Nanoscale Science and Engineering at NSF

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- **Major changes in the first 3 years of NNI (2001-2003)**
- **NSF activities**
- **Planning for the next five years**

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 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

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.; + 25%/yr
  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**

NNI implementation plan published in July 2000

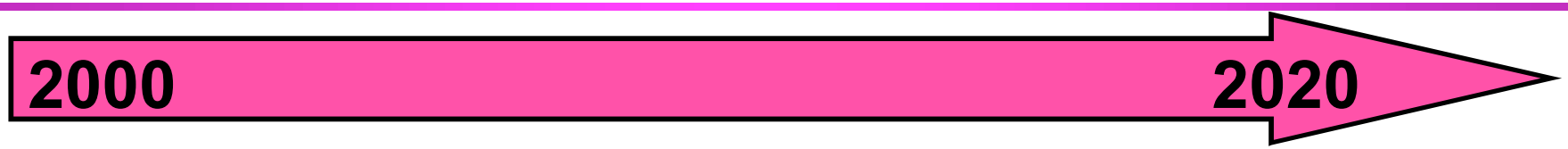
Major changes in the first 3 years of NNI (Part 1)

- **Research**: NNI supports about 2,500 active awards in about 300 academic 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

- **Education**: 7,000 students and teachers trained in 2003; All science and engineering colleges have introduced courses related to NSE

- **Significant infrastructure**: in over 60 universities with user capabilities; Five networks (NCN,NNIN, OKN, DOE, NASA) have been established.

At the beginning of NNI
R&D targets set up in 2000 towards 2020



10 key advancements set up in 2000

- Engineer materials with atomic precision using biosystems as agents
- Create circuits with the logic element a molecule wide
- Assemble DNA, nanocrystals to build molecular devices and systems
- Detect anthrax, other contaminants with unprecedented speed
- Single molecule behavior and interaction
- Artificial genetic system
- Conducting polymers
- New concepts for large scale production of nanotubes, their use
- Drug delivery systems
- Detection of cancer

NNI results faster than expected in 2001-2003: reducing the time of reaching commercial prototypes by at least of factor of two for several key applications

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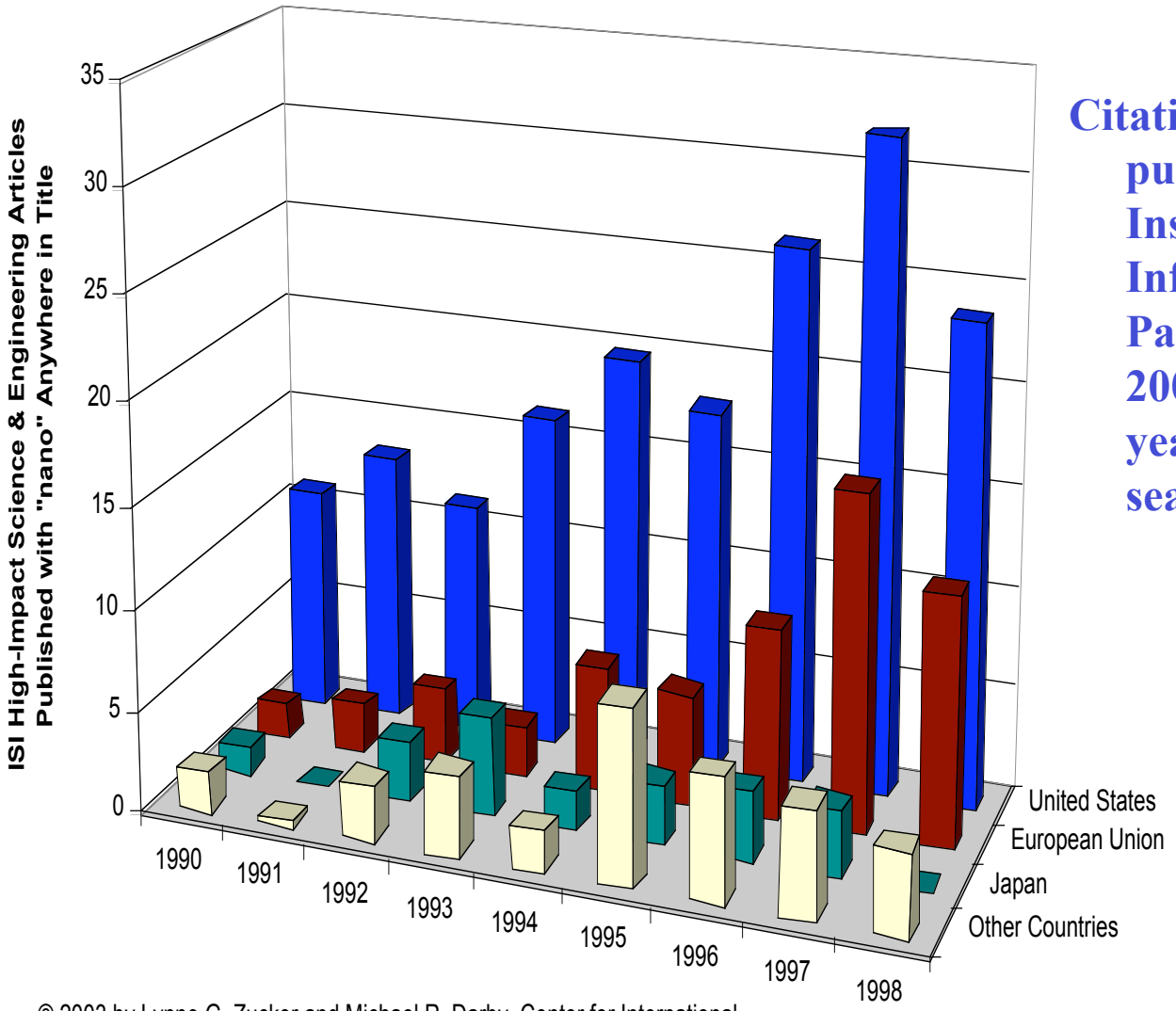
ISI High-Impact Nano-articles, 1990-1998



