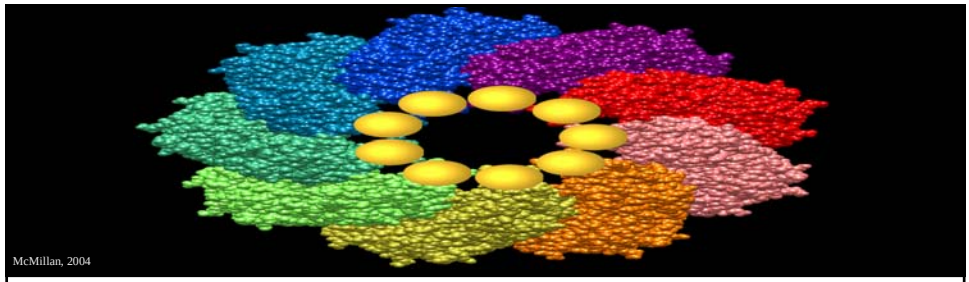


Nanoscale Science and Engineering at NSF

M.C. Roco

Senior Advisor for Nanotechnology, NSF

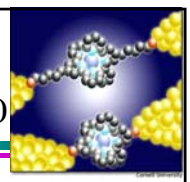
Chair, Subcommittee on Nanoscience, Engineering and Technology (NSET), National Science and Technology Council (NSTC)

- **Major changes in the first 4 years of NNI (2001-2004)**
- **NSF activities. The NSE program solicitation**
- **The national and international context**
- **Planning for the next five years**

Grantees Meeting, December 13, 2004

Nanotechnology

Definition on www.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, create and use 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

MC Roco, 12/13/04

10-20 years vision

Timeline for beginning of industrial prototyping and commercialization

Increased integration, system approach

Converging science and engineering

- **1st Generation:** Passive nanostructures **~ 2000**

Ex: coatings, nanoparticles, nanostructured metals, polymers, ceramics

- **2nd Generation:** Active nanostructures **~ 2005**

Ex: transistors, amplifiers, targeted drugs, actuators, adaptive structures

- **3rd Generation:** Systems of nanosystems **~ 2010**

Ex: guided molecular assembling; 3D networking and new system architectures, robotics, supramolecular

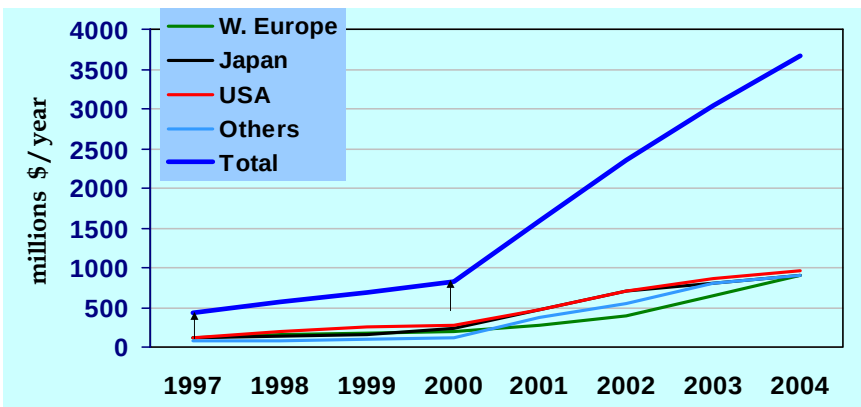
- **4th Generation:** Molecular nanosystems **~ 2020**

Ex: molecules as devices/components 'by design', based on atomic design, hierarchical emerging functions, evolutionary systems

AIChE Journal, 2004, Vol. 50 (5), MC Roco

Context – Nanotechnology in the World

Past government investments 1997-2004 (est. NSF)



Note:

- U.S. begins FY in October, six months in advance of EU & Japan (in March/April)

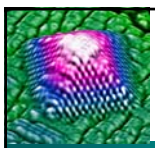
MC. Roco, 12/13/04

NNI: R&D Funding by Agency

Fiscal year (all in million $)	*2000* Actual	*2001* Enact/Actual	*2002* Enact/Actual	*2003* Enact/Actual	2004 Req./ Enact	2005 Req
National Science Foundation	97	150 /150	199 /204	221 /221	249 /254	305
Department of Defense	70	110 /125	180 /224	243 /322	222 /315	276
Department of Energy	58	93 /88	91.1 /89	133 /134	197 /203	211
National Institutes of Health	32	39 /39.6	40.8 /59	65 /78	70 /80	89
NASA	5	20 /22	35 /35	33 /36	31 /37	35
NIST	8	10 /33.4	37.6 /77	66 /64	62 /63	53
EPA	-	/5.8	5 /6	5 /5	5 /5	5
Homeland Security (TSA)	-		2 /2	2 /1	2 /1	1
Department of Agriculture	-	/1.5	1.5 /0	1 /1	10 /1	5
Department of Justice	-	/1.4	1.4 /1	1.4 /1	1.4 /1	1
TOTAL	270	422 /465	600 /697	770 /862	849 /961	982
		+72%	+50%	+24%		

