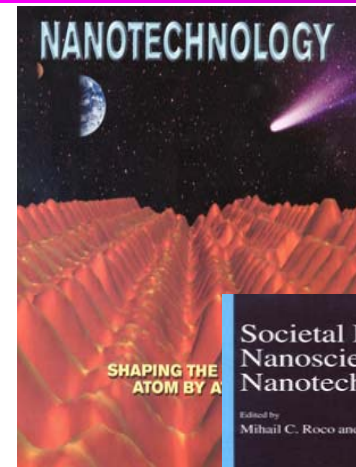
Defining the vision

National Nanotechnology Initiative

1999:
10-year
vision

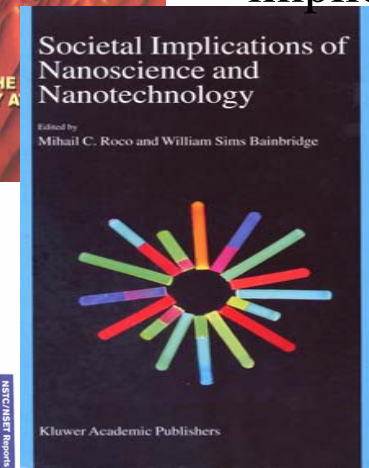


Reports



Brochure for
public

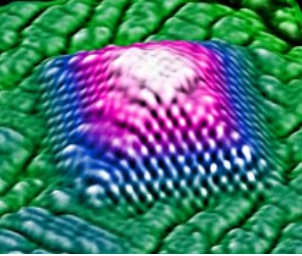
Societal
implications



Government
plan

Worldwide
benchmark

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

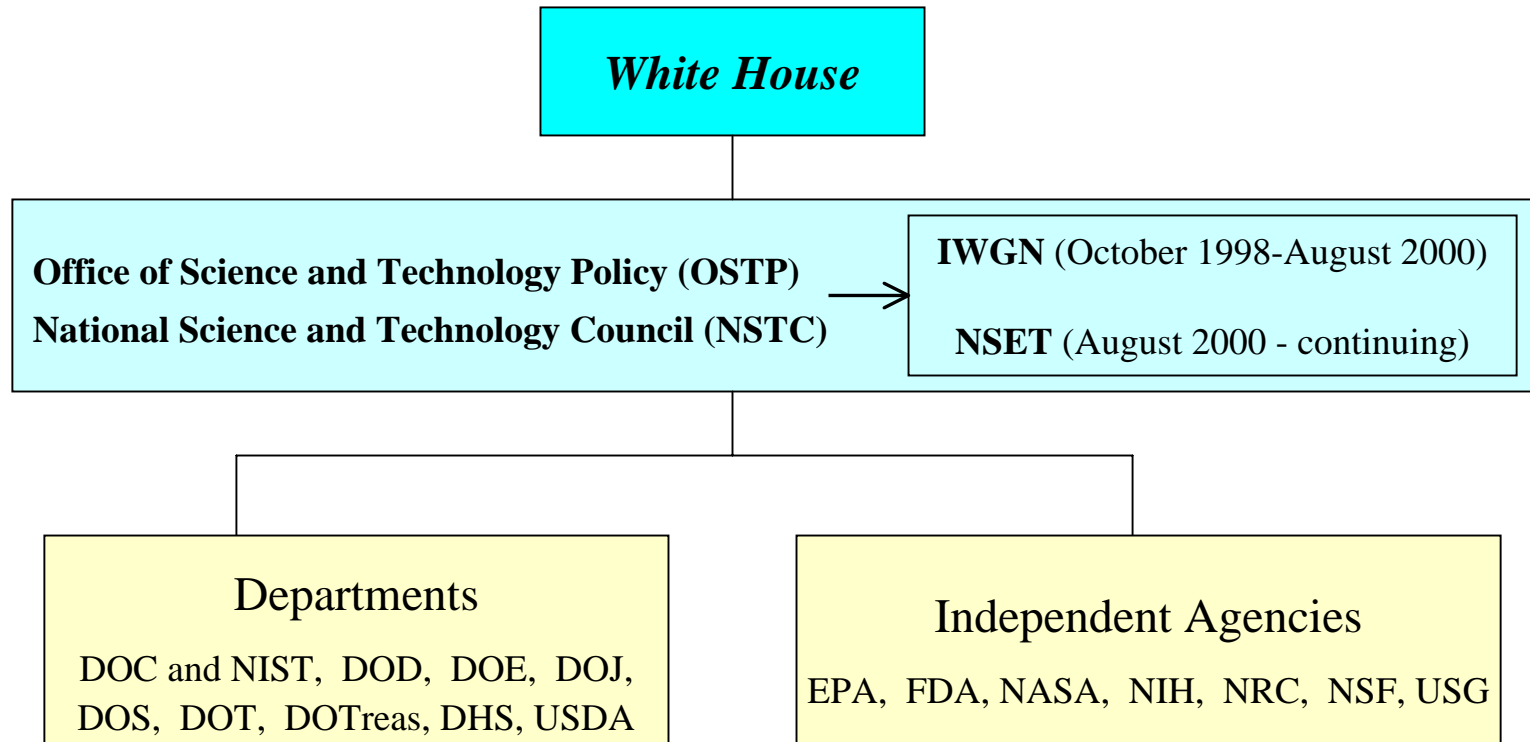
Workshops for receiving input from the community (examples):

