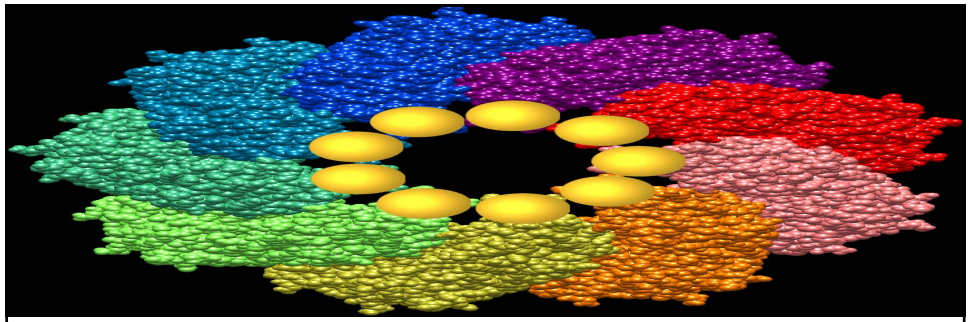


Long View for Nanotechnology R&D

M.C. Roco

National Science Foundation (NSF),
U.S. National Nanotechnology initiative (NNI)
and International Risk Governance Council

American Academy of Nanomedicine Symposium, September 6, 2008

TOPICS

What is nanotechnology?

Five generations of nanotechnology products

NNI in the international context

Convergence of nano and biomedicine

Governance of nanotechnology development

M.C. Roco, 9/6/2008

Benchmark with experts in over 20 countries

"Nanostructure Science and Technology"

Book Springer, 1999

Nanotechnology definition for the R&D program

is the *control and restructuring of matter*

at dimensions of roughly 1 nm (size small molecule) to 100 nm *(at the transition from individual to collective behavior of atoms and molecules),*

where new phenomena enable new applications *(where nanoscale modules are established).*

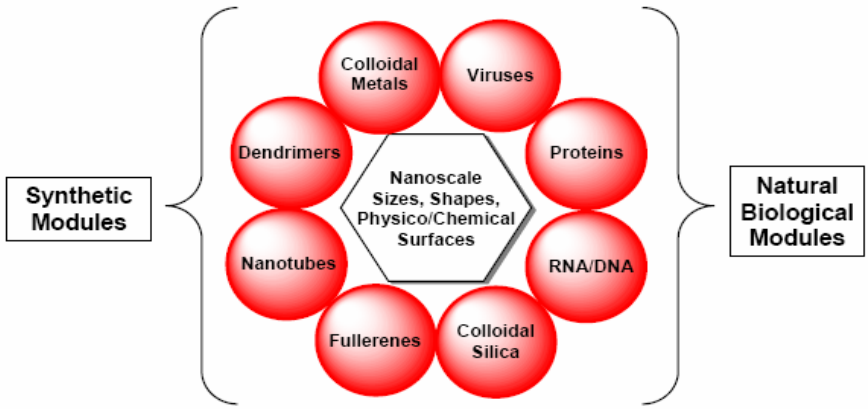
M.C. Roco, 9/6/2008

NANOSCALE IS A NATURAL THRESHOLD OF TRANSITION

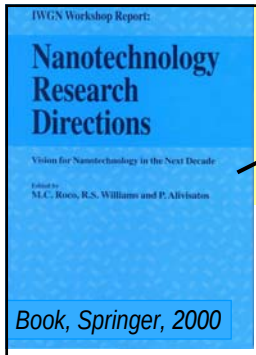
from individual to collective behavior of atoms & molecules,

where nanoscale modules are established

dominated by quantum, selfassembling, etc. effects



NSF Workshop at U. Michigan , April 2008, M.C. Roco, 9/6/2008



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 that benefits society

More important than miniaturization itself:

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

MC Roco, 9/6/2008

The core of NNI's Nanomedicine Initiative at NIH

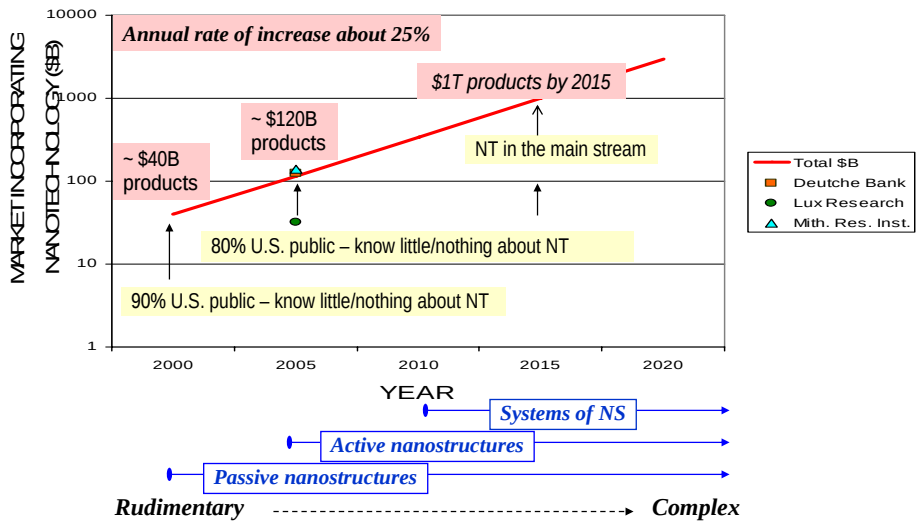
Steps to achieve the goal:

- Characterize entities by the physical and chemical properties of molecules and molecular machinery in cells;
- Gain an understanding of the engineering principles used in living cells to "build" molecules, molecular complexes, organelles, cells, and tissues; and
- Use this knowledge of properties and design principles to develop new technologies, materials, devices and hybrids for repairing tissues and for preventing and curing disease.