- Industry, state and local organizations: about 1.5 times NNI budget in 2003
- 21 NSET departments / agencies, including: OSTP, NSTC, OMB, DOC, DOS, DOT, DOTreas, FDA, NRC, DHS, IC, NIOSH, USPTO; partnerships with others
- NNI budget: 65% to academia; 25% - R&D labs; 10% - industry (7% SBIR)

MC Roco, 12/13/04

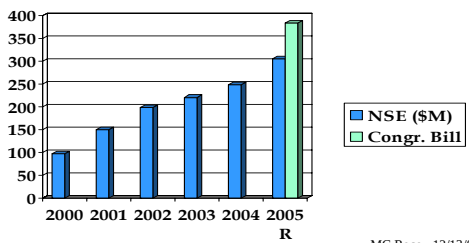


NSF - a pioneer among Federal agencies and at the international level in Nanoscale Science and Engineering (NSE)

FY 2003: ~ **1/4 of Federal** and **1/12 of World Investment**

- **Seven themes**: Biotechnology, Nanostructures 'by design' and novel phenomena, Device and system architecture, Environmental Processes, Multiscale modeling, Nanoscale manufacturing; Societal implications and Improving human performance
- **Establishing the infrastructure**: over 2,000 active projects; 20 large centers, 2 user facilities (NNIN, NCN), multidisciplinary teams
- **Training and education** over 7,000 students and teachers

Fiscal Year	NSF
2000	$97M
2001	$150M
2002	$199M
2003	$221M
2004	$254M
Request 2005	$305M



MC Roco, 12/13/04

Nanoscale Science and Engineering support at NSF in FY 2004

The budget appropriated by Congress: $254M

- **Program solicitations (about $91M, about 1/3)**
  - Nanoscale Science and Engineering - $79M, NSF 03-043
  - Nanoscale Science and Engineering Education - $12M, NSF 03-044
- **Support in the core program (about 2/3) with focus on single investigator & other core**
  - Various research and education programs in all directorates
  - Interdisciplinary fellowships; STC, MRSEC and ERC centers
  - Instrumentation (REG, MRI); Collaboration industry (GOALI, PFI)
  - Network for Computational Nanotechnology ($2.8M/yr)
  - National Nanotechnology Infrastructure Network ($14M/yr)
  - Nanoscale Informal Science and Education (NSF 03-511)
- **SBIR/STTR** (additional ~ $10M)

MC. Roco, 12/13/04

Nanoscale Science and Engineering support at NSF in FY 2005

The budget appropriated by Congress: $305M

- **Program solicitations (about $91M, about 1/3)**
  - Nanoscale Science and Engineering - $81M, NSF 04-043
    - NIRT, NER, NSEC (nanomanufacturing; societal implications)
  - Nanoscale Science and Engineering Education - $10M, NSF 04-xxx
    - Center for Nanoscale Informal Education, NUE
- **Support in the core program (about 2/3) with focus on single investigator & other core**
  - Various research and education programs in all directorates
  - Interdisciplinary fellowships; 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 (NSF 04-xxx)
- **SBIR/STTR** (additional ~ $12M)

MC. Roco, 12/13/04

NNI implementation plan published in July 2000

Major changes in the first 4 years of NNI (Part 1)

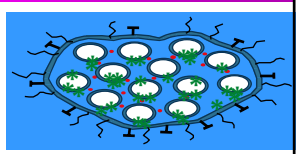
- **Research: NNI supports about 2,500 active awards (of which NSF funds about 2000) in over 300 academic organizations and 200 private organizations in all 50 states**; **Developments faster than expected: Reducing the time of reaching commercial prototypes by at least of factor of two for several key applications. Setting new goals.**
- **Education**: **8,000 students and teachers trained in 2004; All science and engineering colleges have introduced courses related to NSE. Earlier nanotechnology education.**
- **Significant infrastructure: in over 60 universities with user capabilities; Five networks (NCN,NNIN, OKN, DOE, NASA) have been established. About 40,000 workers**