- 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

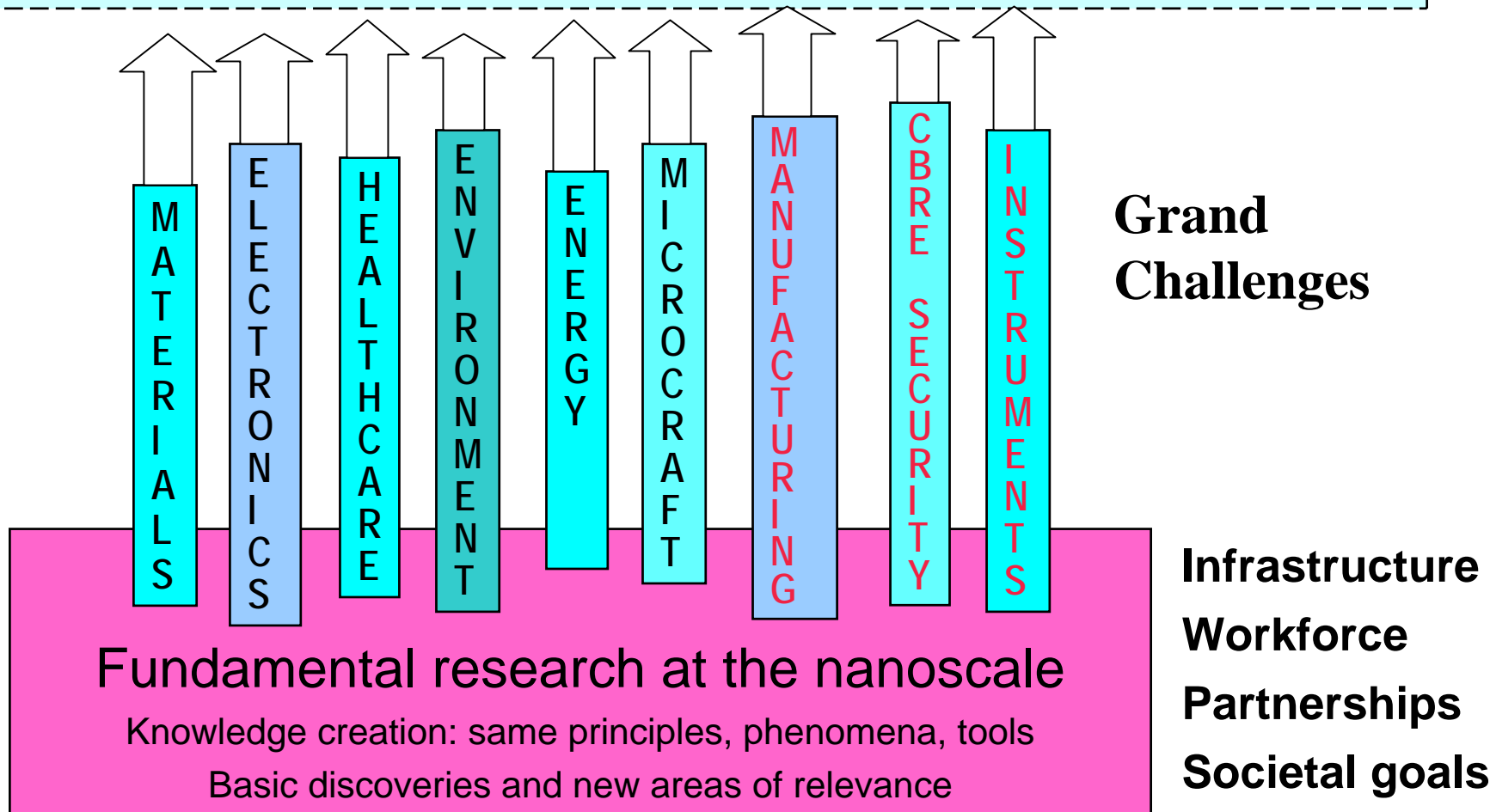
Organizations that have prepared and contribute to the National Nanotechnology Initiative