Citations two years after publication; Data from Institute for Scientific Information, Inc., High Impact Papers, Electronic data base 2000 (using citations for two years after the publ. date; search by nano*)

About half of highly cited articles from U.S.

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Outcomes of 2001-2003: 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)**
  - User facility – 13 nodes (Cornell as the central node)
  - Development measuring & manufacturing tools
  - Education and societal implications
- **Oklahoma Nano Net (EPSCoR award)**

22 new centers and networks supported by NNI since 2001:

10 NSF, 3 DOD, 5 DOE, 4 NASA (at universities); continuing MRSECs

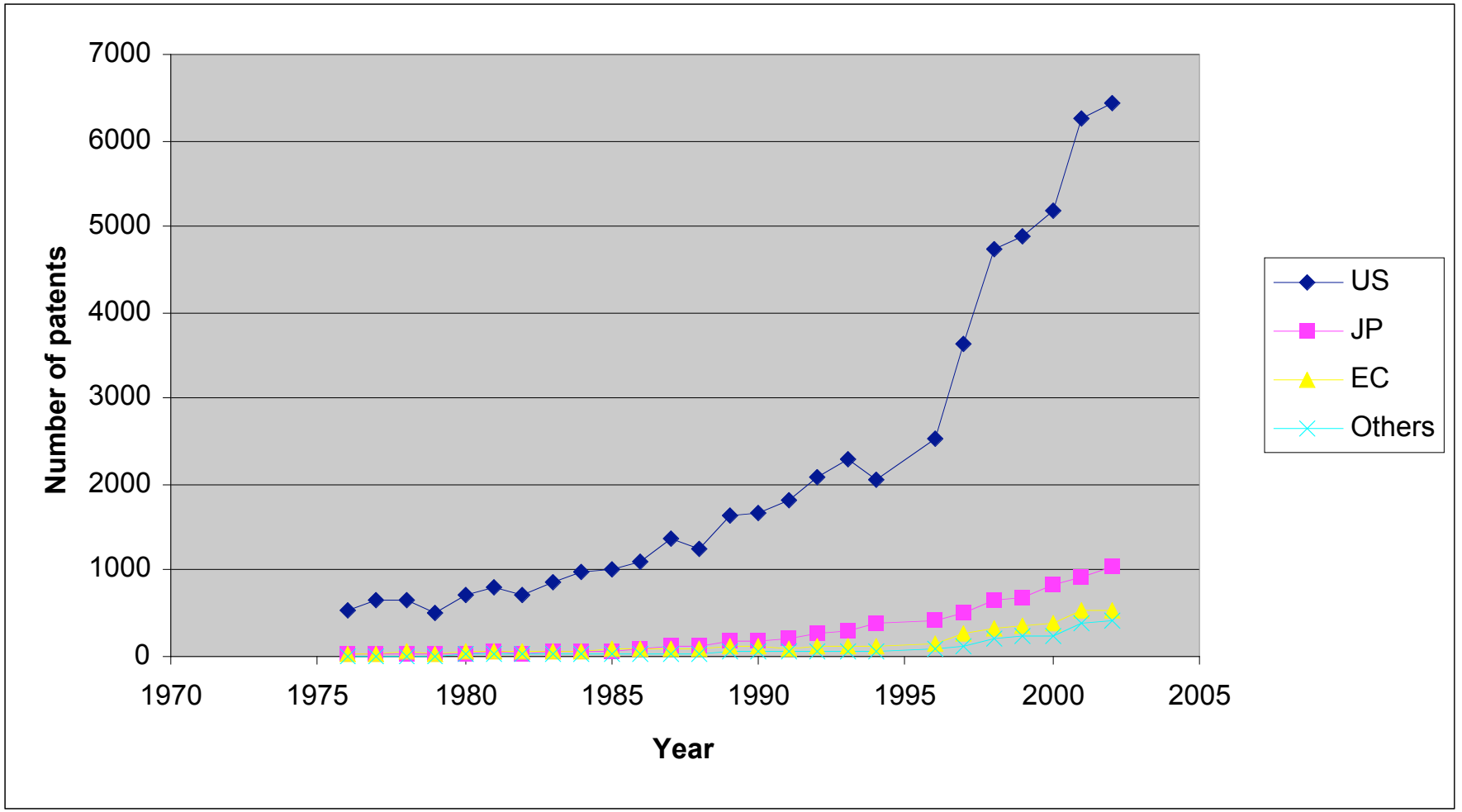
NNI implementation plan published in July 2000

