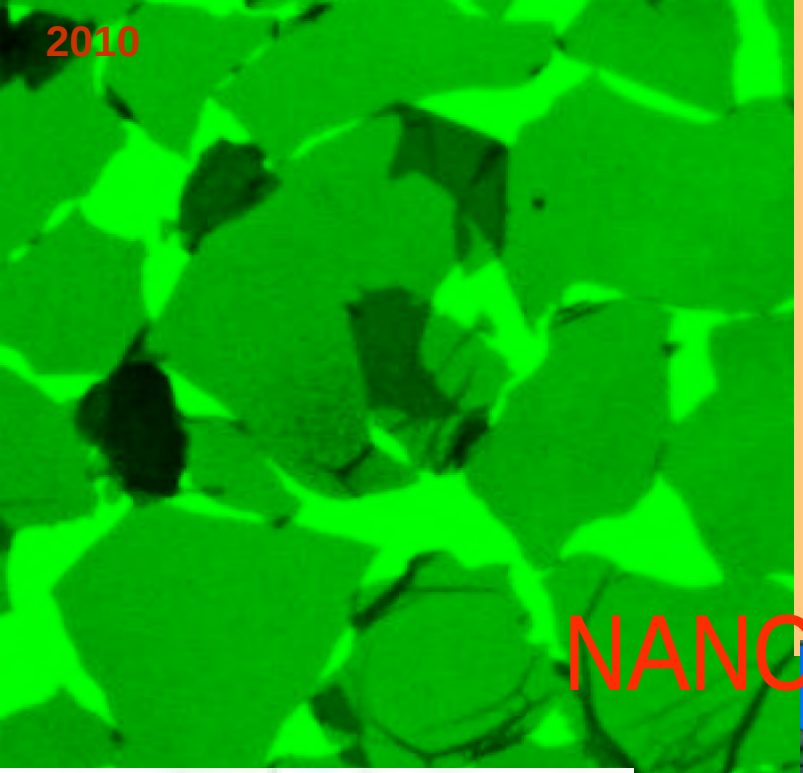
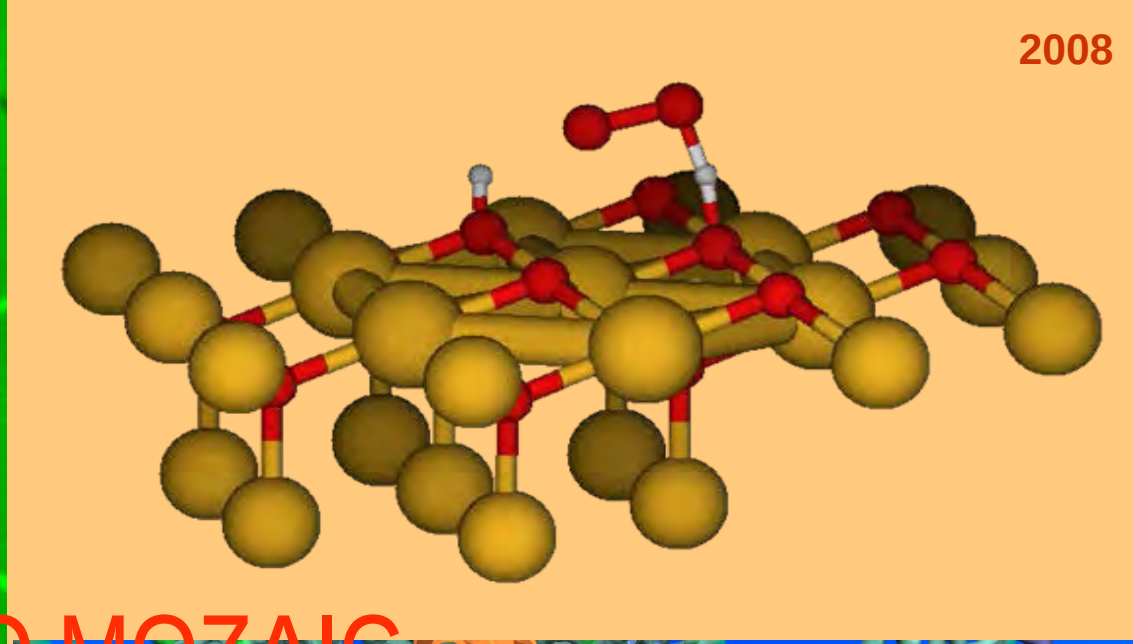
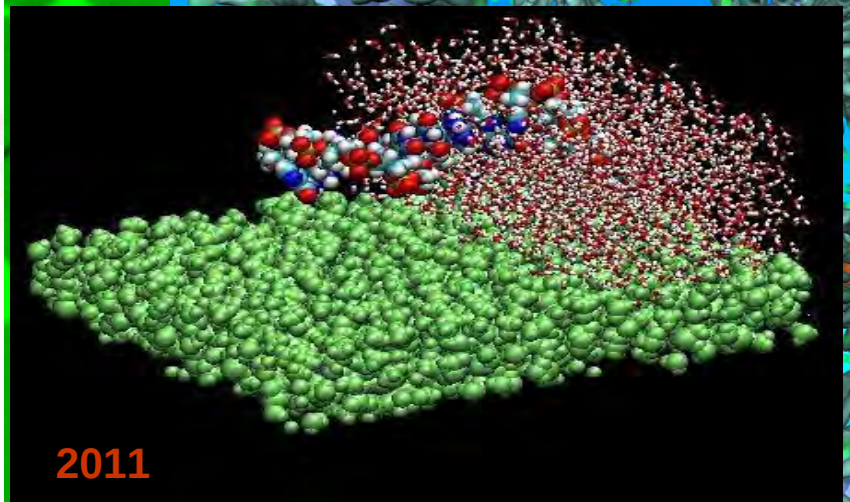
NANO MOZAIC







2012 NSF Nanoscale Science and Engineering Grantees Conference

with a focus on Environment

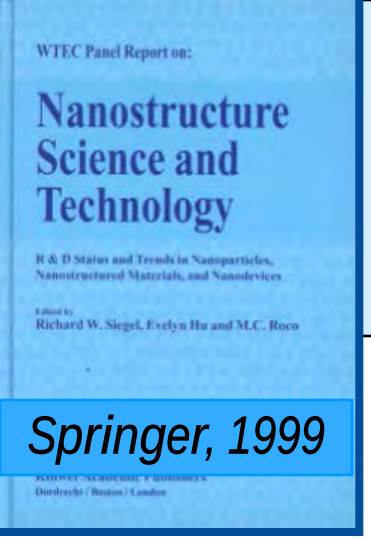
December 3-4, 2012

Nanoscale Science and Engineering at NSF

Mike Roco

NSF and NNI

NSF's Nanoscale Science and Engineering Grantees Conference
Arlington, December 3, 2012



Springer, 1999

Benchmark with experts in over 20 countries in 1997-1999

"Nanostructure Science and Technology"