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

Revolutionary Technologies and Products



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

<i>Fiscal year</i> (all in million \$)	<i>2000</i>	<i>2001</i> Enacted/actual	<i>2002</i> Enacted/actual	<i>2003</i>	<i>2004</i> 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 (NIST 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

- 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

Societal Implications of
Nanoscience and
Nanotechnology

Edited by
Mihail C. Roco and William Sims Bainbridge



Kluwer Academic Publishers

<http://nano.gov>

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.)

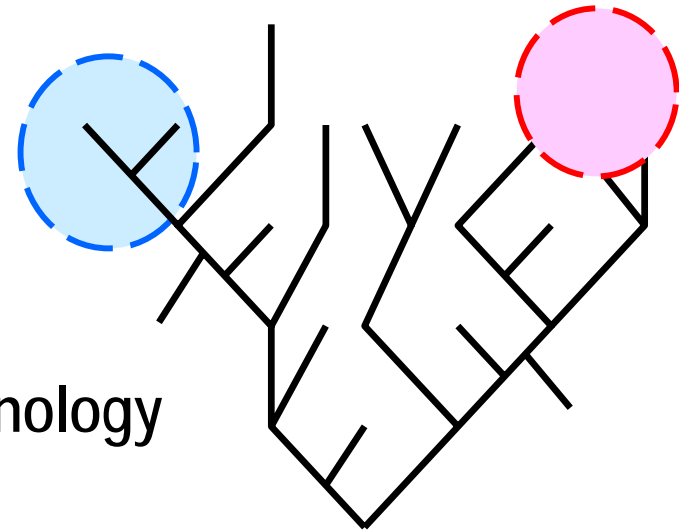
b. For nanoscale R&D with relevance to environment

(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**

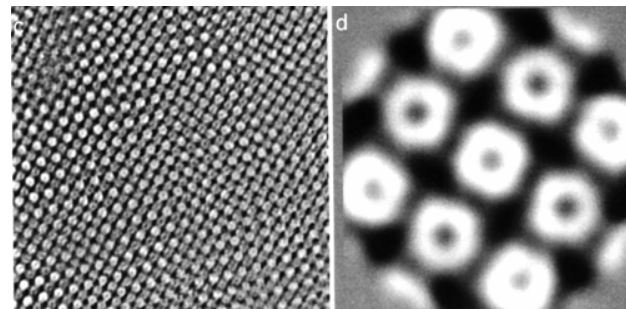
JF Banfield, UCB; PT Cummins, UVB; MK Ridley, TX Tech Univ (NIRT)

- **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.