Major changes in the first 3 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?"
- **Innovation and venture funding:**
  US has over 6,000 patents in 2002 with USPTO (75% world)
- **Estimation on revenues from nanotechnology:**
  Reaching $1trillion in 2015 worldwide, and the estimations moving closer because of accelerated development; growth >25% per year
- **States and regional alliances:** "meltdown" in 2002 -
  > 20 states committed funding, > 22 regional alliances

Nanotechnology patents per region (NSF, 2003)

Searched by keywords at USPTO : nano*, atomic force microscop*, atomistic/molecular simulation, biomotor, molecular device, molecular electronics, molecular modeling, molecular motor, molecular sensor, quantum computing, quantum dot*, quantum effect*, scanning tunneling microscop*, selfassembl*



www.nsf.gov/nano **(from J. of Nanoparticle Research, 2003)**

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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 implementation plan published in July 2000

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

- **Professional societies**: Specialized divisions, workshops, education; AAAS, ACS, APS, MRS, ASME, AIChE, IEEE, AVS, other major societies in the race
- **Government investment**: Worldwide investment has increased 7 times in 6 years reaching $3B in 2003 (of which US $0.77B and NSF $0.22B)
- **Societal implications from the beginning**: Workshop on Societal Implications of Nanoscience and Nanotechnology in 2000; NSF programs on SI since 2000
- **Other broader implications**: In Federal Government (NNI), Legislative (5 year Bill), Judiciary branches, cultural

After 3 years of NNI:
New R&D potential targets for 2015 (ex.)

2004 2015

- Nanoscale visualization and simulation of 3D/m domains
- Transistor beyond/integrated CMOS under 10 nm
- New catalysts for chemical manufacturing
- No suffering and death from cancer when treated
- Control of nanoparticles in air, soils and waters