CONTROL AND MANIPULATE BIOLOGY AT THE NANOSCALE IN VIVO FOR MEDICAL USES

WORLDWIDE MARKET INCORPORATING NANOTECNOLOGY (2000-2015)

(Estimation made in 2000 after international study in > 20 countries; data standing in 2008)

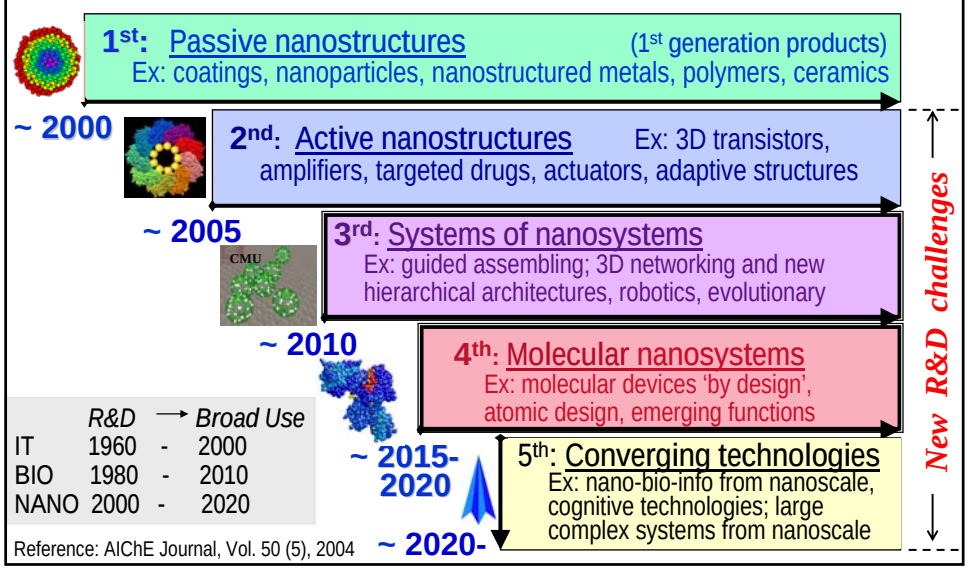


Reference: MC Roco and WS Bainbridge, Springer, 2001

MC Roco, 9/6/2008

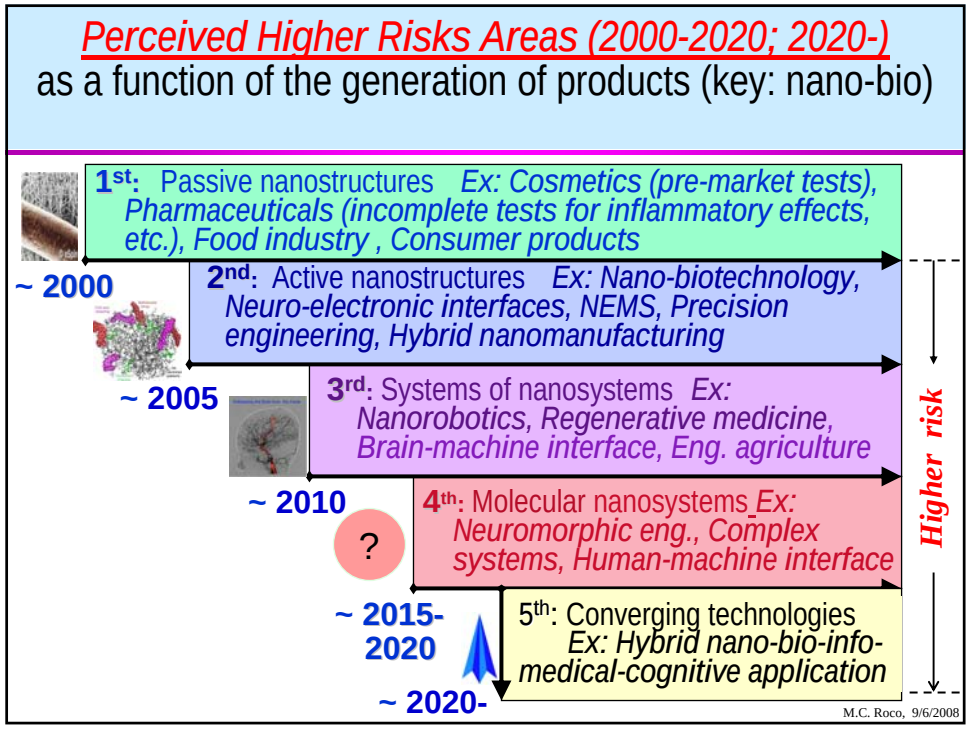
Five Generations of Products and Productive Processes

