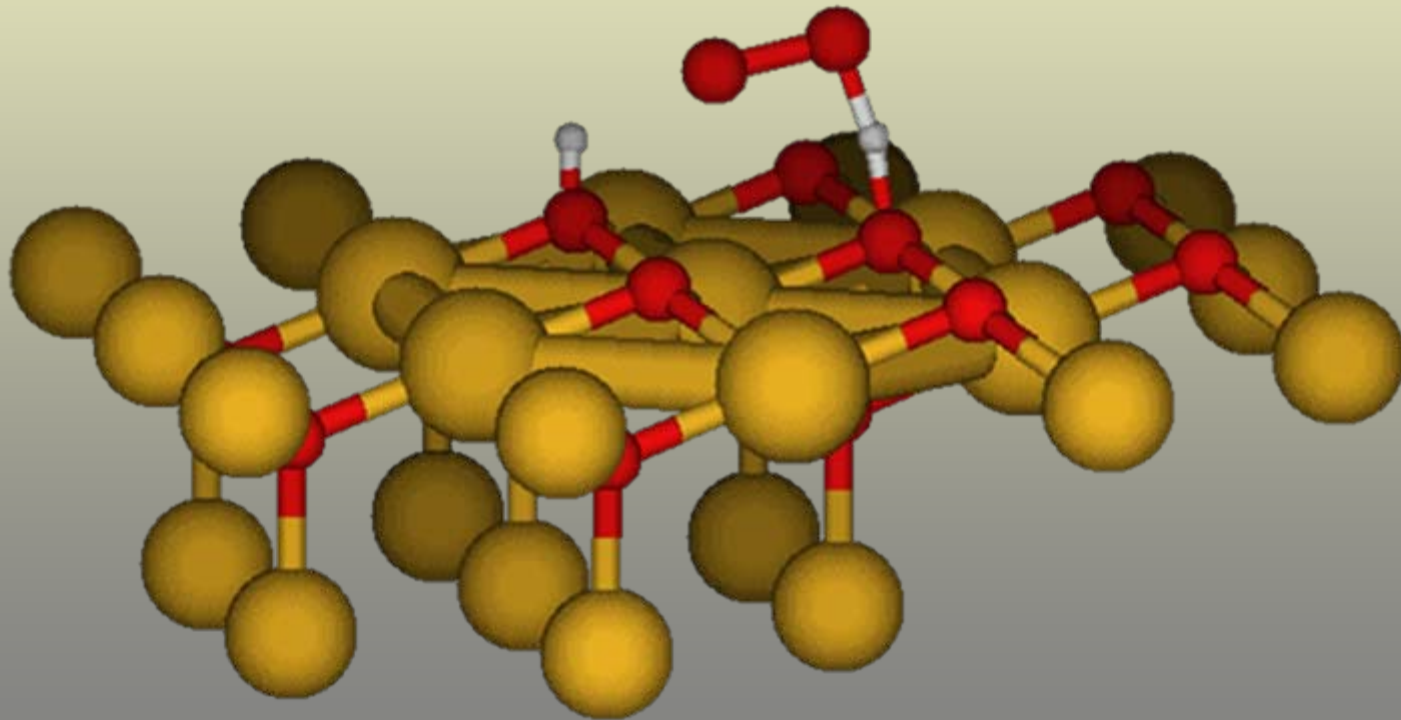


2008 NSF Nanoscale Science
and Engineering Grantees
Conference
December 3-5, 2008



Nanotechnology at NSF

M.C. Roco

**National Science Foundation
and National Nanotechnology Initiative**

NSF's Nanoscale Science and Engineering Grantees Conference
December 3, 2008

Benchmark with experts in over 20 countries

"Nanotechnology Science and Technology"

Book Springer, 1999



Nanotechnology

is creation of materials, devices and systems
by *control and restructuring of matter* at
dimensions of roughly 1 to 100 nanometers,

- ⇒ at the transition from individual to collective behavior of atoms and molecules
- ⇒ where new phenomena
- ⇒ enable new applications

Nanotechnology Research Directions

Vision for Nanotechnology in the Next Decade

Edited by
M.C. Roco, R.S. Williams and P. Alivisatos

Book, Springer, 2000

“Vision for nanotechnology in the next decade” (2001-2010)

Systematic control of matter on the nanoscale will lead to a revolution in technology and industry

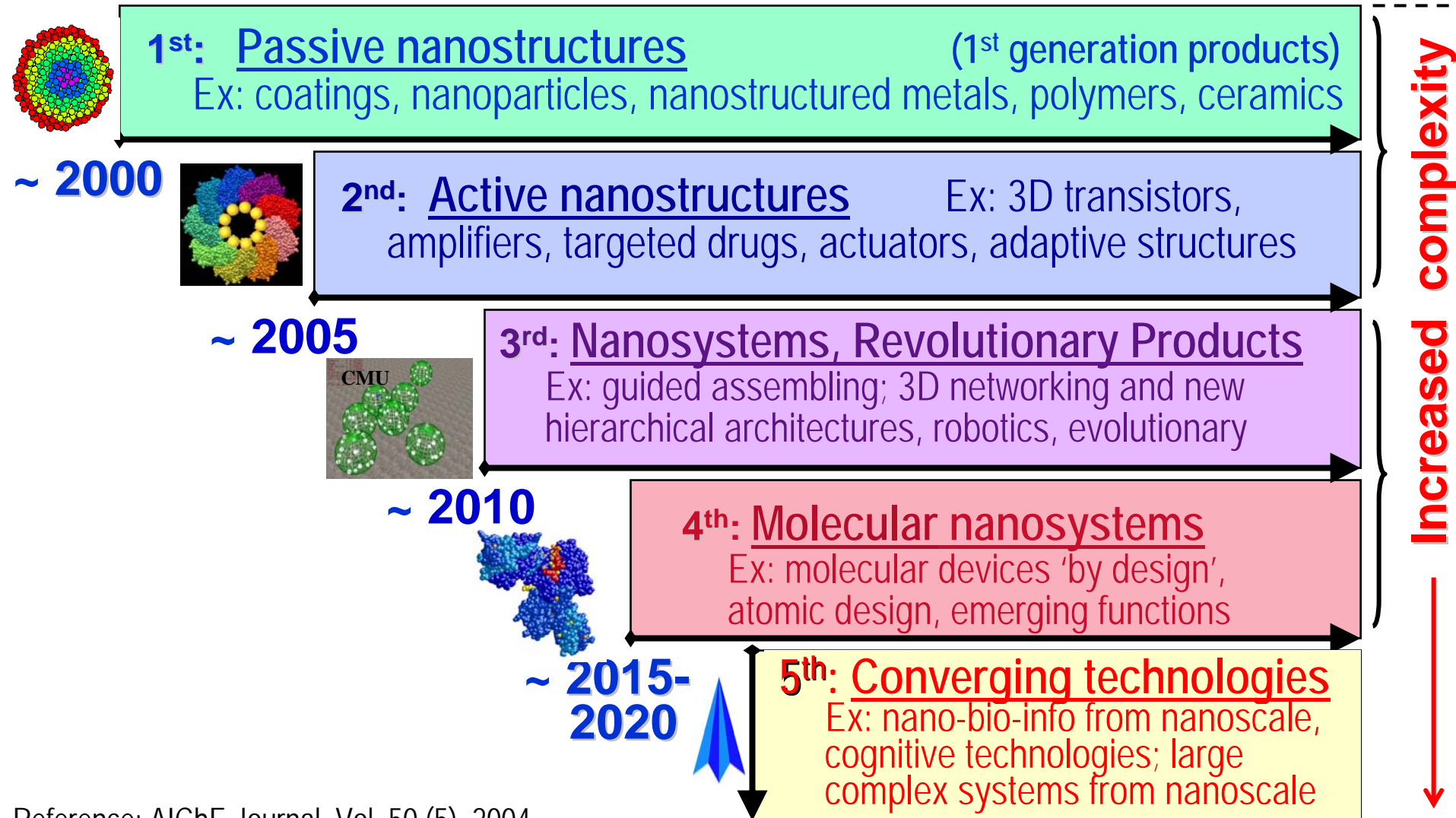
- Change the foundations from micro to nano
- Create a general purpose technology (similar IT)