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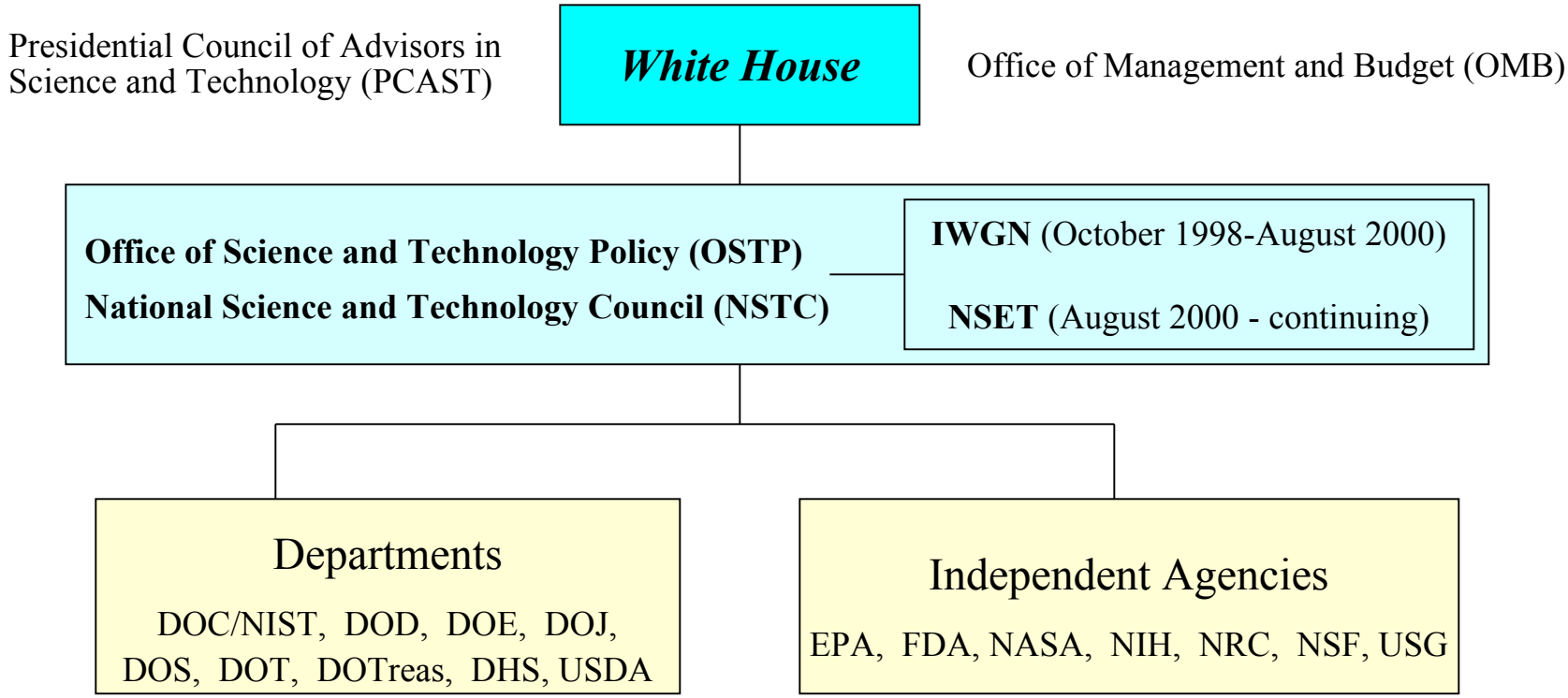
Organizations that have prepared and contribute to the National Nanotechnology Initiative (NNI)



Estimation:

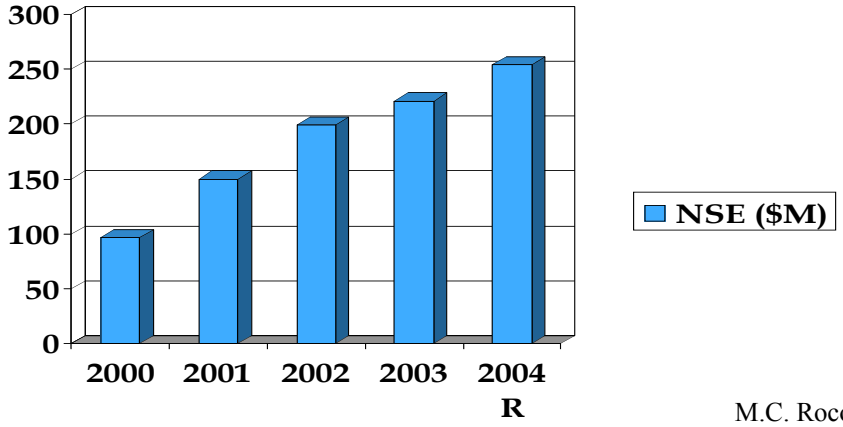
Federal Government R&D funding	NNI (~$700M in 02)
Industry (private sectors)	~ NNI funding
State and local (universities, foundations)	~ 1/2 NNI funding

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

FY 2003: ~ **1/3 of Federal** and **1/10 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**: about 2000 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
Conf. 2004	$254M