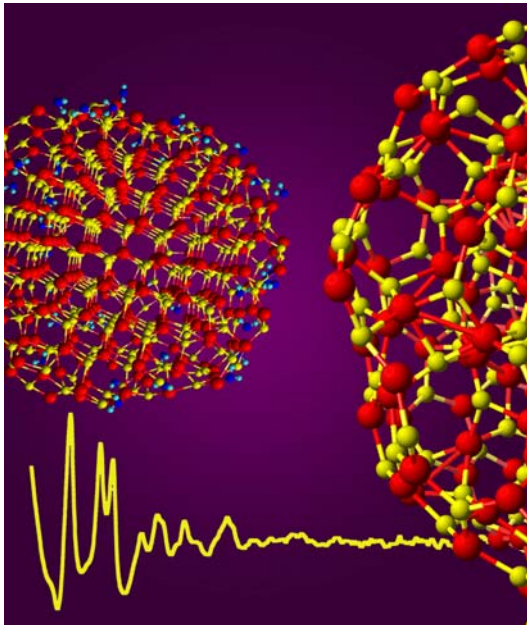
Protein layers of 11 nm diameter by bacteria

- **Biological and environmental nanotechnology**

V. Colvin, Rice U. (NSEC)

Nanoscale Processes in the Environment

J. Banfield, UCB, Wet nanoparticles



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.

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

Published in NATURE
(August 28, 2003)

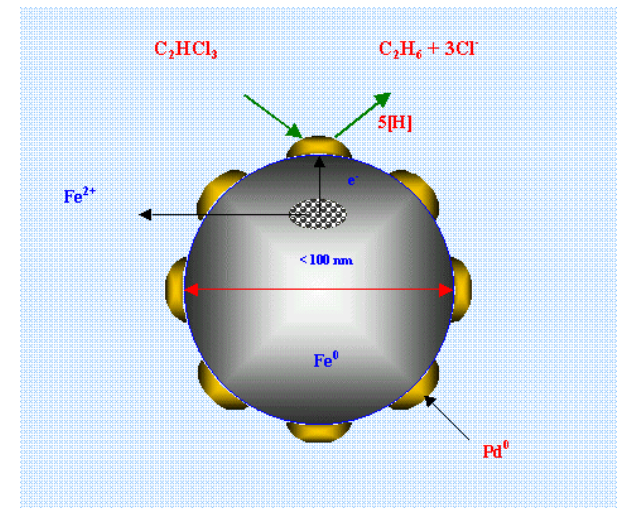
Implications for:

- 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 photocatalyst 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

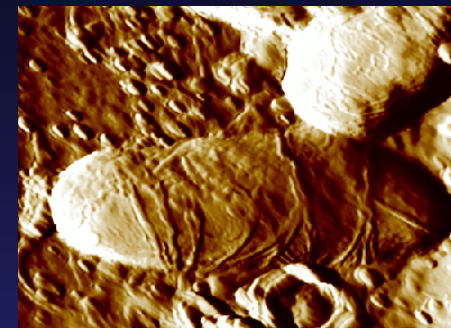
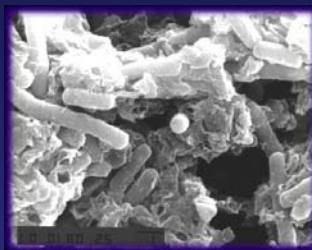
Environmental Molecular Science Institute

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



National Lab/Industry Partnerships

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



Education/Outreach Projects

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



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

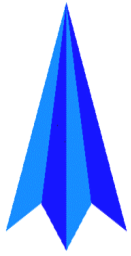
- Texas Nanotechnology Initiative www.texasnano.org
- Virginia Nanotechnology Initiative www.INanoVA.org
- Denver Nano Hub www.nanobusiness.org/denver.html
- Silicon Valley, San Diego and Michigan Nano Hubs **May 2002**
- Massachusetts Nanotech Initiative (MNI) **Jan. 2003**
- Connecticut Nanotechnology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