More important than miniaturization itself:

- Novel properties/ phenomena/ processes
- Unity and generality of principles
- Most efficient length scale for manufacturing
- Show transition from basic phenomena and components to system applications in 10 areas and 10 scientific targets

Generations of Products and Productive Processes

Timeline for beginning of industrial prototyping and nanotechnology commercialization (2000-2020)



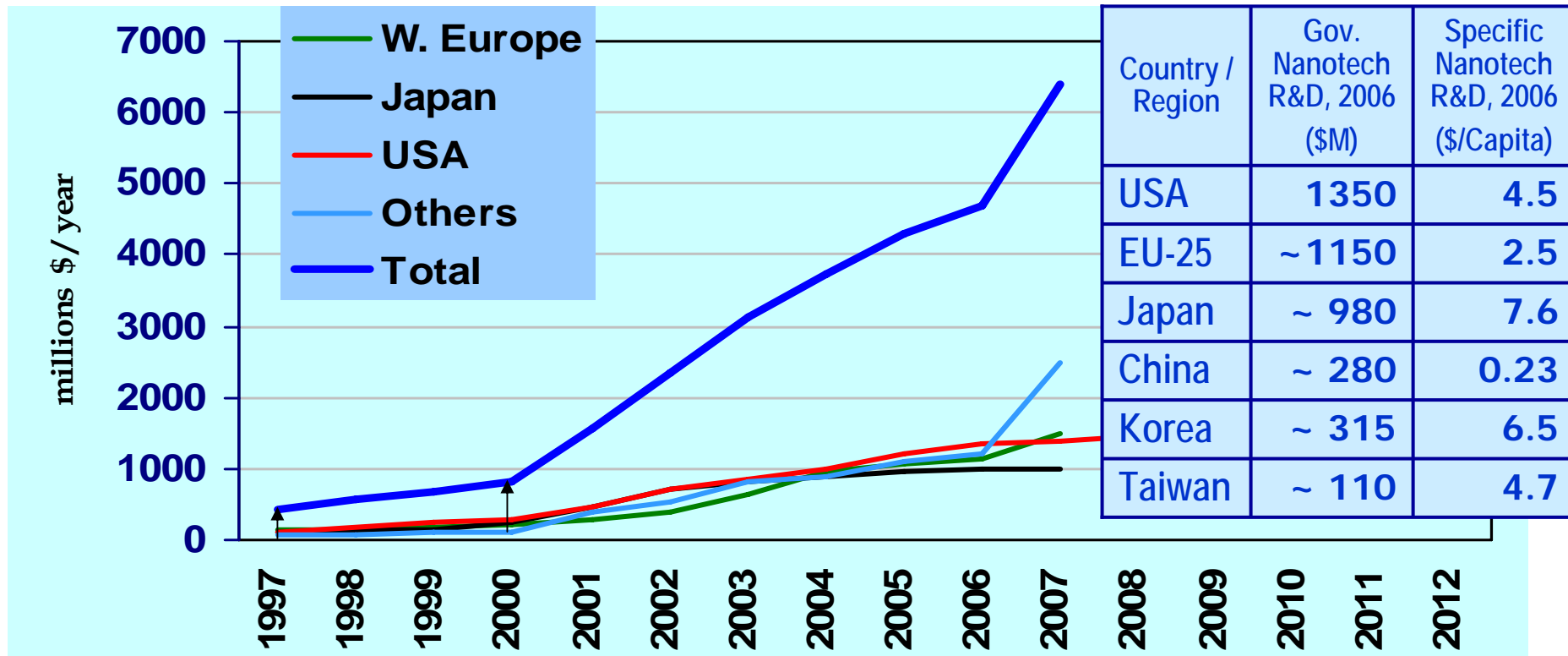
National Nanotechnology Initiative

Collaborative, multi-agency, cross-cut program among 25 Federal agencies



Context – Nanotechnology in the World

National government investments 1997-2007 (est. NSF)



Seed funding
(1991 -)

NNI Preparation
(vision / benchmark)

1st Strategic Plan
(passive nanostructures)