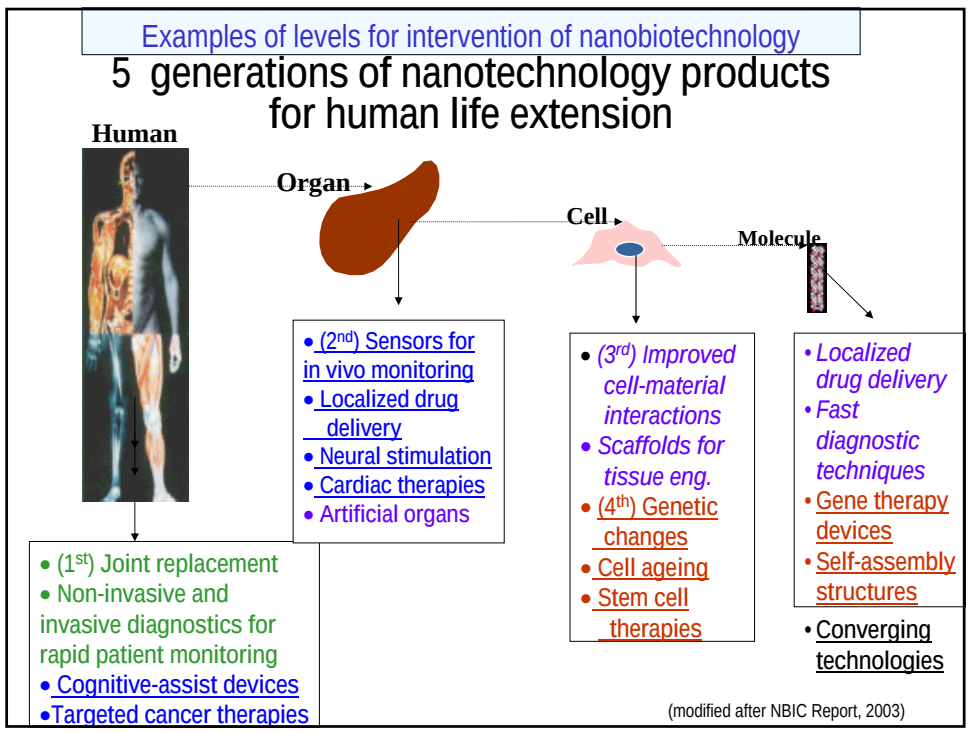
Timeline for beginning of industrial prototyping
and nanotechnology commercialization (2000-2020; 2020-)



	R&D	→	Broad Use
IT	1960	-	2000
BIO	1980	-	2010
NANO	2000	-	2020

Reference: AIChE Journal, Vol. 50 (5), 2004

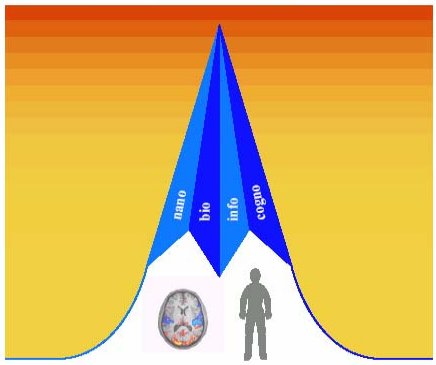

Perceived Higher Risks Areas (2000-2020; 2020-)
as a function of the generation of products (key: nano-bio)
1st: Passive nanostructures Ex: Cosmetics (pre-market tests), Pharmaceuticals (incomplete tests for inflammatory effects, etc.), Food industry , Consumer products
~ 2000
2nd: Active nanostructures Ex: Nano-biotechnology, Neuro-electronic interfaces, NEMS, Precision engineering, Hybrid nanomanufacturing
~ 2005
3rd: Systems of nanosystems Ex: Nanorobotics, Regenerative medicine, Brain-machine interface, Eng. agriculture
~ 2010
?
4th: Molecular nanosystems Ex: Neuromorphic eng., Complex systems, Human-machine interface
~ 2015-2020
5th: Converging technologies Ex: Hybrid nano-bio-info-medical-cognitive application
~ 2020-
Higher risk
M.C. Roco, 9/6/2008


Examples of levels for intervention of nanobiotechnology
5 generations of nanotechnology products for human life extension
Human
Organ
Cell
Molecule
• (2nd) Sensors for in vivo monitoring
• Localized drug delivery
• Neural stimulation
• Cardiac therapies
• Artificial organs
• (3rd) Improved cell-material interactions
• Scaffolds for tissue eng.
• (4th) Genetic changes
• Cell ageing
• Stem cell therapies
• Localized drug delivery
• Fast diagnostic techniques
• Gene therapy devices
• Self-assembly structures
• Converging technologies
• (1st) Joint replacement
• Non-invasive and invasive diagnostics for rapid patient monitoring
• Cognitive-assist devices
• Targeted cancer therapies
(modified after NBIC Report, 2003)

Fifth generation of nano products:

four volumes on convergence

2003, 2006 and 2007 Springer; 2004 NYAS



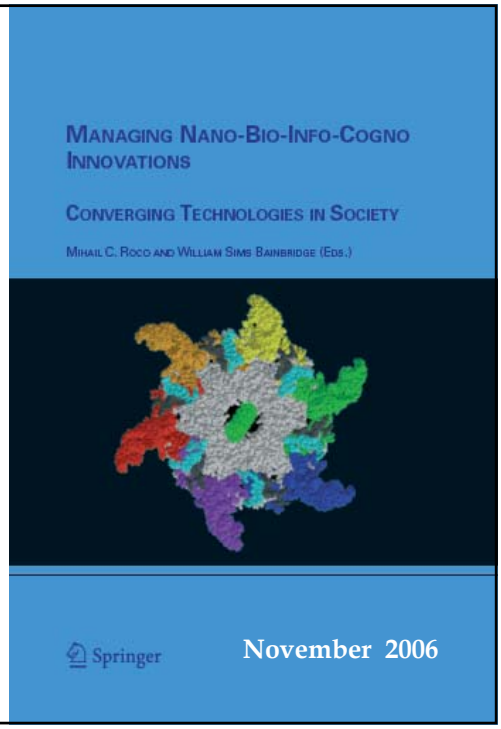
CONVERGING TECHNOLOGIES FOR IMPROVING HUMAN PERFORMANCE

June 2002

Workshop, Dec. 2001

www.nsf.gov/nano

Springer, 2003



Milestones in NNI evolution

- Interagency group (November 1996); Preparatory reports (1997-1999)
- NNI is proposed at WH: March 1999; competition OMB October 1999
- PCAST supports NNI: December 1999
- President Clinton announces NNI in January 2000
- NNI/NSTC subcommittee established: August 2000

➢ October 2001: NNI begins

➢ January 2001: MOU for NNI coordination and NNCO

➢ December 2003: Congress, 21st Century Nanotechnology R&D Act Establishes the National Nanotechnology Advisory Panel (NNAP)