MC Roco, 12/13/04

Example:

Synthesis and control of nanomachines

(examples NSE in 2004, www.nseresearch.org - 250 projects)



- Self-assembly processing of nanoscale bio-materials and devices for micromachines components (UCSB)
- Chemistry to synthesize components of nano machines to work on surfaces and be activated by external electromagnetic fields (UCB)
- Light driven molecular motors (U. Nevada)
- Combinatorial engineering of nanomachines, with application to membranes and filters (U. Penn.)
- Nanoengineering surfaces for probing viral adhesion (UC Davis)

MC Roco, 12/138/04

Exponential growth; About half of the highly cited papers in key journals originate in U.S.

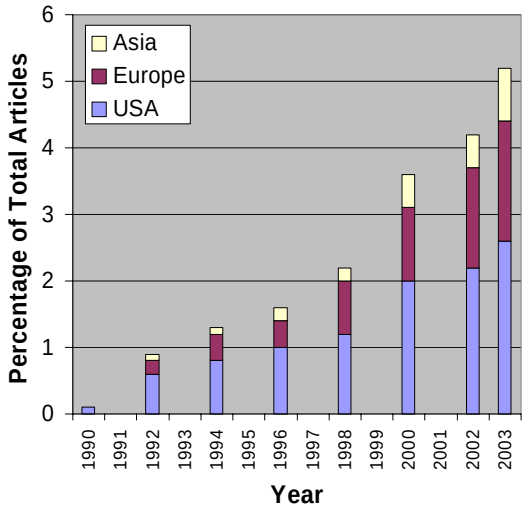
("nano*" keyword search, after NNI Report, 2005)

Journal ISI with high Impact Factors (2001):

Nature	27.9
Science	23.3
Physics Review Letters	6.6

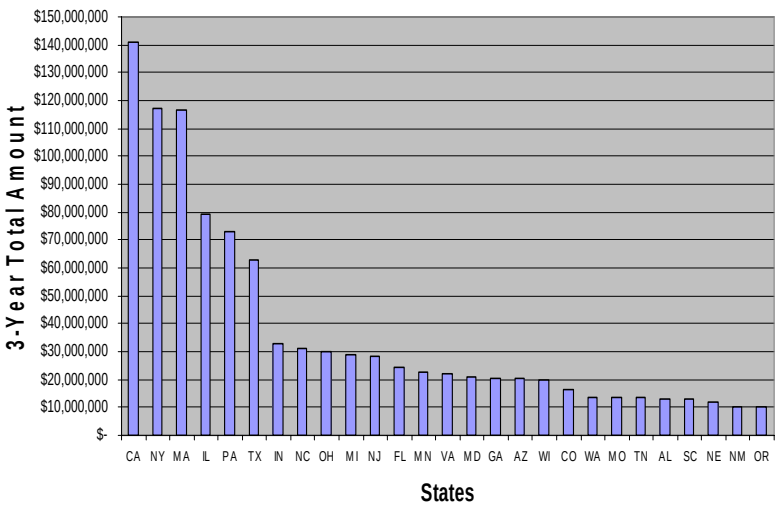
All others journals have impact factors under 4