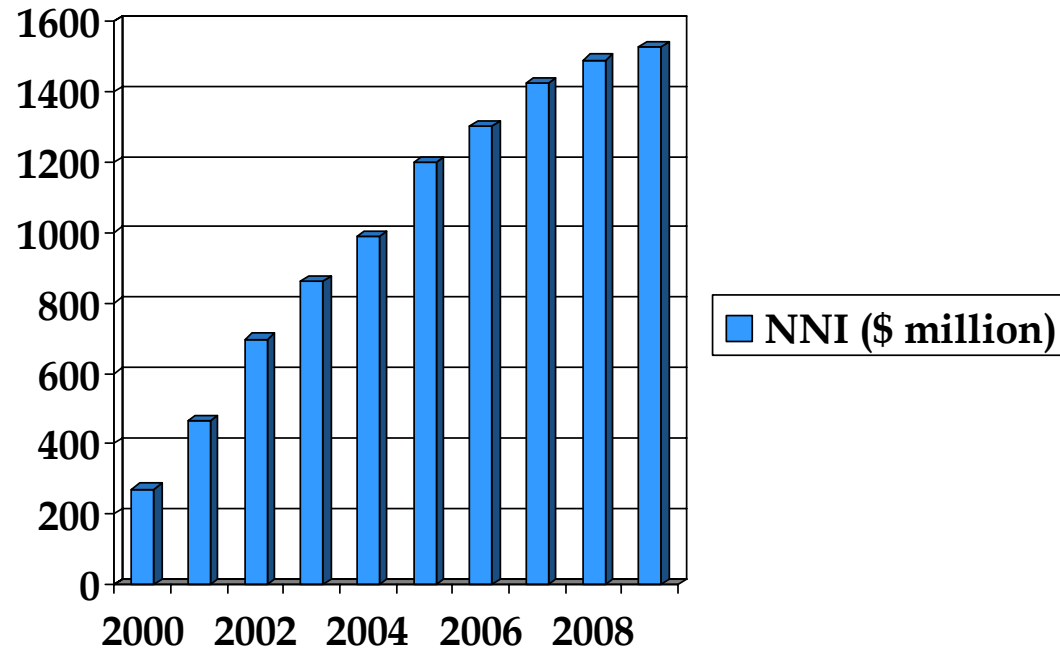
2nd Strategic Plan
(active ns. & systems)

Industry R&D (~\$7.3B) exceeded public R&D (~\$6.5B) in 2007; total \$13.8B

Changing national investment

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

Fiscal Year	NNI
2000	\$270M
2001	\$464M
2002	\$697M
2003	\$862M
2004	\$989M
2005	\$1,200M
2006	\$1,303M
2007	\$1,425M
2008	\$1,491M
R 2009	\$1,527M



NNI / R&D ~ 1/4 of the world R&D



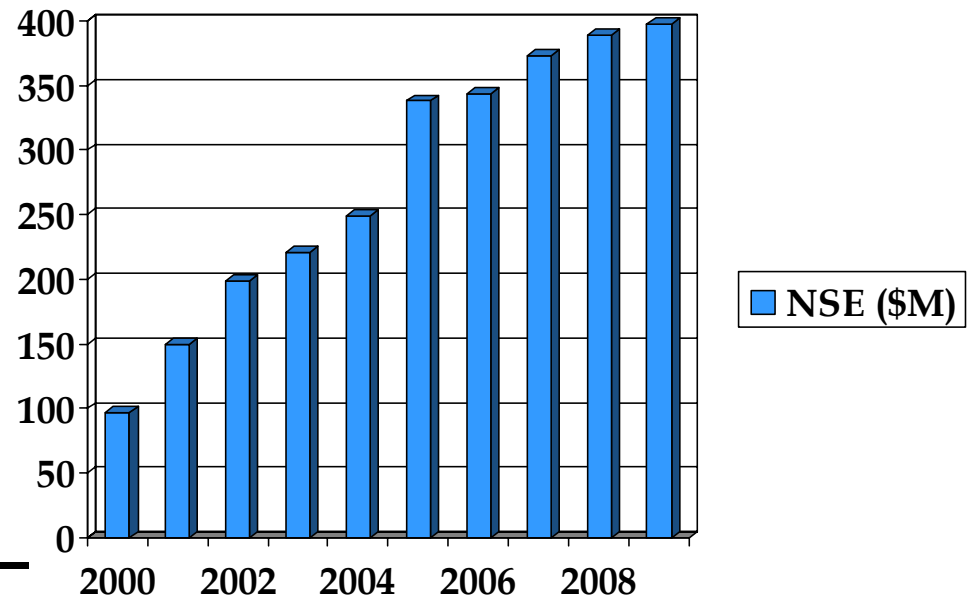
NSF – discovery, innovation and education in Nanoscale Science and Engineering (NSE)

www.nsf.gov/nano , www.nano.gov

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; 26 large centers, 2 user facilities (NNIN, NCN), multidisciplinary teams
- **Training and education** – over 10,000 students and teachers/yr

Fiscal Year	NSF
2000	\$97M
2001	\$150M
2002	\$199M
2003	\$221M
2004	\$254M
2005	\$338M
2006	\$344M
2007	\$373M
2008	\$389M
R 2009	\$397M



NSE: Role of Engineering

Engineering has a leading role in NSE because:

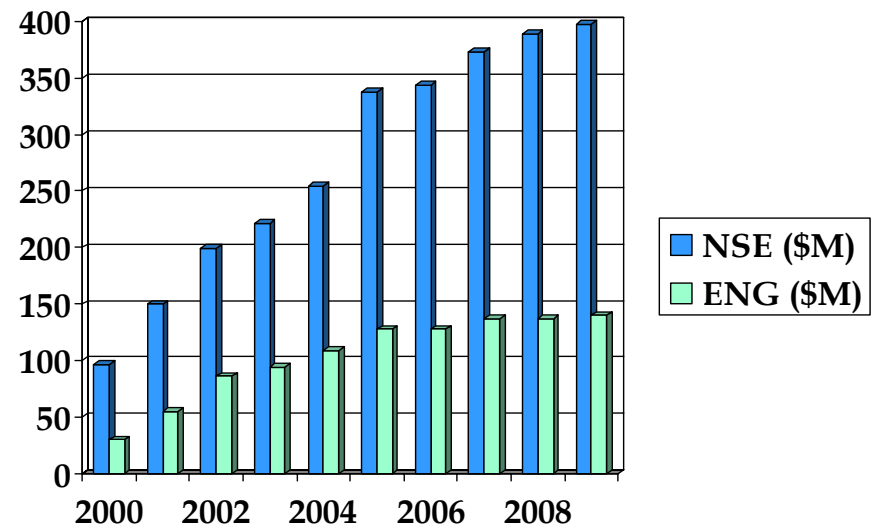
- nanotechnology deals with systems at nanoscale
- integrative, interdisciplinary
- transforming tool

Collaboration with NSF Directorates: MPS, CISE, BIO, GEO, SBE, HER

Also, NNI - 24 departments and agencies (DOE, DOD, NASA, NIH, NIST, EPA, etc.)