NNI preparatory Report, Springer, 1999

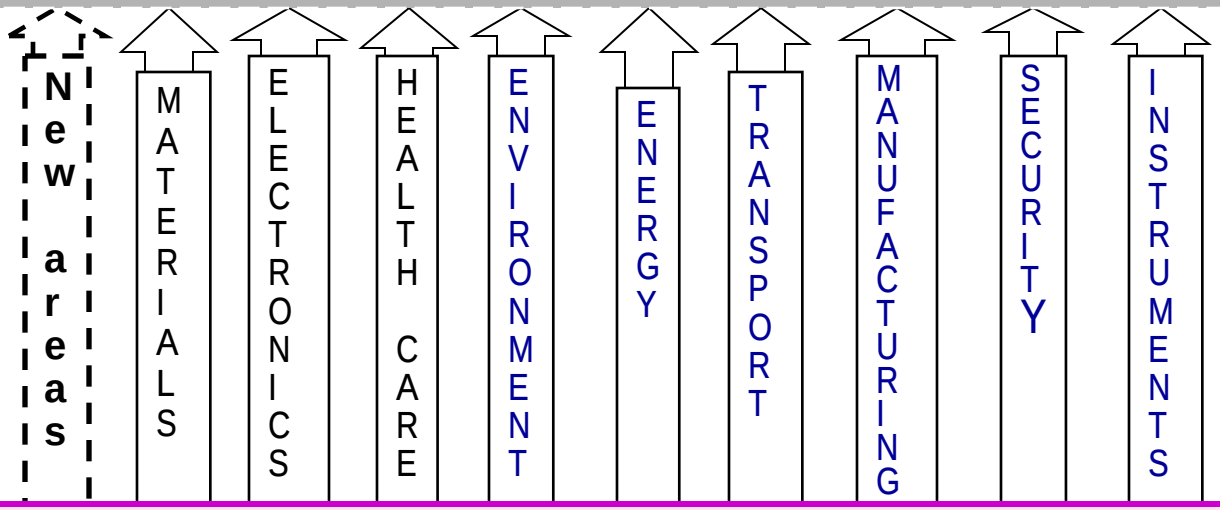
Nanotechnology Definition for the R&D program

Working at the atomic, molecular and supramolecular levels, in the length scale of ~ 1 nm (a small molecule) to ~ 100 nm range, in order to understand, create and use materials, devices and systems with specific, fundamentally new properties and functions because of their small structure (natural threshold)

NNI definition encourages new R&D that were not possible before:

- *the ability to control and restructure matter at nanoscale*
- *collective effects → new phenomena → novel applications*
- *integration along length scales, systems and applications*

Mass Application of Nanotechnology after ~ 2020



CREATING A NEW FIELD AND COMMUNITY IN 2 FOUNDATIONAL STEPS (2000~2020) with 4 generations of nanotechnology products

2020

NS&E integration for general purpose technology

~ 2011 ← nano2 → **~ 2020**

Direct measurements; Science-based design and processes; Collective effects; Create nanosystems by technology integration

New disciplines

New industries

Societal impact

Foundational interdisciplinary research at nanoscale

~ 2001 ← nano1 → **~ 2010**

Indirect measurements, Empirical correlations; Single principles, phenomena, tools; Create nanocomponents by empirical design

Infrastructure

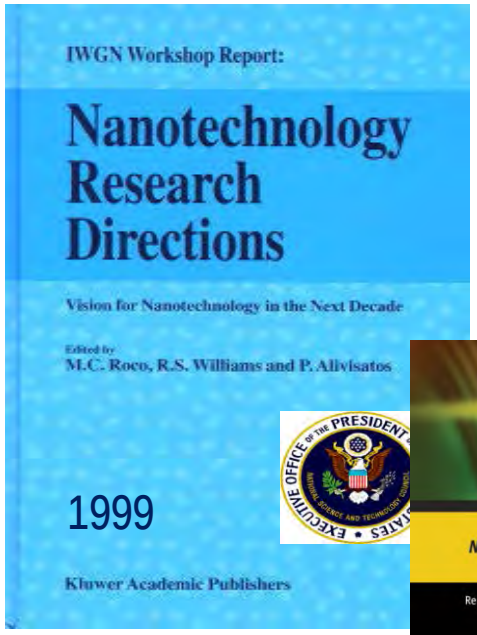
Workforce

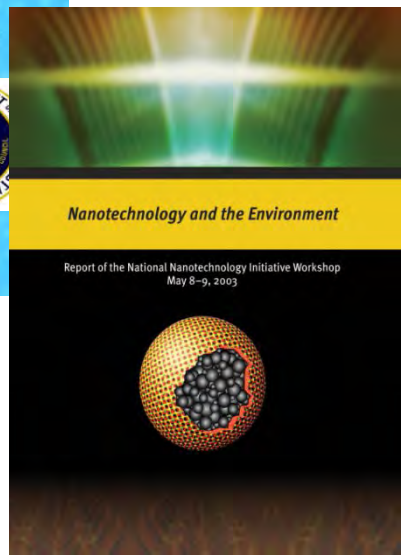
Partnerships

2000

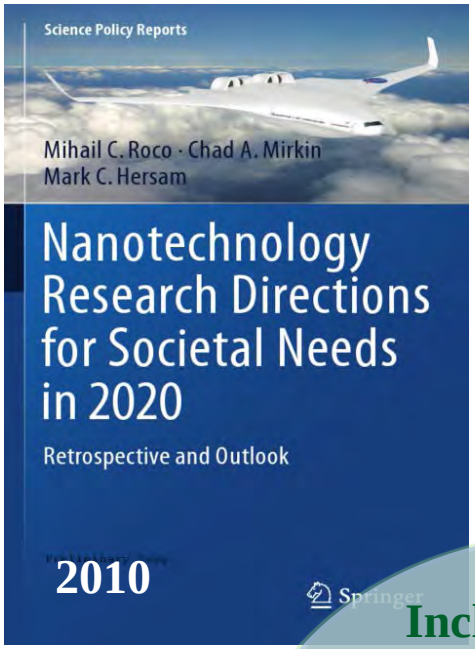
Long-term for nanotechnology research directions
(2000-2020)

nano1





nano2



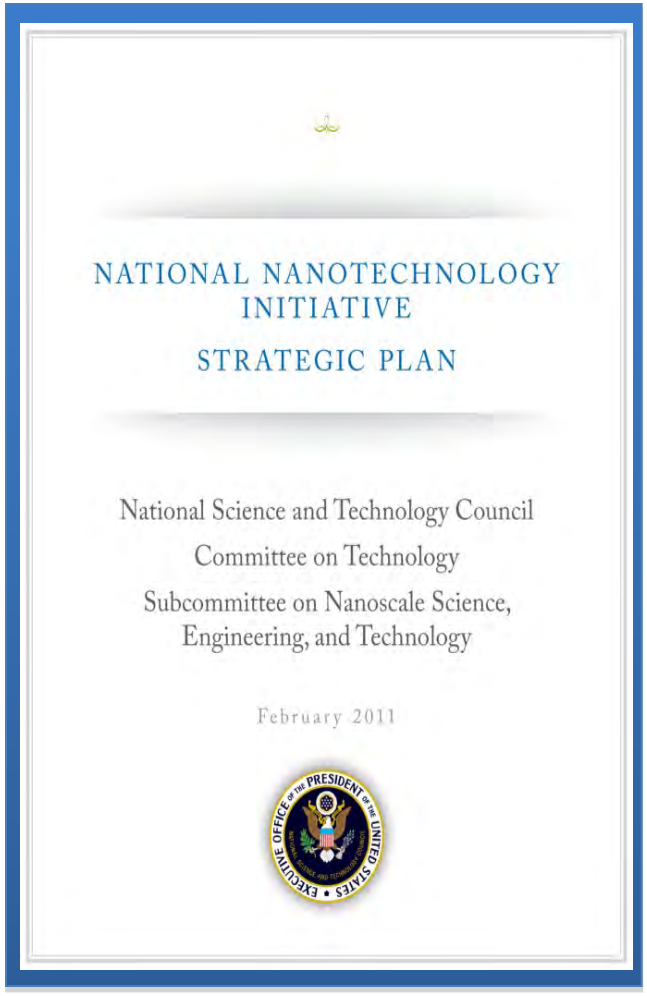
Includes as targets:
- Integrate research on environmental sustainability, nano-EHS and mitigation
- Institutionalize research and education programs in nanotechnology