Correlates well with the overall papers with ISI high impact



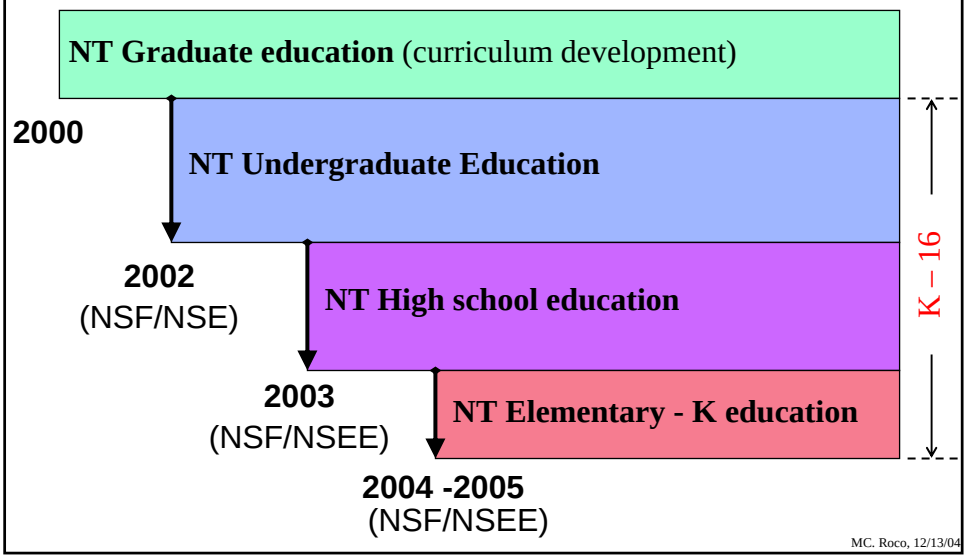
MC Roco, 12/13/04

States (US) awarded $10 million or more by NSF for new research grants in FY 2001-2003

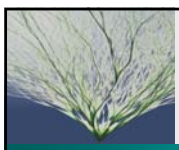


M.C. Roco, 12/13/04

Introducing earlier nanotechnology education
(NSF: Nanoscale Science and Engineering Education)



MC. Roco, 12/13/04



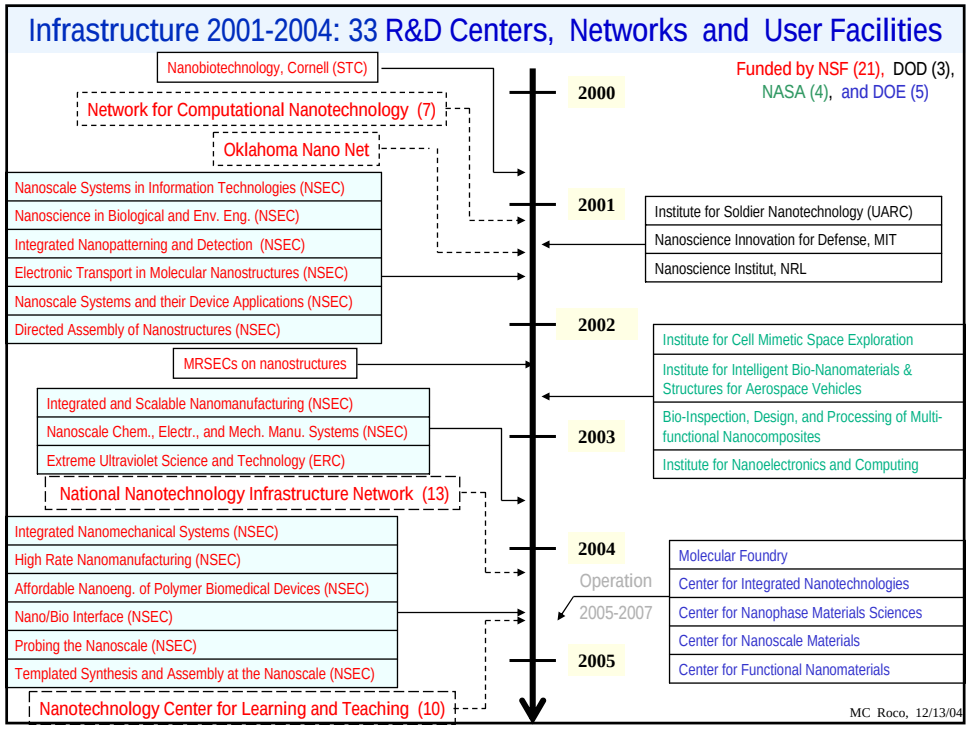
Infrastructure Outcomes of 2001-2004: NSF R&D Networks and User Facilities

- **Network for Computational Nanotechnology** (NCN)
  - **7** universities (Purdue as the central node)
  - Nanoelectronic device simulation/modeling
- **National Nanotechnology Infrastructure Network (NNIN)**
  - 13 universities with user facility
  - Development measuring & manufacturing tools, including NEPM
  - Education and societal implications
- **Oklahoma Nano Net (EPSCoR award)**

NSEC awards: 6 (2001); 0 (2002); 2 on Nanomanu. (2003); 6 (2004)

Note: 33 new centers and networks supported by NNI , 2000 - 2004:
21 NSF, 3 DOD, 5 DOE, 4 NASA (at universities); continuing MRSECs

MC Roco, 12/13/04



NNI implementation plan published in July 2000

Major changes in the first 4 years of NNI (Part 2)