Changing engineering disciplines (research, education, relevance)

2000	\$97M	\$30.0M
2001	\$150M	\$55.3M
2002	\$199M	\$86.3M
2003	\$221M	\$94.4M
2004	\$254M	\$108.9M
2005	\$338M	\$127.8M
2006	\$344M	\$127.8M
2007	\$373M	\$137.2M
2008	\$389M	\$137.2M
2009	\$397M	\$140.0M





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 ~ \$17M/year)

FY 2009 NSF Budget Request to Congress (\$397 M) by Directorates and Program Component Areas

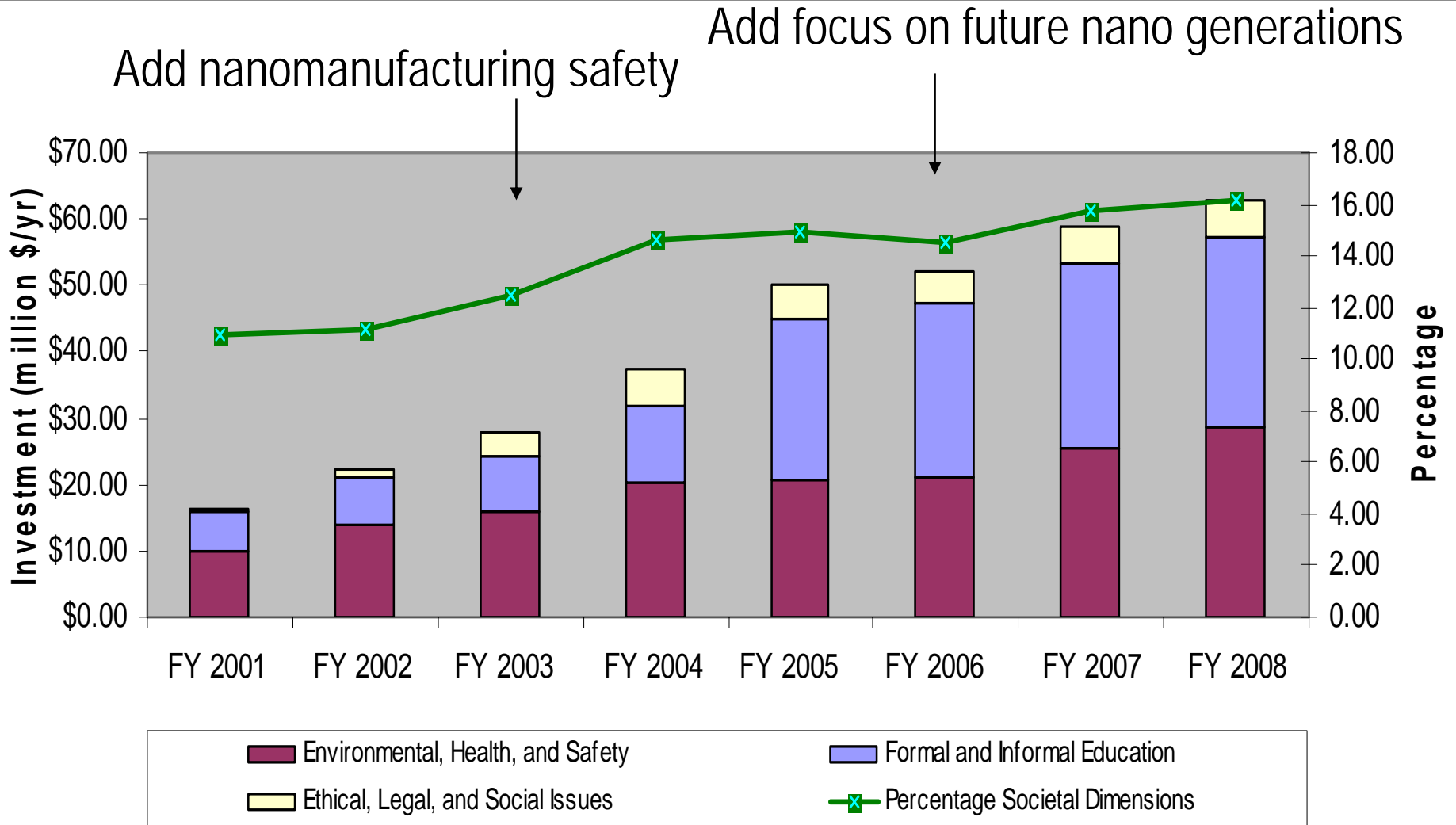
Seven directorates participate

(Dollars in Millions)	BIO	CISE	ENG	GEO	MPS	SBE	R&RA	EHR	Total, NSF
Program Component Area	56.6	11.0	140	6.33	\$178	1.6 7	393.7	\$3.1	396.8
Fundamental Nanoscale Phenomena & Processes	39.5	1.00	19.2		81.52		141.2		141.2
Nanomaterials	0.05		16.0		47.00		63.05		63.1
Nanoscale Devices & Systems	0.50	5.60	44.0		1.50		51.60		51.6
Instrumentation Rsch, Metrology & Stds for Nanotech	6.00		4.50		5.50		16.00		16.0
Nanomanufacturing		2.40	24.0		0.50		26.90		26.9
Major Rsch Facilities & Instrumentation Acquisition	5.00	2.00	6.62		18.47		32.09		32.1
Societal Dimensions: Envir Health & Safety (EHS)	5.05		11.0	6.33	8.26		30.64		30.6
Societal Dimensions: Education (EDUC)	0.50		12.0		14.20		26.70	3.1	29.8
Societal Dimensions: Ethical, Legal & Others (ELSI)			2.70		1.12	1.67	5.49		5.49