➢ June 2004 – International Dialogue initiated by NNI; followed by 2006 ISO in 2006, OECD in 2007, other international organizations

➢ U.S. Congress, June (H.R.5950) - July (S.)2008: Amend the 2003 Act

M.C. Roco, 9/6/2008

The long-term view drives NNI
2000-2020

- NNI was designed as a science project after two years of planning without dedicated funding in 1997-1999:
  - Long-term view ("Nanotechnology Research Directions")
  - Definitions and international benchmarking ("Nanostructure S&T")
  - Science and Engineering Priorities and Grand Challenges ("NNI")
  - Societal implications ("NSF Report", 2000)
  - Plan for government agencies ("National plans and budgets")
  - Public engagement brochure ("Reshaping the word", 1999)
- Combine four time scales in planning (2001-2005):
  Vision - 10-20yrs, Strategic plan - 3-5yrs, Annual budget - 1yr, and Management decisions - 1 month

MC Roco, 9/6/2008

Expanding nanotechnology domains since 2000

2000-2001: nano expanding in almost all disciplines, NNI→

2002-2003: industry moves behind nano development

2003-2004: medical field sets up new goals; >60 countries

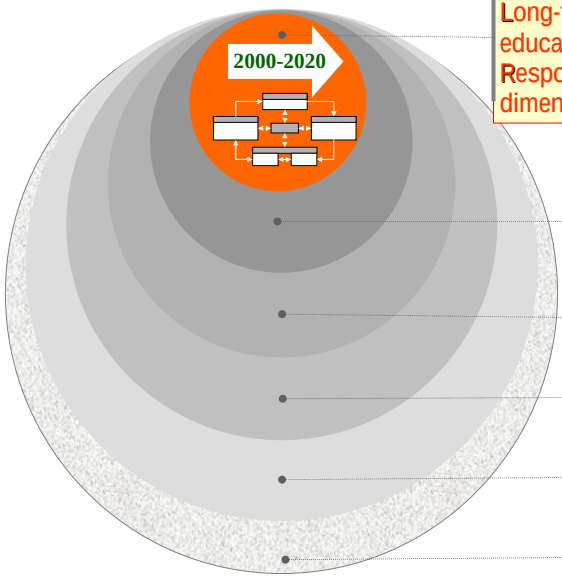
2004-2005: media, NGOs, public, international organizations get involved

2006-2007: new focus on common Earth resources - water, food, environment, energy, materials

2007-2008: increased relevance to economy, sustainability, strategic advantage

M.C. Roco, 9/6/2008

NANOTECHNOLOGY GOVERNANCE OVERVIEW



Core Governance Process:
Long-term view; Transforming (incl. education, innovation); Inclusive; Responsible (addressing societal dimensions, nano risk governance)

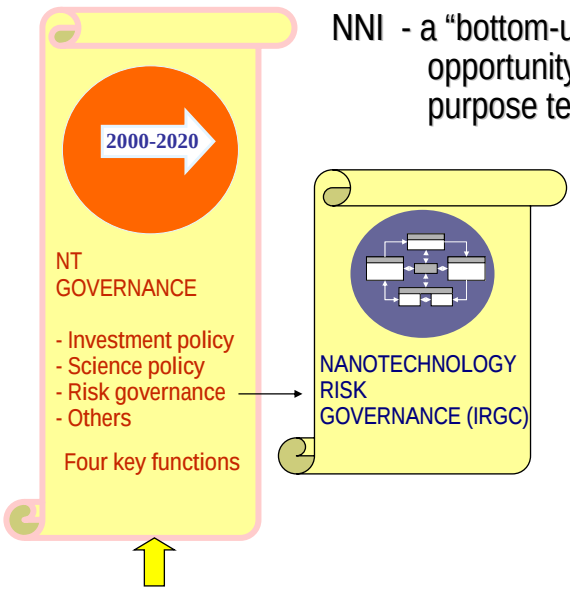
Main Actors:

- R&D Organizations (Academe, industry, gov.)
- Implementation Network (Regulators, business, NGOs, media, public)
- Social Climate (Perceived authority of science, civil involvement)
- National Political Context
- International Interactions

Reference: "NNI: Past, Present Future", Handbook of Nanoscience, Eng. and Techn., MC Roco., Taylor and Francis, 2007

NT Governance and Risk Governance

NNI - a "bottom-up, science opportunity-born, general purpose technology" program



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Governance of nanotechnology development: four roles

- **Visionary**
  Long-term and global view, human development
- **Transformative**
  Investment policy, S&T policy, education
- **Inclusive**
  Building national/international capacity, leveraging
- **Responsible development**
  EHS, ELSI+, Methods for risk governance, communication and participation

Reference: "Possibilities for global governance of converging technologies", MC Roco, J. Nanopart. Res., 10:11-29 (2008)

NNI Vision (2000 -)

Systematic control matter on the nanoscale will lead to a revolution in technology and industry that benefits society

Two concepts:

- Changing the foundation of understanding, control, manufacturing and medicine from the macro and micro domains to the nanoscale, where all fundamental material structures, properties and functions can be efficiently established and changed

- Create general purpose technology that will affect almost all sectors of the society. It will disrupt – produce structural changes - markets, industrial organizations and business models (ex: 50% of new products in advanced industrial areas will use NS&E by 2015)

NNI as part of the U.S. Federal R&D ~ 0.25% (2000) to 1% (2005-2008)

U.S. NNI as part of world nanotech investment ~ 1/4 (2005-2008)

MC Roco, 9/6/2008

A sampling of NSET Subcommittee publications for second strategic plan (2005-2008)