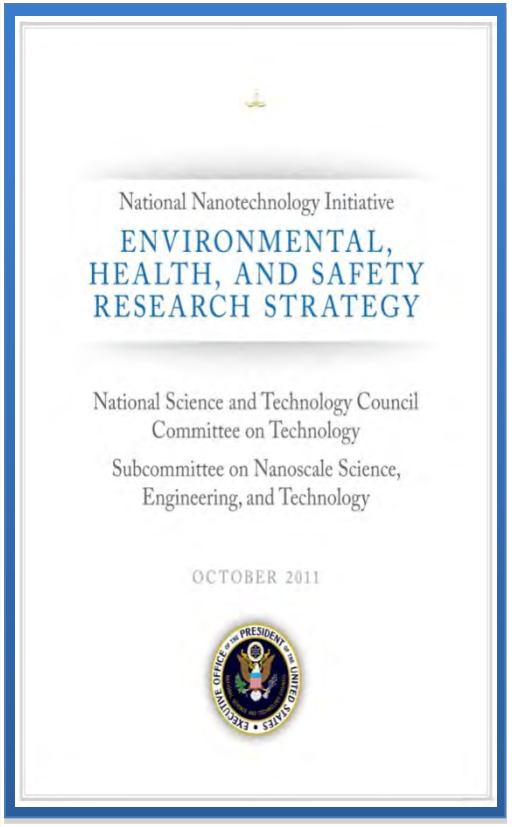
Nanotechnology and the Environment: Applications and Implications
NSF, EPA, August 2002

Available on: www.nano.gov and NSF/WTEC, www.wtec.org/nano2/

NNI periodical documents

Developing the Strategic (each 3 years) and annual Budget Plans





Strategic plans: 2000, 2005, 2008, 2011

Annual NNI Presidential Budget Supplements; Additions in 2011:

- Measureable objectives for each NNI goal
- Nanotechnology Signature Initiatives

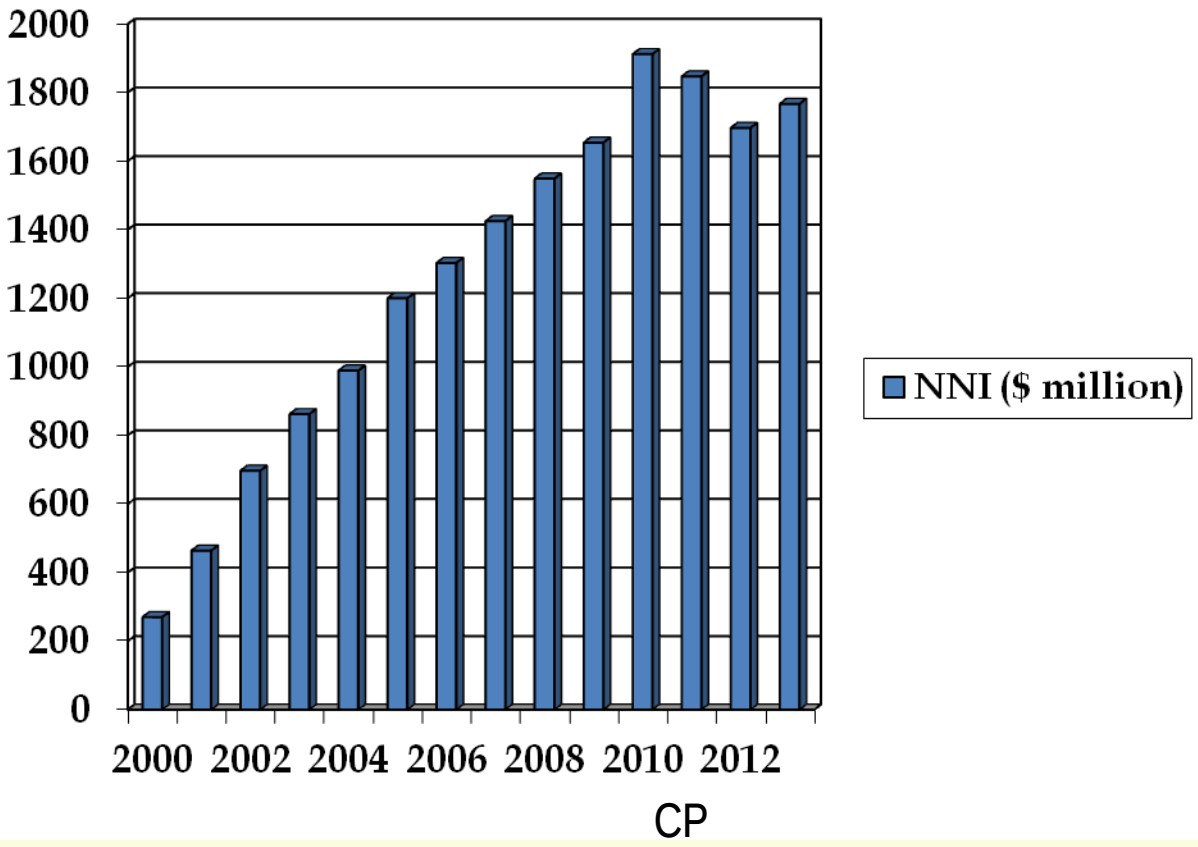
Topical reports, including NNI EHS Strategy (2011), four workshop reports, and follow up documents

2001-2013

US federal NNI R&D investment

FY 2013 NNI Budget Request - $1.767 billion

Fiscal Year	NNI
2000	$270M
2001	$464M
2002	$697M
2003	$862M
2004	$989M
2005	$1,200M
2006	$1,303M
2007	$1,425M
2008	$1,549M
2009	$1,654M
2010	$1,912M
2011	$1,847M
2012 Estimate	$1,697M
2013 Request	$1,767M