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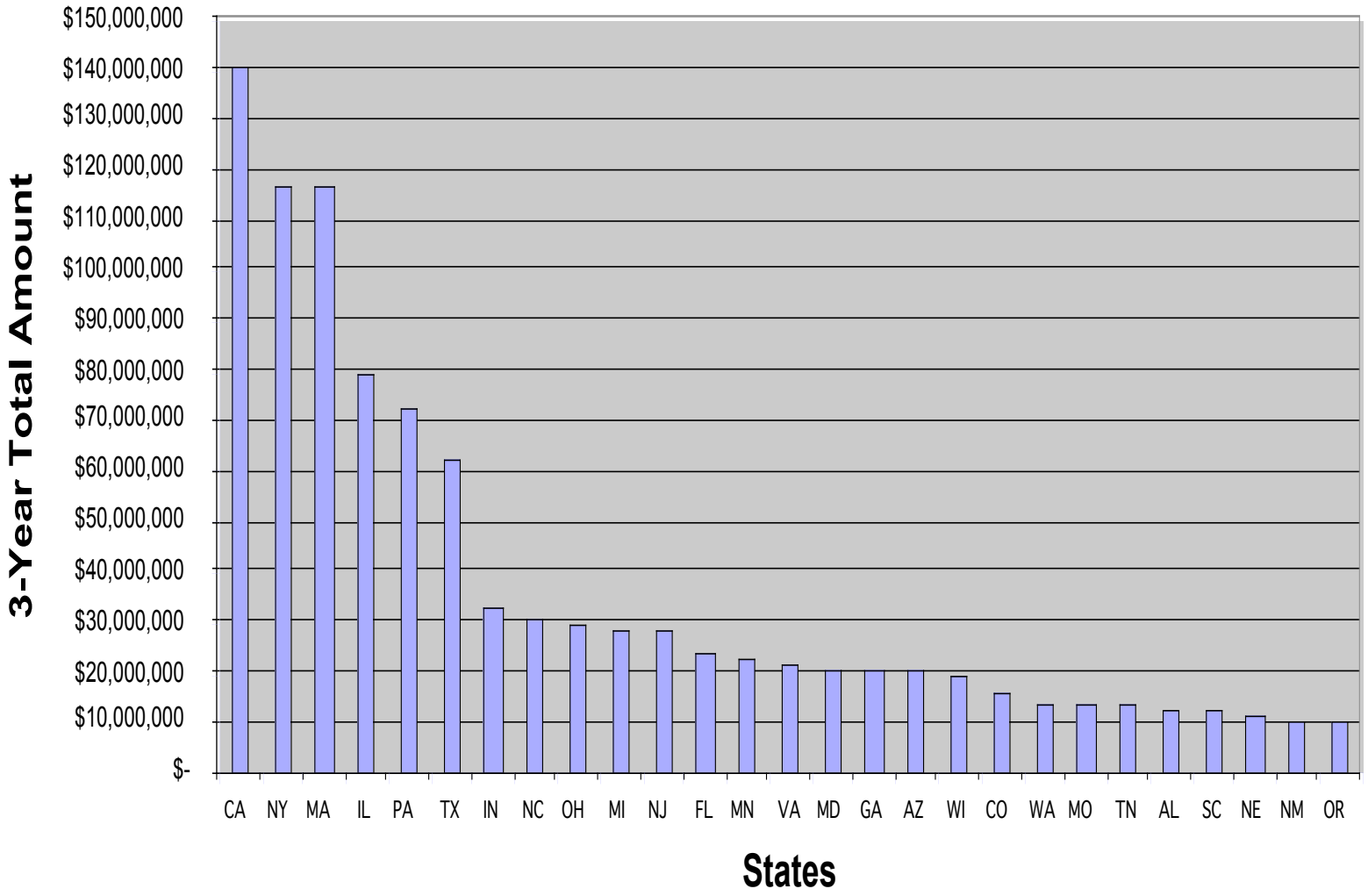
States Awarded $10 million or More by NSF for NEW NNI Research during FY 2001-2003