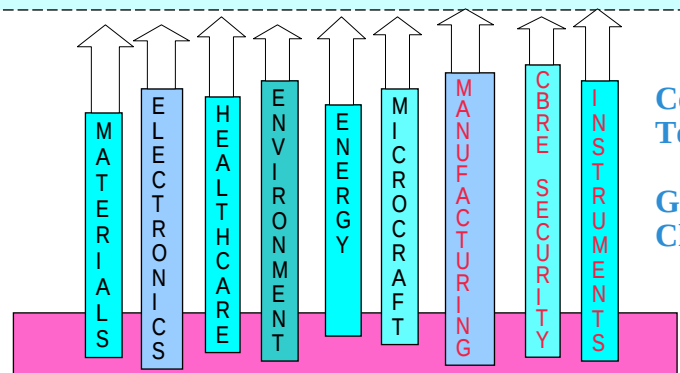
NNI Strategic Plans: 2000 (report vision 10 yr), 2005 (3 yr), 2008 (3yr), ...

M.C. Roco, 9/6/2008

Transformative: Stimulate innovation

Interdisciplinary "horizontal" knowledge creation vs. "vertical" transition from basic concepts to Grand Challenges

Revolutionary Technologies and Products



Converging Technologies

Grand Challenges

Infrastructure

Workforce

Partnerships

Fundamental research at the nanoscale

Knowledge creation: same principles, phenomena, tools

Basic discoveries and new areas of relevance

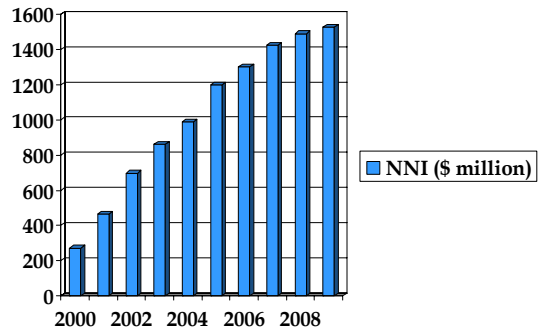
M.C. Roco, 9/6/2008

National investment

FY 2009 NNI Budget Request - $1,527 million

MC Roco, 01/10/200

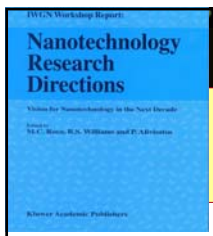
Fiscal Year	NNI
2000	$270M
2001	$464M
2002	$697M
2003	$862M
2004	$989M
2005	$1,200M
2006	$1,303M
2007	$1,425M
2008	$1,491M
R 2009	$1,527M



EHS 2006: $38M (primary; $68M total eff.)
2007: $48M (primary; $86M total est.)
2008: $57M (primary; $102 total est.)
2009: $76M (primary - planned)

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

NNI / EHS > 1/2 of the world EHS R&D



Inclusive: Participants in the NNI (NSET)

Partners: Fed. agencies, states, local org., industry, global

- **FY 2001 - 6 agencies; FY 2008 - 25 NNI agencies**
- **4 working groups: NEHI, NILI, GIN, NPEG**

2001: Six Agencies
NIH, NIST, NASA, DOD, DOE, NSF

2002: Seven New Agencies
DOTr, DOT, EPA, DOS, IC, USDA, DOJ

2003-4: Four New Agencies
FDA, NRC, DHS, DOC TA

2005: Six New Agencies
USDA FS, DOC BIS, USPTO, ITC, CPSC, NIOSH

2006: Three New Agencies
USGS, DOL, DOEd

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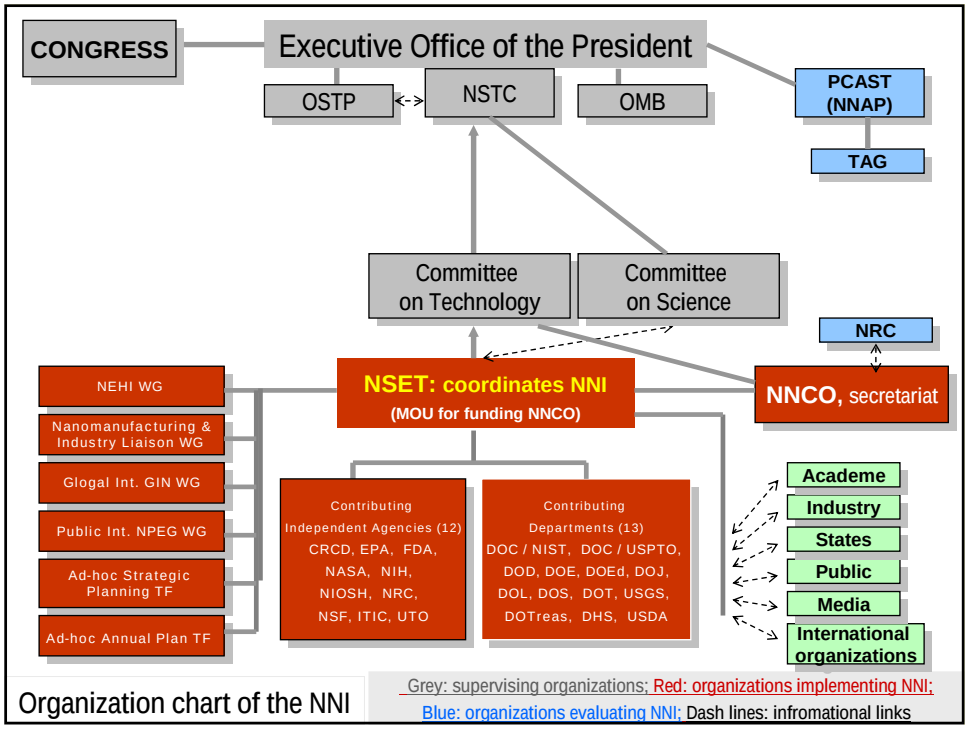