NNI / R&D ~ 1.1% of U.S. S&T ~ 1/4 of the world NT gov. R&D

Note: In 2009 + $140M (ARRA) = $1,794M

2001-2013

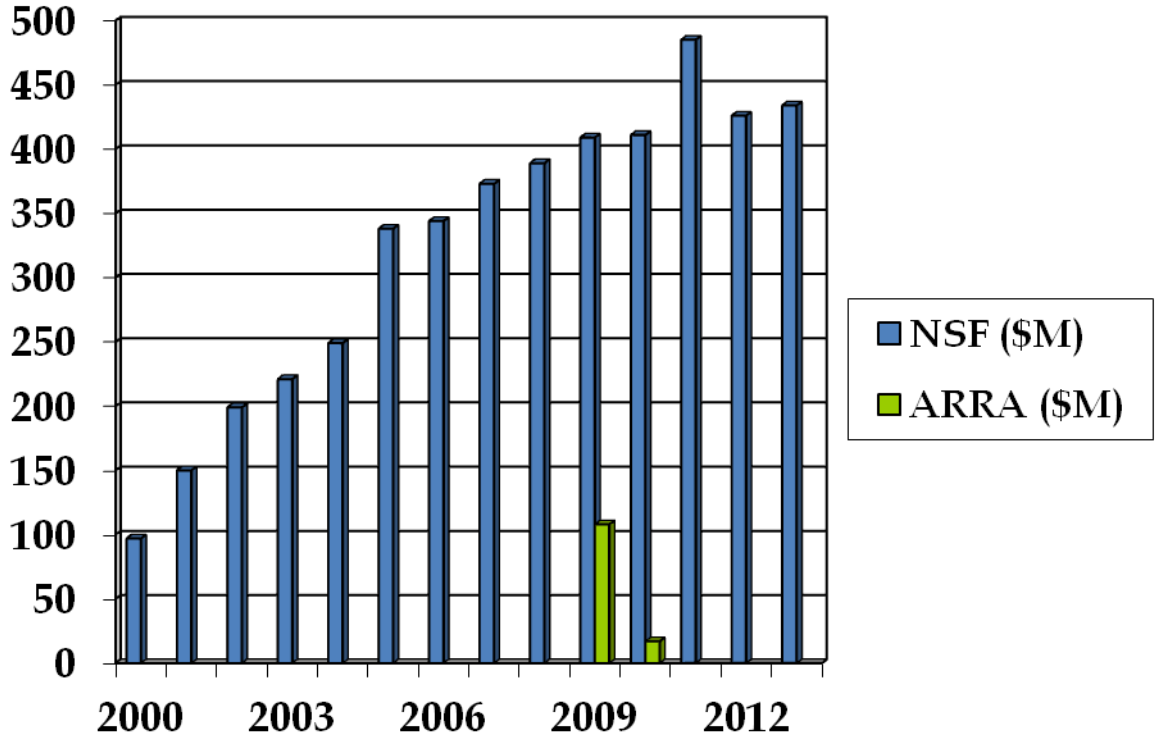
NSF – discovery, innovation and education in Nanoscale Science and Engineering (NSE)

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

FY 2013 Budget Request $434M

- Fundamental research ~ 5,000 active projects
- Establishing the infrastructure - 26 large centers, 2 user facilities, teams
- Training and education >10,000 students and teachers/y; ~ $30M/y

Fiscal Year	NSF	
2000	$97M	
2001	$150M	
2002	$199M	
2003	$221M	
2004	$254M	
2005	$338M	
2006	$344M	
2007	$373M	
2008	$389M	
2009	$409M	
2010	$411M	
2011	$485M	(R $412M)
2012 CP	$426M	
2013 R	$434M	



Note: In 2009 + $108M (ARRA) = $517M
In 2010 + $17M (ARRA) = $428M

MC Roco, Dec 3 2012

2000-2010
Estimates show an average growth rate of key nanotechnology indicators of 16% - 33%

World (US)	People -primary workforce	SCI papers	Patents applicat-ions	Final Products Market	R&D Funding public + private	Venture Capital
2000 *(actual)*	~ 60,000 (25,000)	18,085 (5,342)	1,197 (405)	~ $30 B ($13 B)	~ $1.2 B ($0.37 B)	~ $0.21 B ($0.17 B)
2010 *(actual)*	~ 600,000 (220,000)	78,842 (17,978)	~ 20,000 (5,000)	~ $300 B ($110 B)	~ $18 B ($4.1 B)	~ $1.3 B ($1.0 B)
2000 - 2010 average growth	~ 25% (~23%)	~ 16% (~13%)	~ 33% (~28%)	~ 25% (~24%)	~ 31% (~27%)	~ 30% (~35%)
2015 *(estimation in 2000)*	~ 2,000,000 (800,000)			~ $1,000B ($400B)		
2020 *(extrapolation)*	~ 6,000,000 (2,000,000)			~ $3,000B ($1,000B)		
Evolving Topics	*Research frontiers change from passive nanostructures in 2000-2005, to active nanostructures after 2006, and to nanosystems after 2010*					

2001-2011 Significant outcomes after ten years

- Remarkable scientific discoveries than span better understanding of the smallest living structures, uncovering the behaviors and functions of matter at the nanoscale, and creating a library of 1D - 4D nanostructured building blocks for devices and systems
- New S&E fields have emerged such as: *spintronics, plasmonics, metamaterials, carbon nanoelectronics, molecules by design, nanobiomedicine, branches of nanomanufacturing, and nanosystems*
- Technological breakthroughs in advanced materials, biomedicine, catalysis, electronics, and pharmaceuticals; expansion into energy resources and water filtration, agriculture and forestry; and integration of nanotechnology with other emerging areas such as quantum information systems, neuromorphic engineering, and synthetic and system nanobiology

2001-2013 NNI expenditures have grown ~ 4 times

NNI budget: $1,770M (2013 Request) / $464M (2001 Actual) ~ 4 times

NNI at NSF: $435M (2013 Request) / $97M (2001 Actual) ~ 4.5 times

Fundamental S&E remains the main focus, with increased attention to innovation, manufacturing, societal implications

Nanomanufacturing in 2013 Request: 5% of all NNI; 12.1% at NSF

Nano EHS: NNI has increased from 4% in 2011 to 6% in 2013 Request
NSF has ~ 7 % in the last five years

Nano penetration is time-staggered, in 2012: ~11% in NSF awards, ~5% in all papers, ~2% in USPTO patents, ~ 1% in Nano market/US GDP

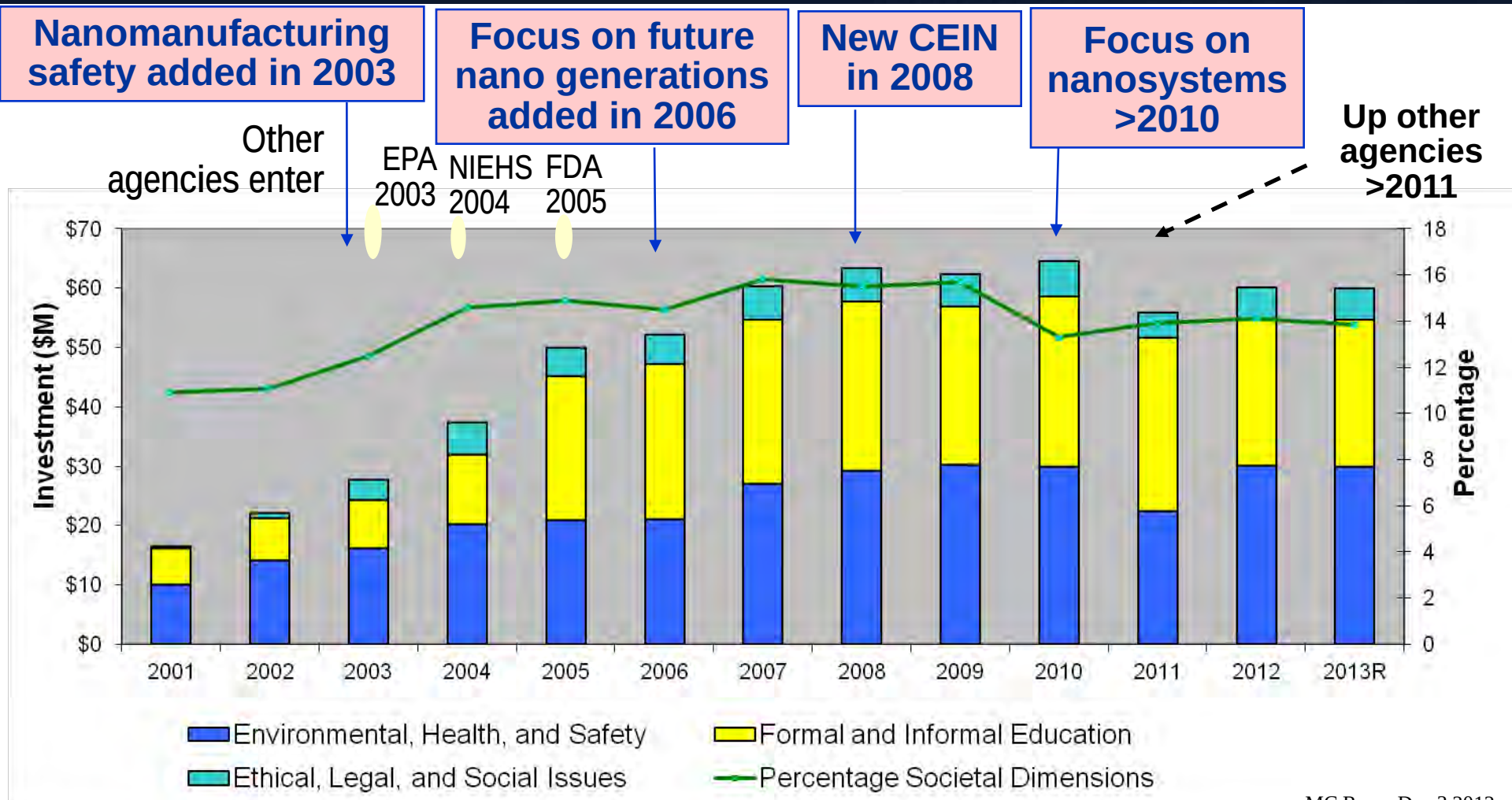
Main funding mechanisms for nano-EHS at NSF