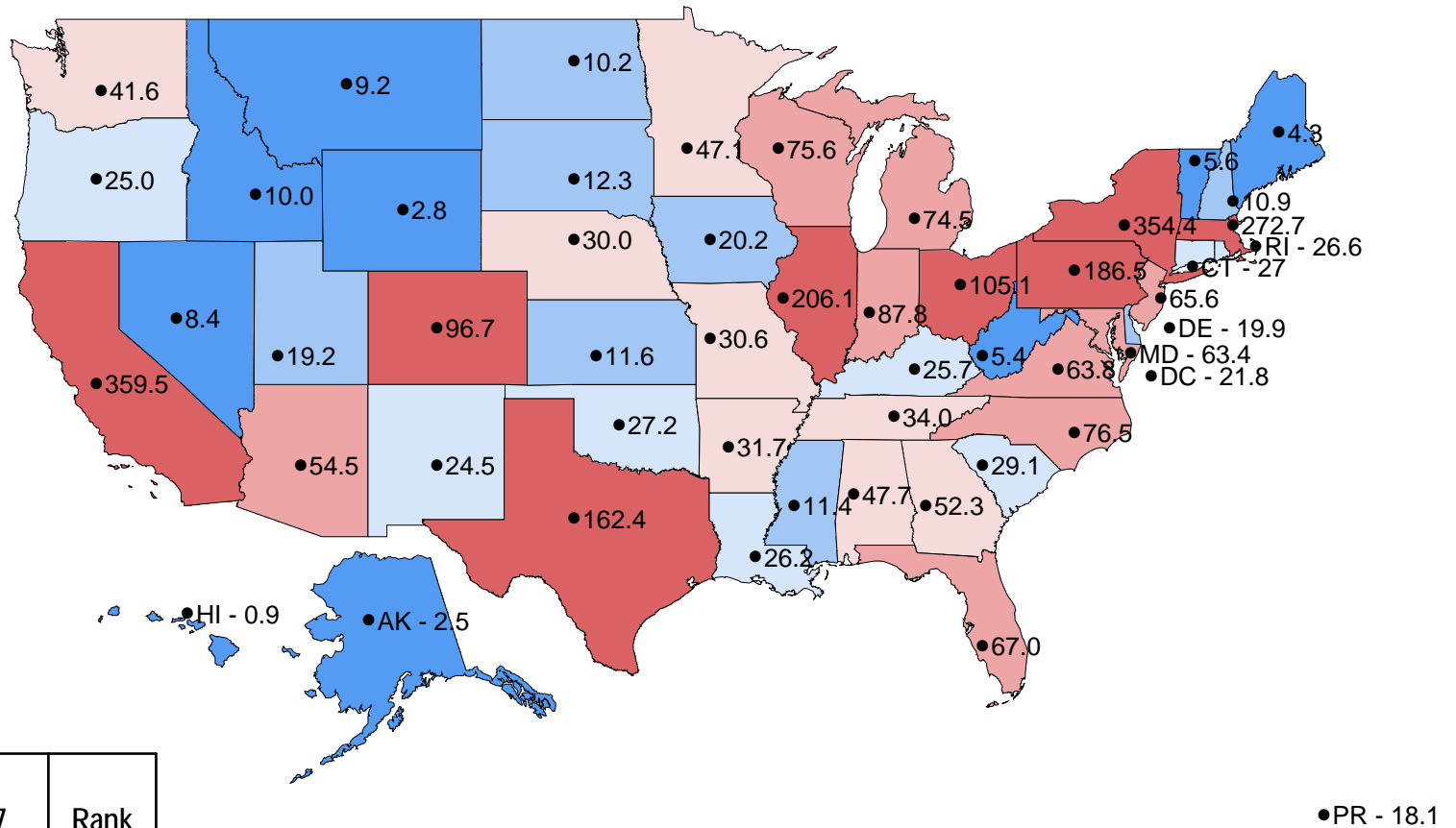


NSF Investment in Societal Dimensions of NT

Of FY 2008 NNI / NSF request of \$390 M,
\$63 M or 16.1% is for SI, and \$28.8 M (7.4%) for nano ENV/EHS



Total Amount for NEW NS&E Awards FY 2001 – 2007 by State



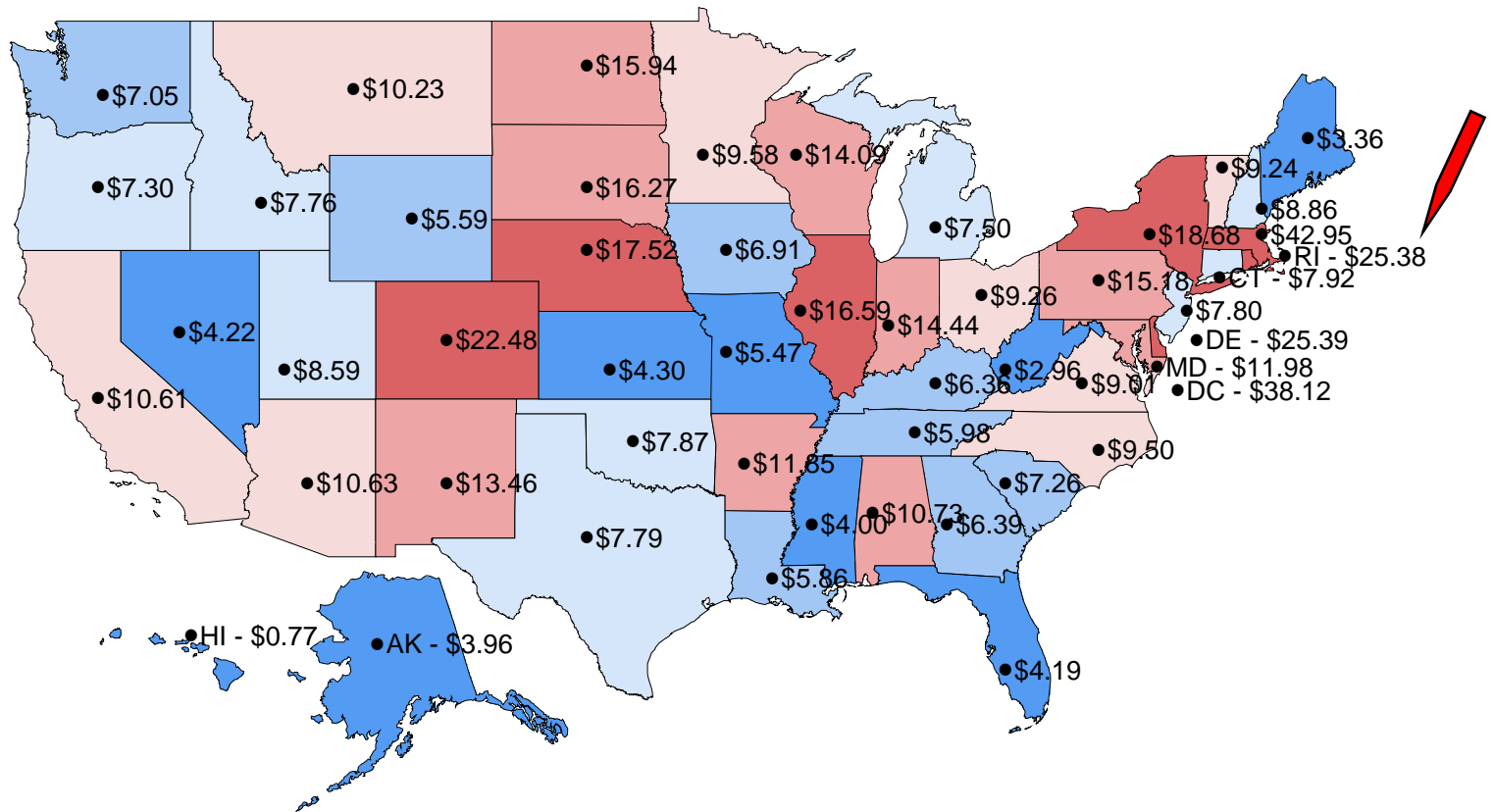
State	NEW FY 2001-2007	Rank
CA	\$359,529,514	1
NY	\$354,432,745	2
MA	\$272,681,724	3
IL	\$206,073,629	4
PA	\$186,473,981	5

NEW Awd. Amt. FY01-07 (\$10^6)

- ≤ 10
- 10 - 20.2
- 20.2 - 29.1
- 29.1 - 52.3
- 52.3 - 87.8
- 87.8 - 359.5

• PR - 18.1

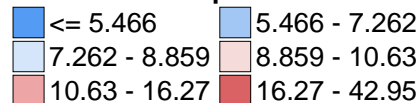
Per Capita Amount for NEW NS&E Awards FY 2001 – 2007 by State



●PR - \$4.79

State	NEW FY 2001-2007	\$ Per Capita	Rank
MA	\$272,681,724	\$42.95	1
DC	\$21,804,945	\$38.12	2
DE	\$19,893,702	\$25.39	3
RI	\$26,604,737	\$25.38	4
CO	\$96,677,354	\$22.48	5

FY01-07 PerCapita NEW Amt.