Organization chart of the NNI

Grey: supervising organizations; Red: organizations implementing NNI; Blue: organizations evaluating NNI; Dash lines: infromational links

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**

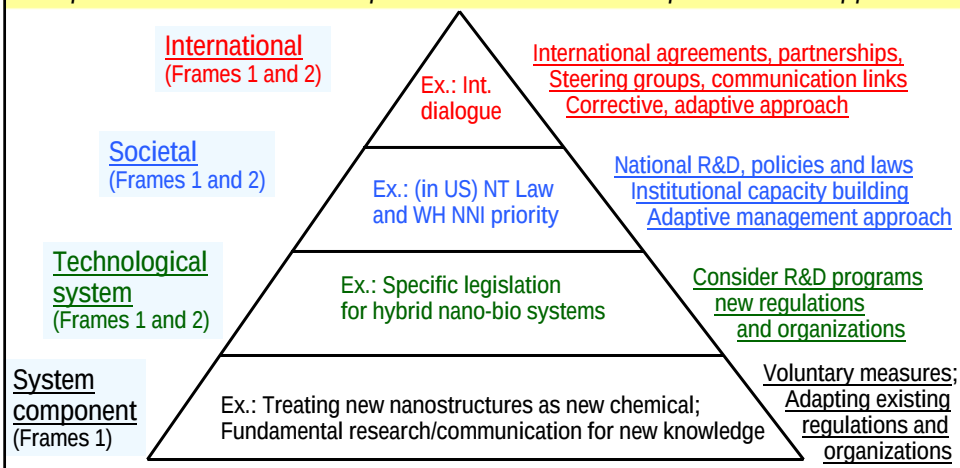
American Forest & Paper Association

MC Roco, 9/6/2008

Responsible development

Multi-level structure of NT risk governance

Implication Domain / Examples of RG activities / Implementation approach



References: International Risk Governance Council, http://www.irgc.org/irgc/projects/nanotechnology/ ;

Context for the long-term view

- Changing research frontier focus
  - Nano-bio-medical increases share
- Key societal issues in long term
  - EHS/ELSI challenge for new NT generations
- Changing infrastructure
  - Nanotechnology education challenge
- International context

M.C. Roco, 9/6/2008

Changing research frontier focus

2000-2002

Nanoparticles, nanotubes, quantum dots, coatings

2003-2005

Self- and guided molecular assembling Expands nanobio technology and medicine

2006-2008

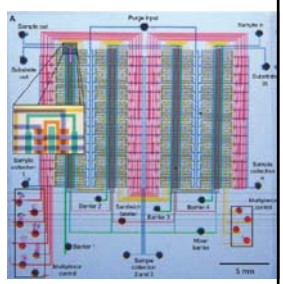
Focus on nanodevices and components of nanosystems

> *2008* from COMPONENT to SYSTEM NANOTECHNOLOGY

M.C. Roco, 9/6/2008

Challenges in Systems Nanotechnology

- Create controllable systems built from nanoscale components: unifying principles that enable control of emergent behavior in complex nanosystems
- Wide application: petascale computing, organ regeneration, sensors for health monitoring
- Enable other goals for: nanomanufacturing, efficient use of energy; and sensor capabilities
- Development of a new framework for risk assessment



Ferreira, UIUC

M.C. Roco, 9/6/2008

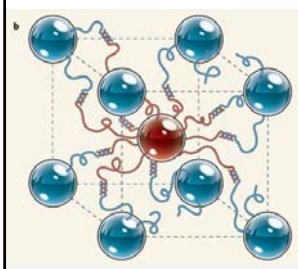
Nanosystems

Examples new topics and prototypes of products in 2008

- A. Zettl (UCB), J. Rogers (U Illinois): nano radio = antenna, filter, amplifier
- IBM: Manipulation with atomic precision
- C. Mirkin (NU), O. Gang (BNL) Architectures for new, designed crystals

This image, taken by a transmission electron microscope, shows the carbon-nanotube radio (UCB)

M.C. Roco, 7/7/2008



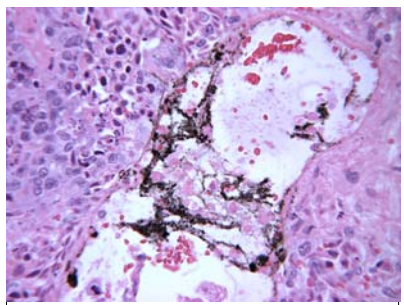
Selfassembling of atoms through DNA strands

- Graphene to build electronic systems
- Informatics for nanosystem design
- Nanolayers for energy conversion
- Water filtration using nano membranes

Radio waves fire up nanotubes embedded in tumor cells to destroy cancer (applied to liver)

Single-wall carbon nanotubes (SWNTs) convert radiofrequency (RF) radiation into heat

Rice University and
MD Anderson Cancer Center



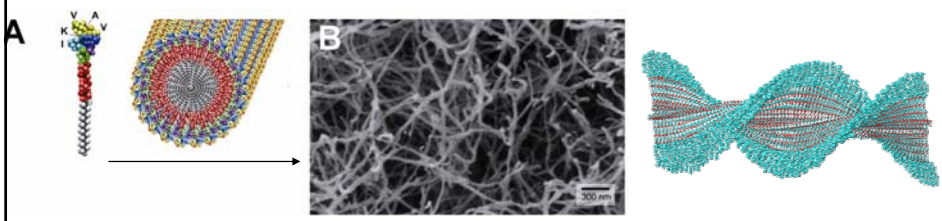
The micrograph shows necrotic tumor cells, inflammatory cells, and long collections of coalesced SWNTs (black strands, arrow)

RICE

Example 4th generation (in research)