- Dedicated program was institutionalized in 2010: *"Environmental Health and Safety of Nanotechnology Engineering and Sustainability"* (ENG)
- Individual or small-group awards can be funded in other core programs in five directorates: ENG, BIO, MPS, GEO and SBE (no special funds for nano-EHS, awards based on review)
- Research and education centers (ten year awards, the program is not institutionalized)
- Nano-EHS supplements to NSECs and other awards

NSF Overview on nano ENV (1)

- "Upstream" research and education since 2000;
  - 2000 – nanoparticles and other passive nanostructures
  - 2003 – nanomanufacturing safety; NISE, NCLT, NSEC
  - 2006 – added focus on the 2nd-3rd generations
  - 2008 – two CEIN have been established (NSF-EPA)
  - 2010 – to focus on nanosystems (more complex, dynamic)
- Main topics funded since 2006 in the EHS NNI cross-cut
  - (a) instrumentation and analytical methods
  - (b) effects on biological systems and human health
  - (c) effects on the environment
  - (d) exposure of nanomaterials
  - (e) risk assessment and management methods

NSF Investment in Nanotechnology Implications for Safety and Society



Collaborative interagency activities

- Planning and coordination in NNI
- Interagency funding coordination: Examples solicitations - 2008 CEINs ($38.4 M for 5 years) with EPA; Interagency solicitations in 2008 and 2010 with EPA, USDA, DOE
- Directly and through grantees: with other agency projects (NIOSH, NIEHS, CDC, EPA), industry partners, international (individual countries, OECD, twin-projects)
- Nanotechnology in Society centers support public participation

2001-2011 *Objectives not fully realized after ten years*

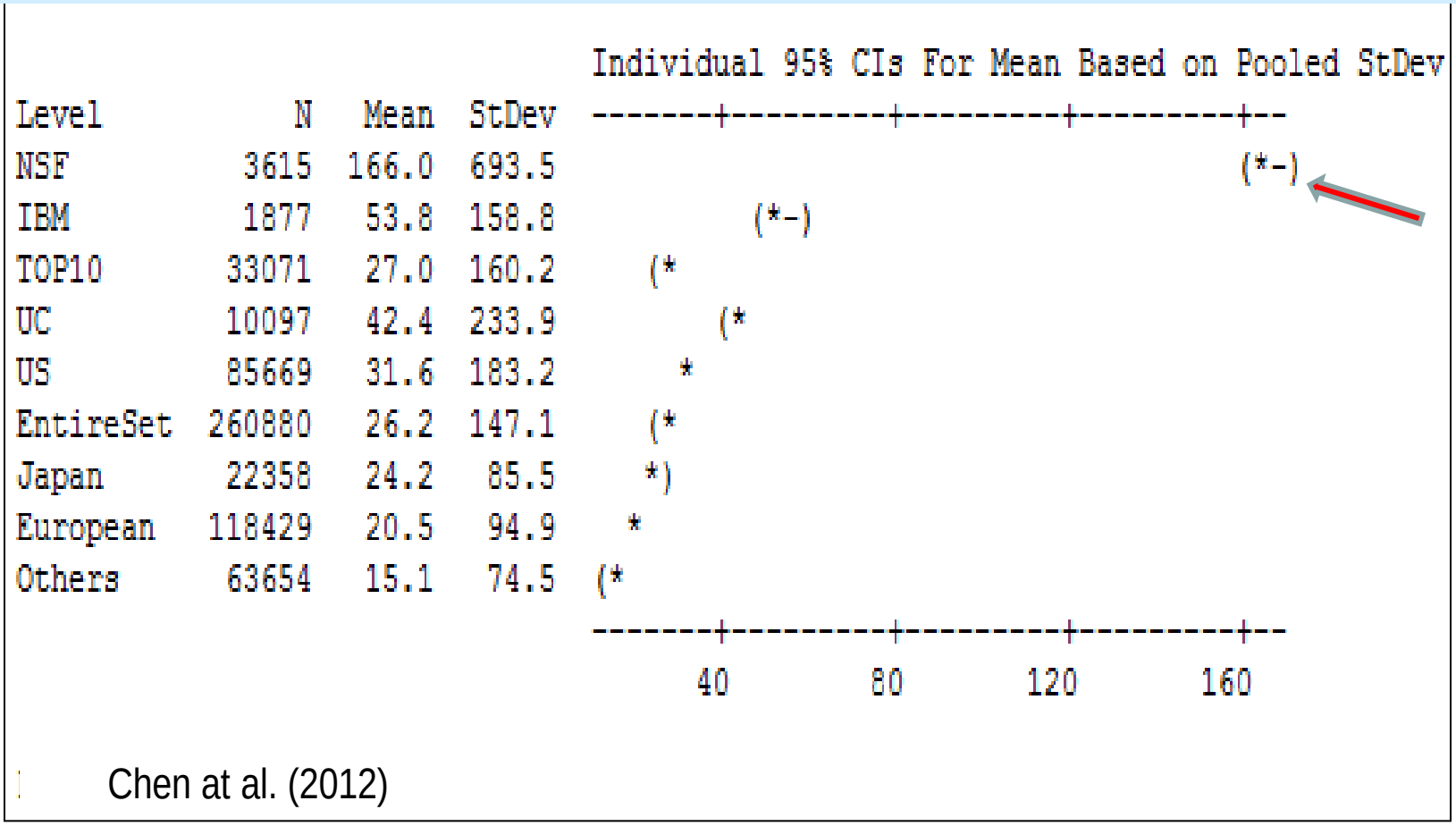
- General methods for **"materials by design"** and composite materials (because the direct simulation and measuring techniques methods were not ready)
- **Sustainable development projects** - only energy projects received significant attention in the last 5 years; Nanotechnology for water filtration and desalination only limited; Delay on nanotechnology for climate research (because of insufficient support from beneficiary stakeholders?)
- **Widespread public awareness of nanotechnology** – awareness low ~30% in U.S.; Challenge for public participation