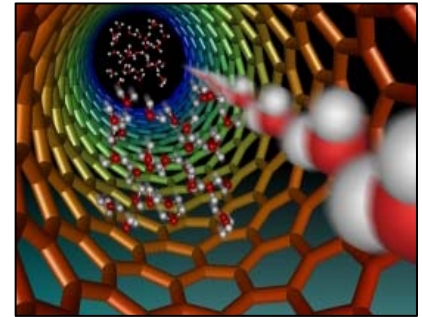
Nanotechnology in 2008, still in an earlier formative phase of development

- Characterization of nanomodules is using micro parameters and not internal structure
- Measurements and simulations of a domain of biological or engineering relevance cannot be done with atomic precision and time resolution of chemical reactions
- Manufacturing Processes – empirical, synthesis by trial and error, some control only for one chemical component and in steady state
- Nanotechnology products are using only rudimentary nanostructures (dispersions in catalysts, layers in electronics) incorporated in existing products or systems
- Knowledge for risk governance – in formation



FY 2009 NS&E Priorities Research Areas (1)

The long-term objective is building a foundation of fundamental research to understand and restructure matter at nanoscale in all areas of S&E



A. Scientific challenges

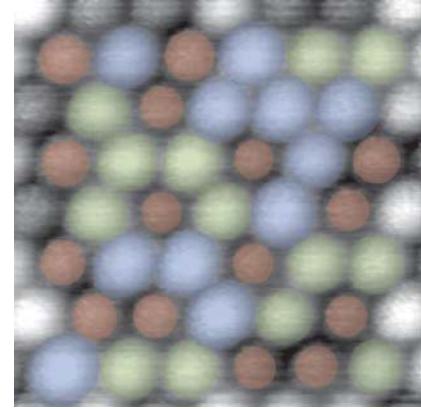
- **New theories at nanoscale**
Ex: transition from quantum to classical physics, collective behavior, for simultaneous phenomena
- **Non-equilibrium processes**
- **Designing new molecules with engineered functions**
- **New architectures for assemblies of nanocomponents**
- **The emergent behavior of nanosystems**



FY 2009 NS&E Priorities Research Areas (2)

B. Development of nanotechnology

- Tools for measuring and restructuring with atomic precision and time resolution of chemical reactions
- Understanding and use of quantum phenomena
- Understanding and use of multi-scale selfassembling
- Nanobiotechnology – sub-cellular and systems approach
- Nanomanufacturing hybrid, on site
- Systems nanotechnology

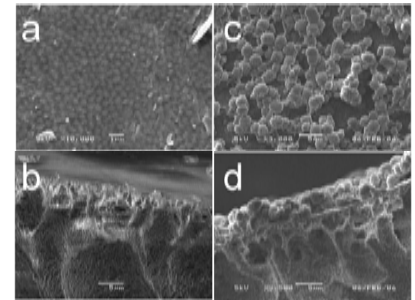




FY 2009 NS&E Priorities Research Areas (3)

C. Integration of nanotechnology in application areas

- Replacing electron charge as the information carrier in electronics
- Energy conversion, water filtration / desalinization using new principles



SEM micrographs of membranes (UIUC)

- Efficient nanomanufacturing and sustainable environment
- Nano-bio interfaces between the human body and manmade devices
- Nano-informatics for better communication and nanosystem design



From FY 2009 NSF priority research areas (4)

Societal dimensions of nanotechnology

- Understanding and sustainable ENV, including research for natural/ incidental/ manufactured nanomaterials

Key nano- EHS priorities at NSF

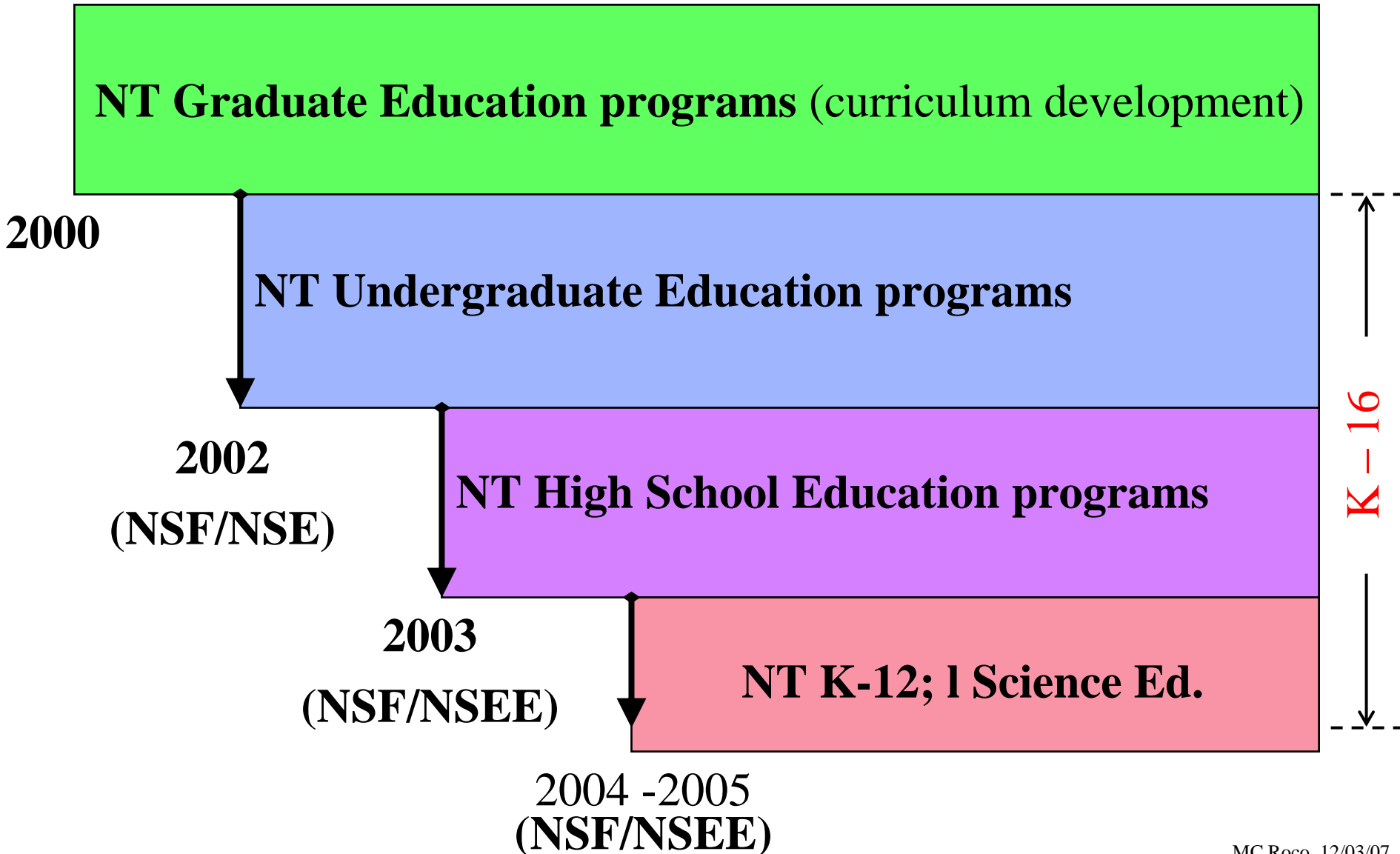
- New instrumentation for nanoparticle characterization and nanotoxicity
- Transport phenomena and physico- chem.- biological processes
- Nano-bio interface: ecological and human health implications
- Predictive models for interaction of nanomat. with cells/living tissues
- Separation of nanoparticles from fluids
- Safety of manufacturing nanoparticles
- Earlier formal and informal education
- Social issues and public engagement