Designing molecules for hierarchical selfassembling

EX: - Biomaterials for human repair: nerves, tissues, wounds (Sam Stupp, NU)

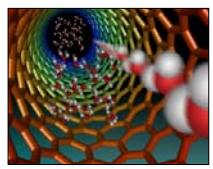


- New nanomachines based on DNA architectures (Ned Seeman, Poly. Inst.)
- Designed molecules for self-assembled porous walls (Virgil Percec, U. PA)
- Self-assembly processing for artificial cells (Matt Tirrell, UCSB)
- Block co-polymers for 3-D structures on surfaces (U. Mass, U. Wisconsin)

M.C. Roco, 9/6/2008

FY 2008 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

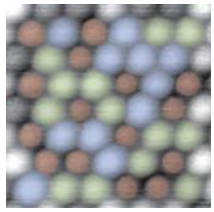


A. Scientific challenges

- New theories at nanoscale
  Ex: transition from quantum to classical physics, bio interfaces, 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

M.C. Roco, 9/6/2008

FY 2008 NS&E Priorities Research Areas (2)



B. Development of nanotechnology

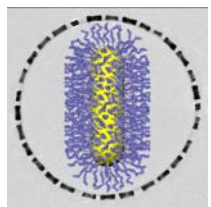
- Tools for measuring and restructuring
  with atomic precision
  and time resolution of chemical reactions
- Understanding and use of quantum phenomena
- Understanding and use of multi-scale selfassembling
- Nanobiotechnology – sub-cellular and systems approach
- Nanomanufacturing hybrid, on site
-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

M.C. Roco, 9/6/2008

FY 2008 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
  using new principles
- Efficient nanomanufacturing and
  sustainable environment
- Nano-bio interfaces between the human body
  and manmade devices
- Nano-informatics for better communication and
  nanosystem design



Hybrid Nanorods
Credit: Bishnu Khanal

M.C. Roco, 9/6/2008

From FY 2008 NSF priority research areas (4)

Societal dimensions of nanotechnology

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

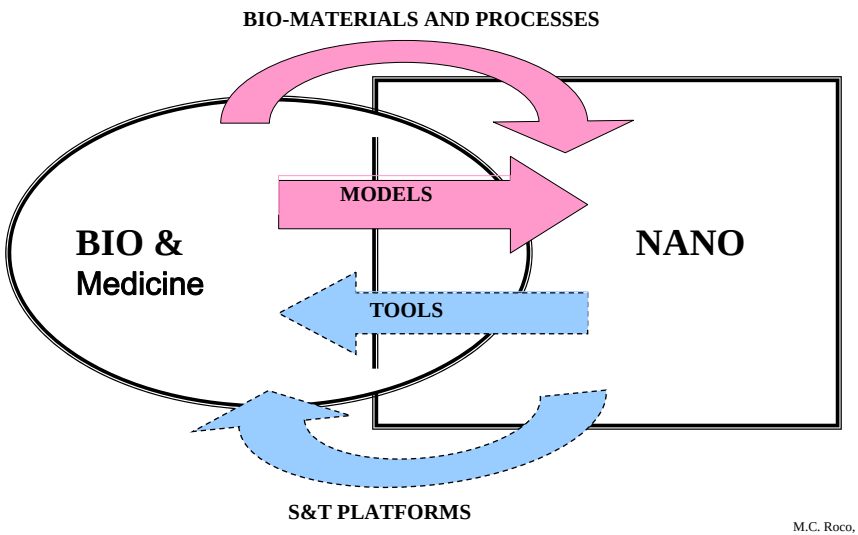
  Key nano- EHS priorities at NSF
  - New instrumentation for nanoparticle characterization and nanotoxicity
  - Transport phenomena and physico- chem.- biological processes
  - Nano-bio interface: ecological and human health implications
  - Predictive models for interaction of nanomat. with cells/living tissues
  - Separation of nanoparticles from fluids
  - Safety of manufacturing nanoparticles

- Earlier formal (earlier K-12 and public education integrated in K – Gray) and informal education

- Social issues and public engagement

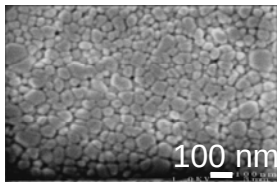
M.C. Roco, 9/6/2008

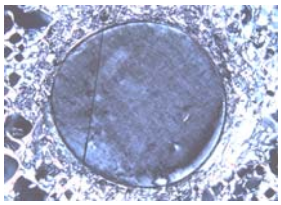
Nanotechnology, Biology and Medicine are Becoming One



M.C. Roco, 9/6/2008

Example 1st generation **Angstrom Medica's nanostructured calcium phosphate technology for bone-based orthopedic implants**





NanOss™ Calcium Phosphate Nanocrystals

$Ca_{10}(PO_4)_6(OH)_2$ and $Ca_3(PO_4)_2$

Composition and morphology of bone
Enhanced bioactivity and strength

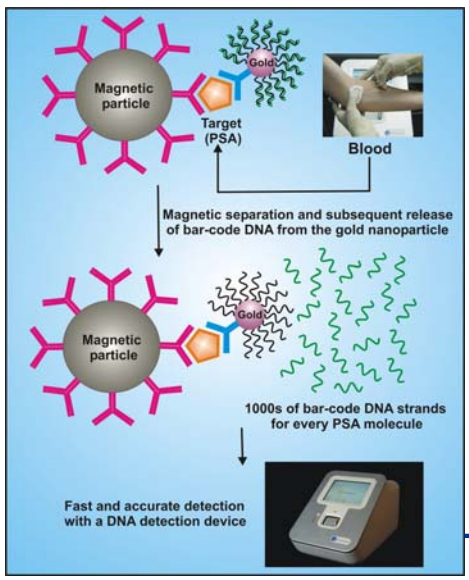
Bone bonding in 2 weeks and osteointegration in 4 weeks because the nanostructure closely match that found in human bone