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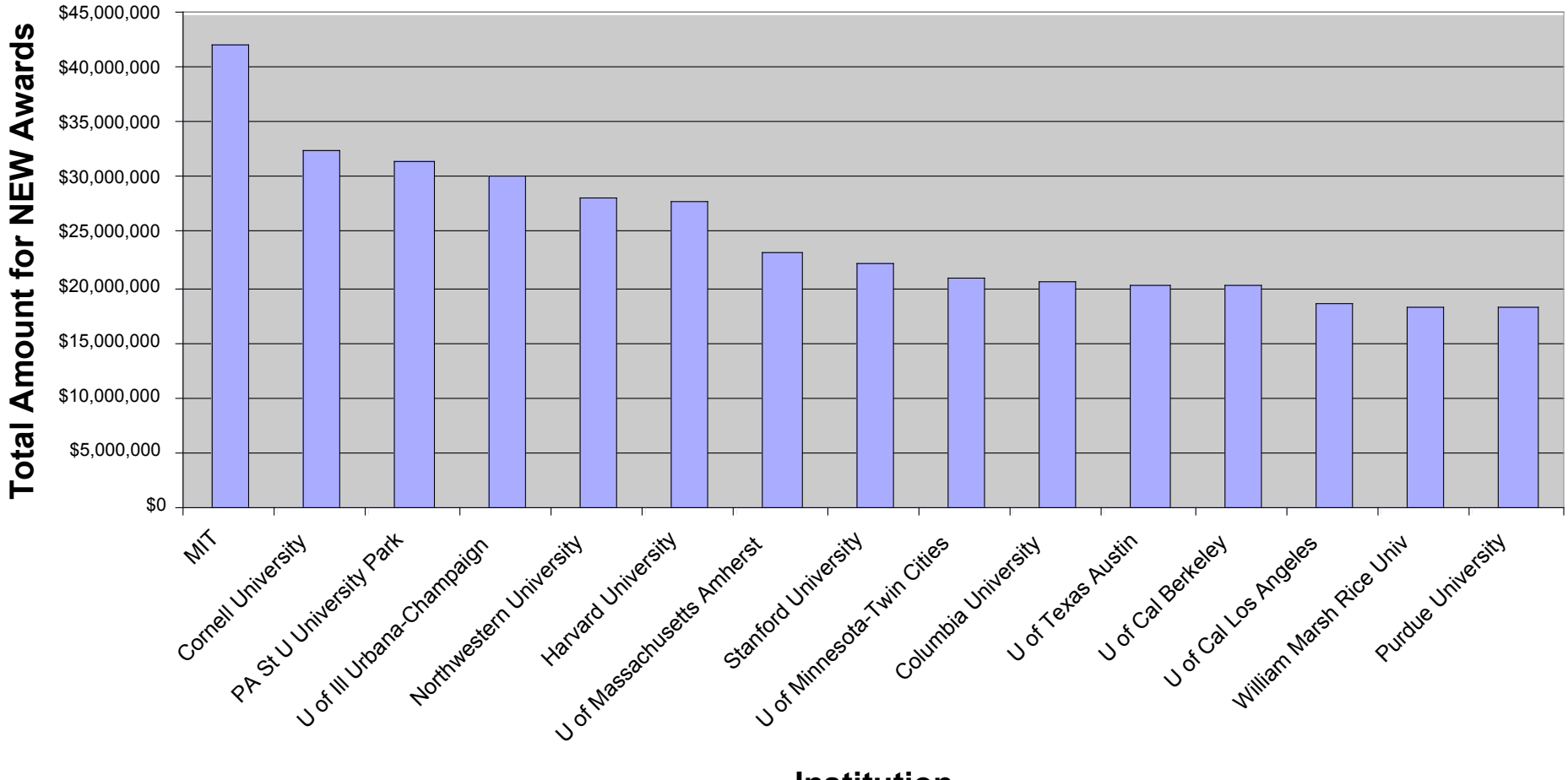
NNI outcomes



Nanoscale Science and Engineering program (NSF 02-148, FY 2003)

- **FY 2003 budget**

  $221M, of which $71M for solicitation and $150M for core

- **Outcomes of the solicitation**

  171 awards, $71M + $19M other/future commitments; total $90M

  - **Interdisciplinary Research Teams** (4 proposals/university)
    62 awards (~$74M) - 16% per number of proposals
  - **Nanoscale Science and Engineering Centers** (1 proposal/univ)
    2 new centers on nanomanufacturing (~$5.4M/yr) for 5 yr
  - **Nanoscale Exploratory Research** (4 proposals/ university)
    84 awards (~$7.7M)
  - **Nanotechnology Undergraduate Education** (1 proposal/ univ.)
    33 awards (~$3.3M)

  Success rate (awarded funds / requested funds):
  9.5% = 7.5% from FY 2002 NSE funding + **2%** others

  (less than NSF success rate even with limited proposals)