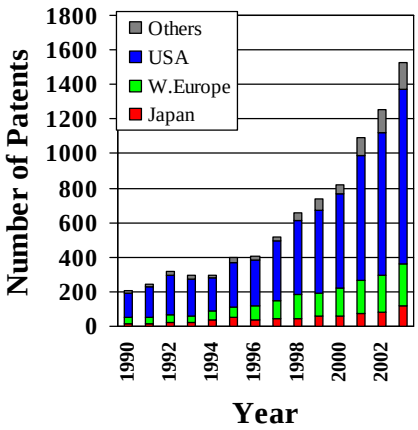
- **Industry:** about the same level of investment as NNI in medium and long-term research; Investment by large companies; From "if?" to "how?" and "who will lead?" All 'Fortune 500' in manufacturing, over 875 companies
- **Innovation and venture funding:** US has over 5,300 patents in 2003 with USPTO (61% world)
- **Estimation on revenues from nanotechnology:** Reaching $1 trillion in 2015 (or earlier) worldwide, accelerated development; growth >25% per year (catalysts, pharmaceutics, IT, ..)
- **States and regional alliances:** since 2002 > 20 states committed funding, > 22 regional alliances

MC. Roco, 12/13/04

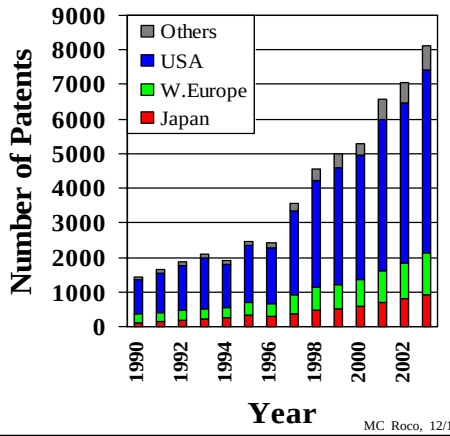
US has about 61% of world NT Patents (USPTO database)

using "Title-claims"and "Full-text" search for nanotechnology by keywords
(using intelligent search engine, after J. Nanoparticle Research, 2004, Vol. 6, Issue 4)

"Title-claims" search:
nanotechnology claims



"Full-text" search:
nanotechnology claims,
or/and NSE tools and methods



MC Roco, 12/13/04

NNI implementation plan published in July 2000

Major changes in the first 4 years of NNI (Part 3)

- **Professional societies**: Specialized divisions, workshops, education; AAAS, ACS, APS, MRS, ASME, AIChE, IEEE, other major societies in the race
- **Government investment**: Worldwide investment has increased 8 times in 7 years reaching $3.6B in 2004 (of which US $0.96B and NSF $0.25B)
- **Societal implications from the beginning (10%)**: Workshop on Societal Implications of Nanoscience and Nanotechnology in 2000; NSF programs since 2000
- **Other broader implications**:
  - Gain legislative support (H.R. 766, S. 189, Law 108-153)
  - Create a multidisciplinary nanotechnology community

M.C. Roco, 12/13/04

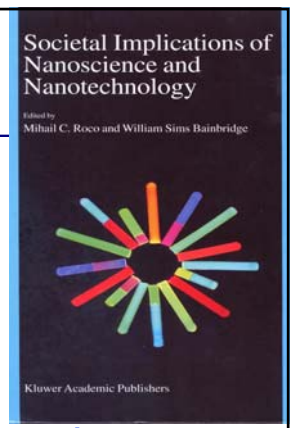
NNI-Industry Consultative Boards for Advancing Nanotech

Key for development of nanotechnology, Reciprocal gains

- **NNI-Electronic Industry (SRC lead), October 2003**
  - Collaborative activities in key R&D areas
  - 5 working groups, Periodical joint actions and reports
  - NSF-SRC agreement for joint funding; other joint funding
- **NNI-Chemical Industry (CCR lead)**
  - **Joint road map for nanomaterials R&D**
  - **2 working groups, including on EHS**
  - **Use of NNI R&D results, and identify R&D opportunities**
- **NNI – Organizations and business (IRI lead)**
  - **Joint activities in R&D technology management**
  - **2 working groups (nanotech in industry, EHS)**
  - **Exchange information, use NNI results, support new topics**
- **In developments: NNI - Pharmaceuticals (Phrma lead)**
  NNI - Automotive industry