2001-2011

Better than expected after ten years

- ✓ Unanticipated discoveries and advances in several S&E fields: plasmonics, metamaterials, spintronics, graphene, cancer detection and treatment, drug delivery, synthetic biology, neuromorphic engineering, quantum information ..
- ✓ Major industry involvement after 2002-2003
  Ex: >5,400 companies with papers/patents or products (US, 2008); NBA in 2002; Keeping the Moore law continue 10 years after serious doubt raised din 2000
- ✓ The formation / strength of the international community, including in nanotechnology EHS and ELSI that continue to grow

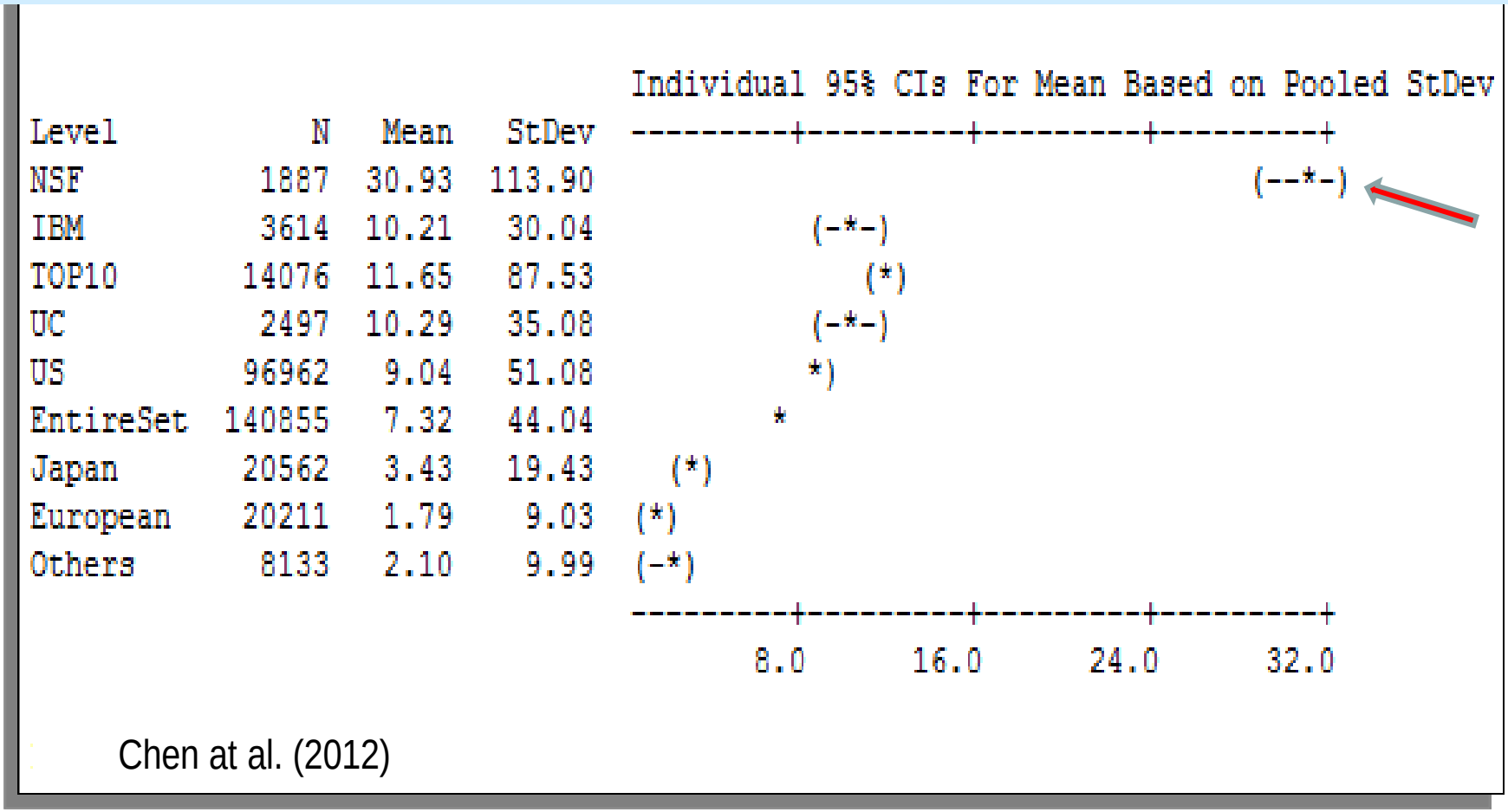
Article citations by NSF Principal Investigators



Chen at al. (2012)

NSF-funded PIs (1991-2010) have a higher number of citations (166 in average) than researchers in other groups: IBM, UC, US (32 in average), Entire world Set (26 in average), Japan, European, Others

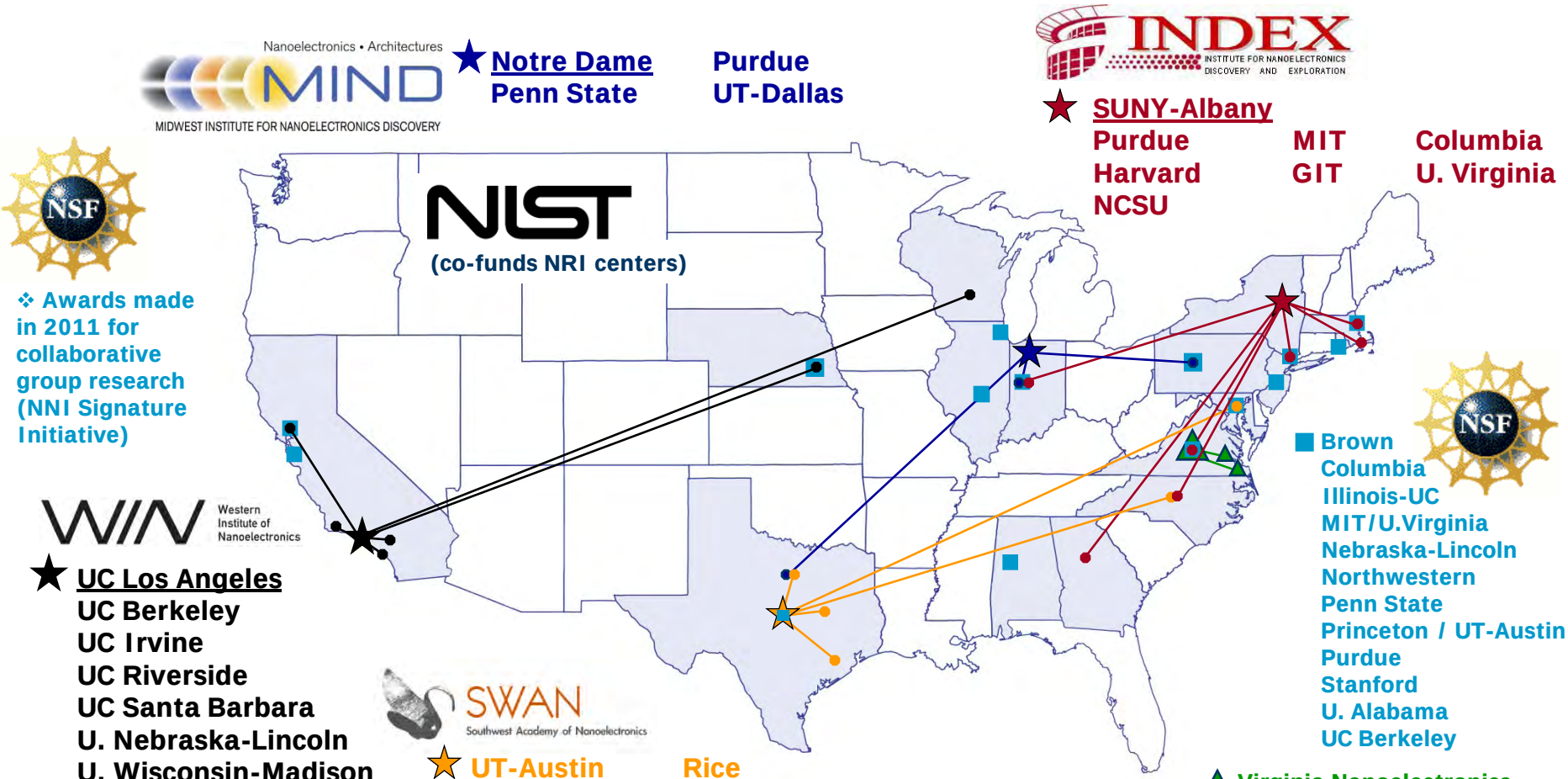
Number of patent citations by NSF P.I.-Inventors