Nanoscale Science and Engineering support at NSF in FY 2004

The budget allocation expected between $254M (Congress Conference)

- **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)

Education and Training

- **Integrated research and education - Make Every Lab a Place of Learning: Aiming at systemic changes**

  ~ 7,000 students/year, technicians, teachers, and faculty in 2003

- **Curriculum development: New foundation, Training earlier**

  Nano- instead of micro-based; From elementary schools to continuing education (Undergraduate education ~ 33 awards in FY 2003; Expand to K -12 education in 2004); Industry fellowships

- **All NSF centers have education and outreach programs**

  Including science museums Boston, Chicago, Milwaukee, LA

- **International education opportunities**

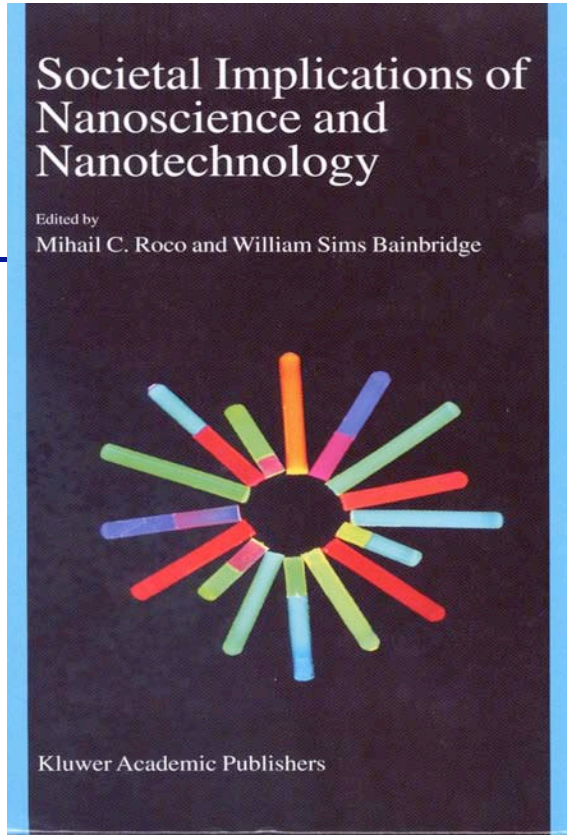
  Young researchers to Japan and Europe; REU sites; attend courses abroad; PASI - Latin America, NSF-E.C.; bi-lateral workshops and exchanges

Nanoscale Science and Engineering Education program (NSF 03-044, new in FY 2004)

NSEE to produce systemic changes in nanoscale science and engineering education. $12M in FY 2004. Components:

- **Centers for Learning and Teaching (NCLT):** Create educational leadership for nanotechnology education (doctoral programs representing collaborations of researchers in nanoscale science and engineering, education, and cognitive and behavioral sciences)
- **Informal Science Education (NISE):** Foster public awareness and understanding of nanoscale science and engineering through development of media projects (film, radio, television) and exhibits.
- **Instructional Materials Development (NIMD):** Support development of prototype instructional materials that promote student learning and interest in nanoscale science, engineering, and technology concepts for grades 7-12.
- **Nanotechnology Undergraduate Education (NUE):** Introduce nanoscale science and technology through a variety of interdisciplinary approaches into undergraduate education, particularly in the first two collegiate years.

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 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 Europe and Asia**

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

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 included nanotechnology in May 2002** (2 program announcements; focus in 2003: nanoparticles implications)
- **EC: Program on environmental aspects in March 2003**
- **Other countries** (Taiwan, UK, Switzerland) may consider such programs in the future

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

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

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
- Catalysts that function at the nanoscale - 06/03
- Nanoelectronics, optoelectronics and magnetics - 11/02, 2/03
- CBRE protection and detection - 05/02
- Advanced healthcare, therapeutics, diagnostics - 06/00
- Nano-biology and medicine - 10/03
- Environmental improvement - 06/02, 08/02, 07/03, 09/03
- Efficient energy conversion and storage - 10/02, 02/03
- Microcraft space exploration and industrialization - Spring 04
- Manufacturing processes - 01/02, 05/02; Instrumentation – 01/04
- Agriculture and food systems - 11/02; Converging Technologies – 09/03
- Societal implications (II) - 12/03; Education (NSEE) – 09/03

"Nanotechnology Research Directions (II)" - 2004

Revisit the NNI long-term vision formulated in 1999

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