MC Roco, 12/13/04

Societal Implications: Follow-up of the September 2000 report

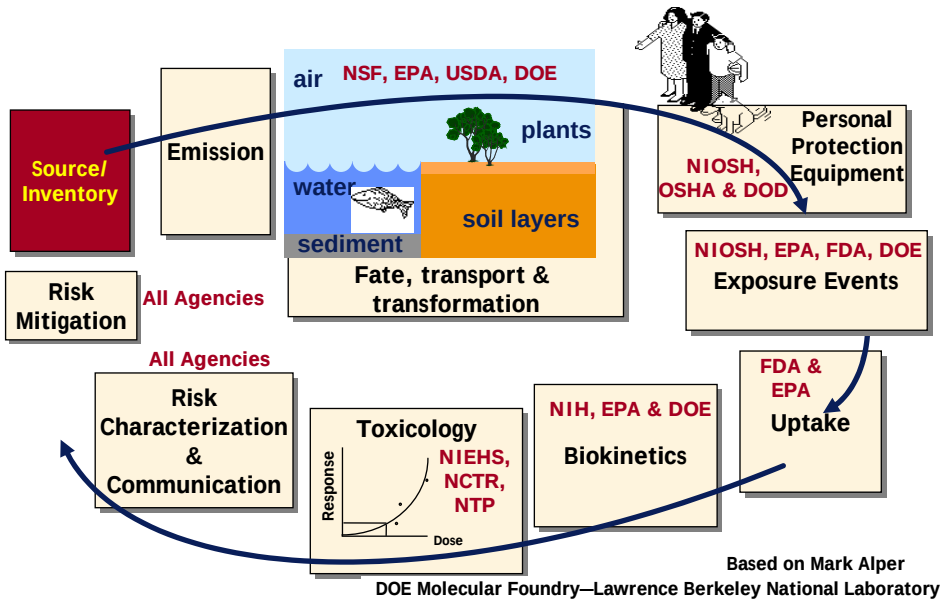


http://nano.gov

- Make support for social, ethical, and economic research studies a priority:
  (a) New theme in the NSF program solicitations;
  (b) Centers with societal implications programs;
  (c) Initiative on the impact of technology, NBIC, HSD
- NNCO – communicate with the public and address Environmental, Health and and Safety issues, and unexpected consequences
- NSET's Nanostructures Environmental and Health Issues working group has been established in 8/2003, 12 agencies
- Workshop with EC (2001); Links to Europe, Americas, Asia; International Dialogue (26 countries, NSF-sponsored)

MC Roco,12/13/04

B. Regulatory and Research Topics for EHS



NSE environmental, multidisciplinary projects (examples)

Center (details on www.nsf.gov/home/crssprgm/nano/nni01_03_env.htm)	**Institution**
Nanoscience in Biological and Environmental Engineering (est. 50% in environment), NSEC	Rice University ($11.8M)
NIRT: Investigating Nano-carbon Particles in the Atmosphere: Formation and Transformation	University of Utah ($1.7M)
NIRT: Nanoscale Processes in the Environment - Atmospheric Nanoparticles	Harvard University ($1.6M)
NIRT: Nanoscale Sensing Device for Measuring the Supply of Iron to Phytoplankton in Marine Systems	University of Maine ($0.9M)
NIRT: Combustion-generated Nanoparticles: The role of Transition Metals in Nanoparticles and Pollutant Formation	Louisiana St. University, ($1.2 million)
NIRT: The Role of Nanoscale and Molecular Structures in Dictating Environmental Reactivity	University of Alaska, Fairbanks ($1.5 million)
NIRT: Response of Aquatic and Terrestrial Microoganisms to Carbon-based Manufactured Nanoparticles	Purdue University, $1.6 million (2004-2008)

M.C. Roco, 12/13/04

Defining the vision (II)

National Nanotechnology Initiative

2004

2004: 10-year vision

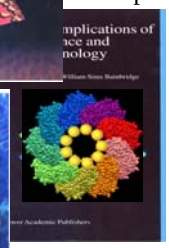
Government Plan (annual)

Survey manufacturing

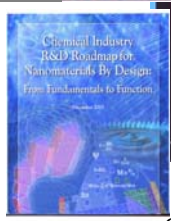
Agriculture and Food

Energy

Societal Implications 2004



Reports



Other topical reports on www.nano.gov

2004: Update 10 year vision, and develop strategic plan

MC Roco, 9/08/04

This grantees meeting

- Review awards from the NSE solicitation

  Each presentation:
  Focus on the group's R&E themes, highlights of results, future work and opportunities for collaboration

- Timely exchanges and collaborations
  research teams – centers - education groups - industry
  See posters from centers and industry
  Four discussion rooms are available

  Address common issues:
  New research and education directions,
  EHS, collaboration with industry sectors (see panels)

- An outcome:
  Strengthen the NSE interdisciplinary community