NSE program emphasis in FY 2009

- Increased focus on complex, large nanosystems
- Three-dimensional measurements of domains of engineering relevance with good time resolution
- Converging science, engineering and technology from the nanoscale (in manufacturing, information systems, medicine, environment, etc.)
- R&D themes on sustainable development (energy, water, food, climate)
- Expanded joint research program addressing societal implications of nanotechnology; partner with other agencies
- Earlier educational programs and teaching materials, including for K-12, by remote access to NSF educational networks (NU, NISE, NNIN)
- Expand partnerships of academic researchers with industry, medical facilities and states through GOALI, PFI and other programs

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





Nine Nanoscale Science and Engineering networks with national outreach

TOOLS

Network for Computational Nanotechnology (2002-) *> 50,000 users/ 2007*

National Nanotechnology Infrastructure Network (2003-) *4,500 users/ 2007*



Nationwide Impact

TOPICAL

Nanotechnology Center Learning and Teaching (2004-) *1 million students/ 5yr*

Center for Nanotechnology Informal Science Education (2005-) *100 sites/ 5yr*

Network for Nanotechnology in Society (2005-) *Involve academia, public, industry*

National Nanomanufacturing Network (2006-) *4 NSETs, DOD centers, and NIST*

Environmental Implications of Nanotechnology (2008-) *with EPA*

GENERAL RESEARCH AND EDUCATION

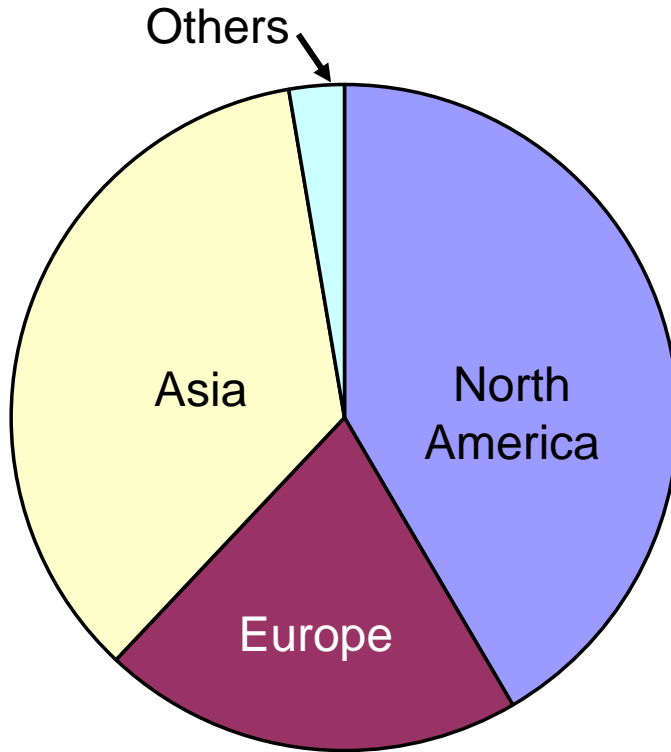
NSEC Network (2001-) *17 research & education centers*

MRSEC Network (2001-) *6 new research & education centers since 2000*

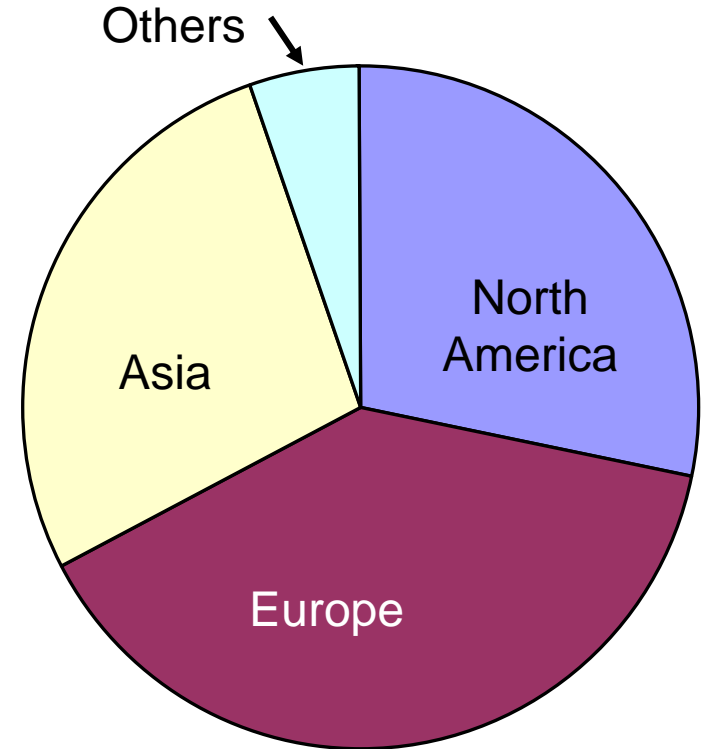
Industry-academe-government R&D partnerships – increased relevance