Chen at al. (2012)

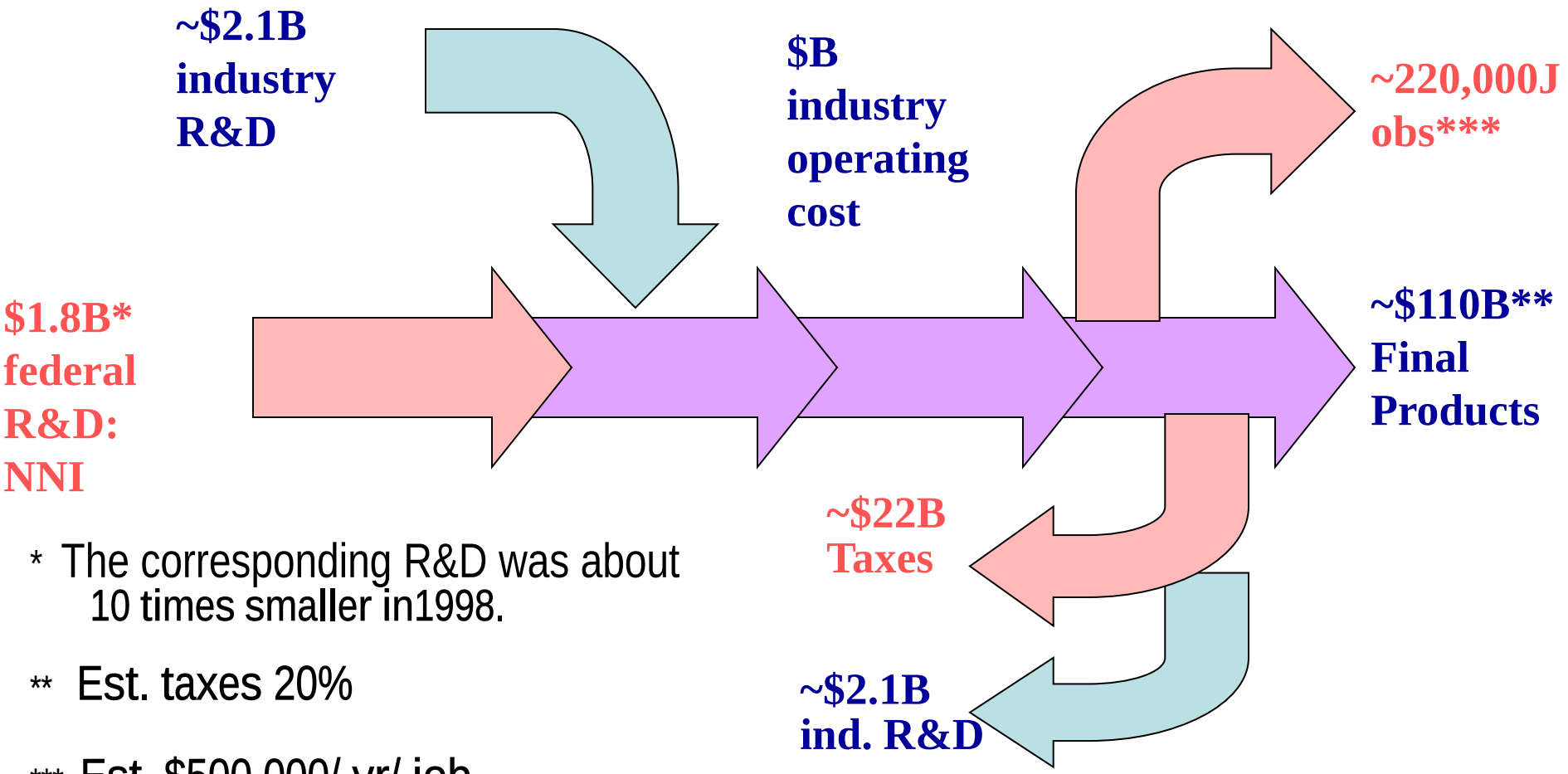
NSF-funded PI-Inventors (1991-2010) have more citations (31 in average) than inventors in the TOP10, UC, IBM, US (9 in average), Entire World Set (7 in average), Japan, Others, and European group

Nanoelectronics Research Initiative Funded Universities (SIA, NSF, NIST)



Partnerships NSF, NIST, SIA, SRC with over 30 Universities in 16 States

Return on investment: Estimation of Annual Implications of U.S. Federal Investment in Nanotechnology R&D (2010)



* The corresponding R&D was about 10 times smaller in1998.

** Est. taxes 20%

*** Est. $500,000/ yr/ job

FY 2011 NS&E Priorities Research Areas

The long-term objective is systematic understanding, control and restructuring of matter at the nanoscale for societal benefit

Scientific challenges

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

Twelve trends to 2020

www.wtec.org/nano2/

- Theory, modeling & simulation: x1000 faster, essential design
- "Direct" measurements – x6000 brighter, accelerate R&D & use
- A shift from "passive" to "active" nanostructures/nanosystems
- Nanosystems, some self powered, self repairing, dynamic
- Penetration of nanotechnology in industry - toward mass use; catalysts, electronics; innovation– platforms, consortia
- Nano-EHS – more predictive, integrated with nanobio & env.
- Personalized nanomedicine - from monitoring to treatment
- Photonics, electronics, magnetics – new capabilities, integrated
- Energy photosynthesis, storage use – solar economic by 2015
- Enabling and integrating with new areas – bio, info, cognition
- Earlier preparing nanotechnology workers – system integration
- Governance of nano for societal benefit - institutionalization

NNI "signature initiatives" at NSF

2011-2012

Sustainable Nanomanufacturing (NSF 10614)

FY 2011: Program solicitation $11.3M + core programs
FY 2012: Estimate $57.2M

Nanoelectronics for 2020 and Beyond (NSF 10618)

FY 2011: Program solicitation with SRC $20M + Core
FY 2012: Estimate $50M

Nanotechnology for Solar Energy

FY 2011: Program solicitations, one with DOE + Core
FY 2012: Estimate $32M

NNI "signature initiatives" relate to ENV

2013

Sustainable Nanomanufacturing

Includes: sustainable development, ENV

Nanoelectronics for 2020 and Beyond

Includes: nano-EHS for nanoelectronics

Nanotechnology for Solar Energy

Includes: sustainable development, ENV

Nanotechnology Knowledge Infrastructure

Includes: ENV and nano-EHS M&S and informatics

Nanotechnology for Sensors

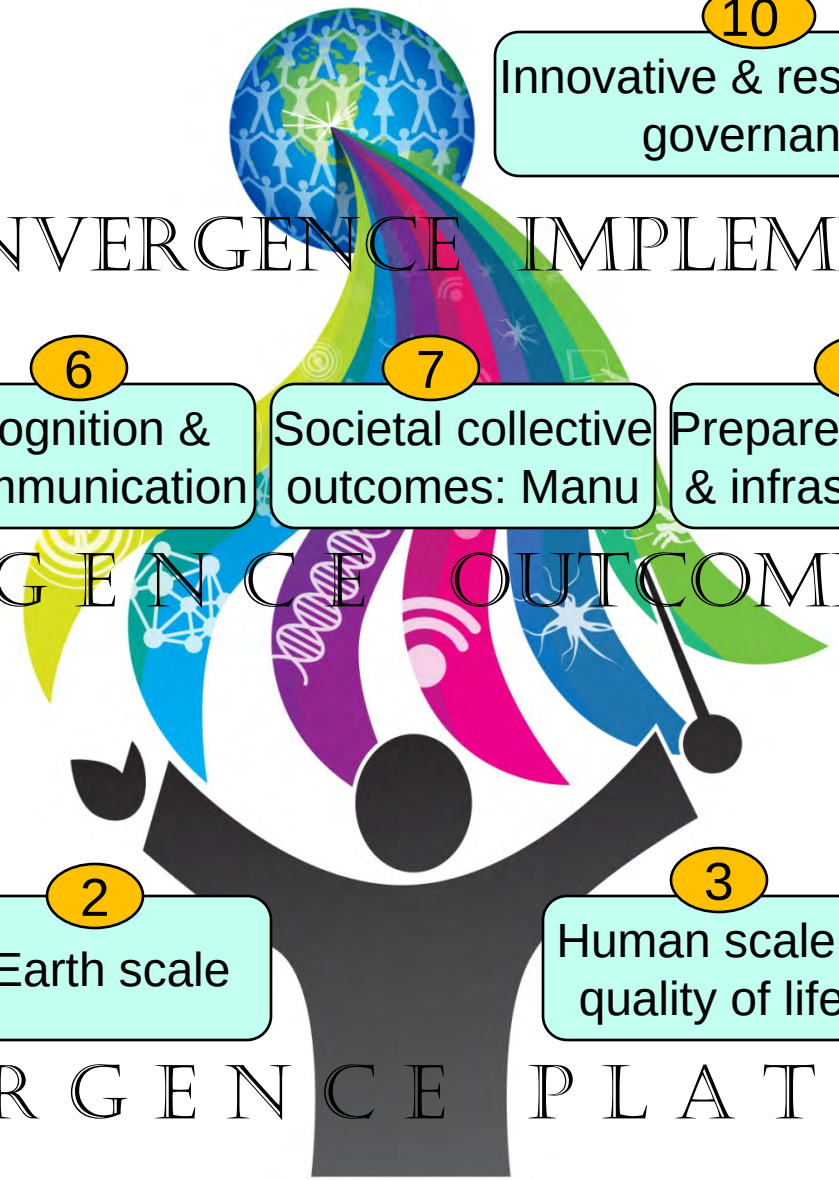
Includes: applications to ENV and nano-EHS

Three NSF awards of $55.5 million for Nanosystems Engineering Research Centers

- Advanced Self-Powered Systems of Integrated Sensors and Technology, North Carolina State University: self-powered wearable systems that simultaneously monitor a person's environment and health; links exposure to pollutants and chronic diseases.
- Nanomanufacturing Systems for Mobile Computing and Mobile Energy Technologies, UT-Austin: high-throughput, reliable, and versatile nanomanufacturing process systems and will demonstrate them through the manufacture of mobile nanodevices.
- Transformational Applications of Nanoscale Multiferroic Systems, UCLA: exploit nanoscale phenomena to reduce the size and increase the efficiency of components and systems whose functions rely on the manipulation of either magnetic or electromagnetic fields.

Converging Technologies for Societal Benefit

Report presentation: Dec 11 2012 (Room 1235, NSF)



10 Innovative & responsible governance

CONVERGENCE IMPLEMENTATION

5 Human health & Physical potential

6 Cognition & communication

7 Societal collective outcomes: Manu

8 Prepare people & infrastructure

9 Sustainable development

CONVERGENCE OUTCOMES DOMAINS

1 Foundational Tools - NBIC

2 Earth scale

3 Human scale & quality of life

4 System approach & synergism

CONVERGENCE PLATFORMS

Main Evaluations of NNI with NSF input

Congress; WH/ OSTP and OMB - annually

PCAST - 1999, 2005, 2008, 2010, (2013)

Academies, NRC: 2002, 2005, 2008, 2011, (2013)

GAO - 2007, 2009, 2010, 2011, 2012, (2013)

NSF - Annually (GPRA, annual plan, cross-agency, for centers)

- NSF COVs; SRI (2005-2006), NSECs (2010), NSEE, ..
- International evaluation and vision for ten years ahead, WTEC (1999-2000), WTEC (2010), WTEC (2012)
- Topical NSE meetings sponsored by NNI, NSF

International organizations: OECD, UNESCO, ISO, APEC, …

2011-2015: Key R&D areas of emphasis

www.wtec.org/nano2/

- Integration of knowledge at the nanoscale and assembling nanocomponents into nanosystems by design
- Better experimental and simulation control of processes such as: molecular self-assembly, quantum behavior, creation of new molecules, and interaction of nanostructures with external fields
- Understanding of biological processes and of nano-bio interfaces with abiotic materials, and their biomedical applications
- Nanotechnology solutions for sustainable development; nano-EHS
- Governance to increase innovation and public-private partnerships; education and infrastructure; oversight of nanotechnology, public and international participation.

Several Possibilities

- Institutionalize research programs (for planned structure and level of funding)
- Increased R&D focus on the next generations of nanotechnology processes, systems and products (support funding and building capacity)
- Integrate R&D for clean environmental technologies with nano-EHS and mitigation efforts

FY 2012 NSF's Grantees Meeting

- Reviews of selected NSE awards with a focus on ENV
  Keynotes, posters and panels to facilitate exchanges, partnerships, and research planning
- Strengthen NSE trans-disciplinary community
  Prepare for increased complexity in NSE research
- Meetings between researchers/educators with P.D.s

Several background references

"Nanotechnology Research Directions“, book Springer 2000

"Societal Implications of Nanoscience and Nanotechnology", Springer (2001); updated in 2 volumes in 2007

“International strategy for nanotechnology research and development”, Journal of Nanoparticle Research 3, 353–360 2001

“The NNI: Past, Present and Future”, in Handbook on Nanoscience, Engineering and Technology, CRC, Taylor and Francis 2007

“Nanotechnology Risk Governance” in Global Risk Governance Framework, book Springer 2007

“Possibilities for Global Governance of Converging Technologies”, J. Nanoparticle Res. 2008

"Mapping Nanotechnology Innovations and Knowledge" book Springer 2009

“Nanotechnology Research Directions for Societal Needs in 2020” book Springer (Roco, Mirkin and Hersam 2011)

“Nanotechnology: From Discovery to Innovation and Socioeconomic Projects” AIChE/CEP Roco, May 2011)