- Increased role of industry in funding nanotechnology R&D ; changes in gov. funding because other oblig.
- Special role of local governments (state, county) for infrastructure, education and small business
- Global partnerships for nanotechnology knowledge, markets and organizations
- Cross-industry R&D consortia for nano-platforms

Growing nanotechnology R&D investment - \$13.8 billion in 2007



Private (Corp. + VC)
Total = **\$7.3 billion**



Public (National, regional, state)
Total = **\$6.5 billion**

National governments ~ \$4.7 billion
Local governments and organizations ~ \$1.8 billion

NNI-Industry Consultative Boards for Advancing Nanotech

Key for development of nanotechnology, Reciprocal gains

❑ **NNI-Electronic Industry (SRC lead), 10/2003 -**

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; Report in 2004
2 working groups, including on EHS
Use of NNI R&D results, and identify R&D opportunities



❑ **NNI – Organizations and business (IRI lead)**

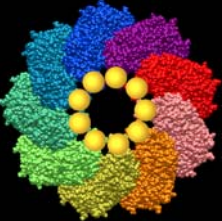
Joint activities in R&D technology management
2 working groups (nanotech in industry, EHS)
Exchange information, use NNI results, support new topics



❑ **NNI – Forestry and paper products (AF&PA lead, 4/2007), 10/2004-** Workshop / roadmap for R&D

Exchange information



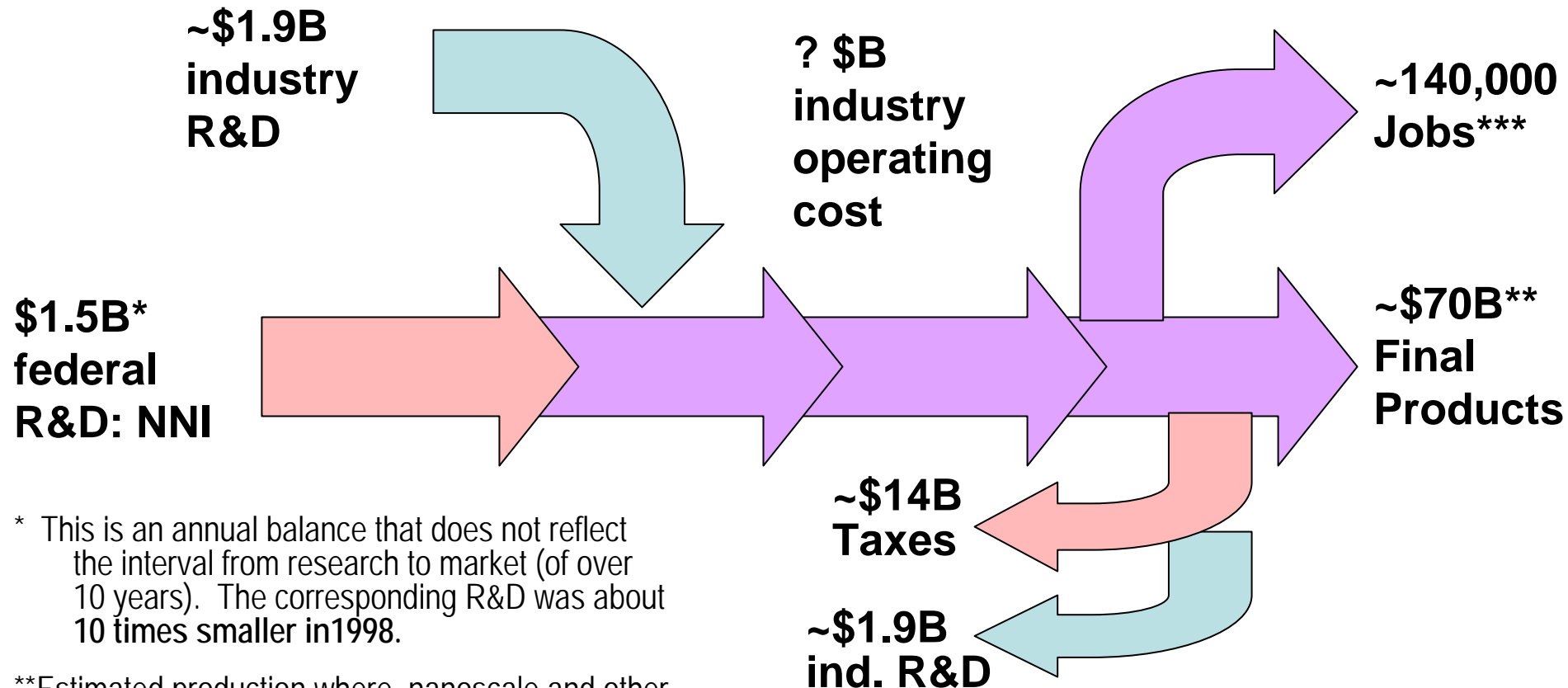


Several NNI Accomplishments

- Developed foundational knowledge for control of matter at the nanoscale:
over 4,000 active projects in > 500 universities, private sector institutions and government 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 2007 (U.S.)
- Infrastructure:
82 new large nanotechnology research centers, networks and user facilities; over 50,000 users in 2 academic-based networks

(1) NSF Committee of Visitors, 2004; (2) Journal of Nanoparticle Research, 2004; (3) NanoBusiness Alliance, 2004

Estimation of Annual Implications of Federal Investment in Nanotechnology R&D (FY 2008)



* This is an annual balance that does not reflect the interval from research to market (of over 10 years). The corresponding R&D was about 10 times smaller in 1998.

** Estimated production where nanoscale and other components are essential. Proportions for taxes based on CCR estimation for chemical industry

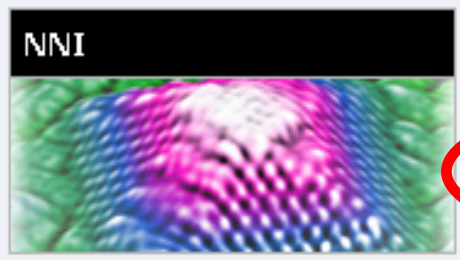
*** Estimated number of nanotechnology related jobs assuming \$500,000/yr/job

FY 2008 NSF's Grantees Meeting

- Review selected NSE awards: FY 2007 NIRT, NSEC . . .
Posters, keynotes and panels to facilitate exchanges, partnerships, and research planning
- Presentations from the DOD, EPA and FDA
- Strengthen NSE trans-disciplinary community
Prepare for increased complexity in research



www.nsf.gov/nano
or link www.nano.gov



Solicitations & Outcomes

New Items

Activities

Program Reviews

NSF & NNI Symposia

NSF & NNI Reports

NSF & NNI Reports

Links to Related Reports

NNI Endorsements

NNI Presentations

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*, selfassembly 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](#)