Angstrom Medica received SBIR in 2003 (NSF-0232733) and 2004 (NSF-0349884)

The product received "marketing clearance" from FDA in 2005

M.C. Roco, 9/6/2008

***Example 2nd generation*: NanoBio-Bar-Code Assay,**
Chad Mirkin (Northwestern U. and spin-off Nanosphere, Inc.)

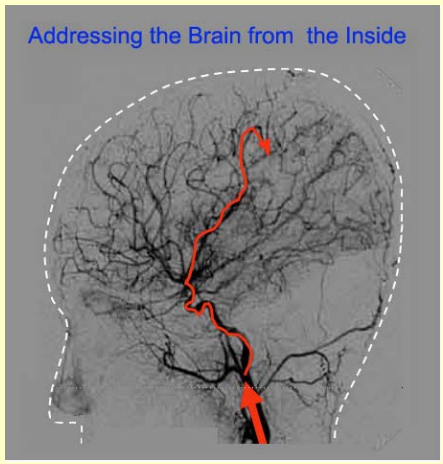


1. **One million times more sensitive than previous technology**
2. **Evaluate new biomarkers for diagnosing and following human diseases (e.g. HIV and Alzheimer's Disease).**
3. **Single-cell protein expression experiments.**
4. **In advance clinical testing**

M.C. Roco, 9/6/2008

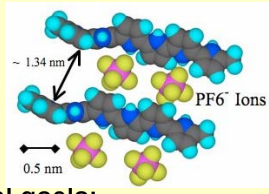
Example 3rd generation: Neuro-vascular Central Nervous Recording/ Stimulating System: Using Nanotechnology Probes

R.R. Llinás, NYU School of Medicine
I. Hunter, MIT, Bioengineering



J. Nanoparticle Research, 2005, Issue 2

Nanostructured polymeric wires, Conducting biocompatible, biodegradable and with guidance



Several goals:

- neuro-to-neuron interaction
- simultaneous multiple probes for describing the system
- treatment Parkinson disease

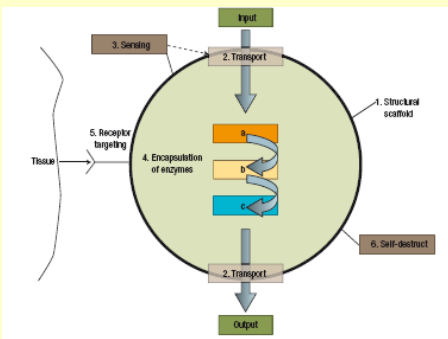
M.C. Roco, 9/6/2008

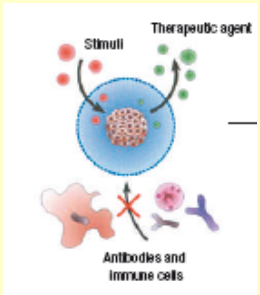
Example 3rd & 4th generation – nanosystems and converging technologies

In vivo biologically inspired nanofactory

Create "pseudo-cell' nanofactories that work with molecules already in the body to fight disease (P.R. Leduc, CMU, 2007)

(1) shell, (2) conveying biomolecules to and from the environment, (3) sensing , (4) encapsulation of biochemical machinery, (5) targeting of the factory within the body, (6) externally triggered degradation to terminate a treatment





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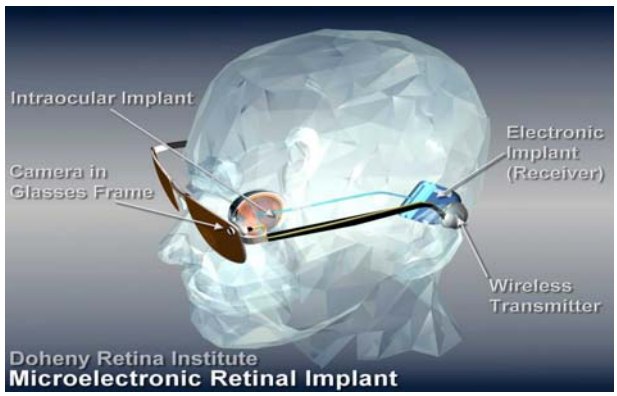
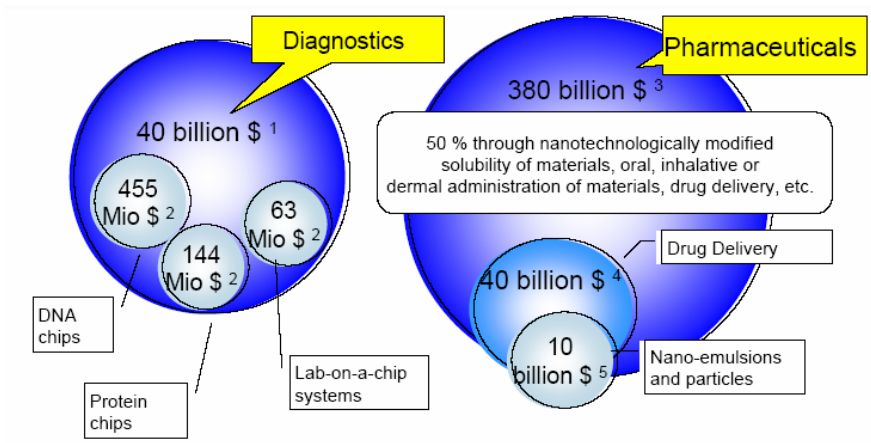
Biomedical engineering

- Build tissues. Ex: artificial retina using flexible electronics (2008)



M.C. Roco, 9/6/2008

Medicine: two lead markets for nanotechnology



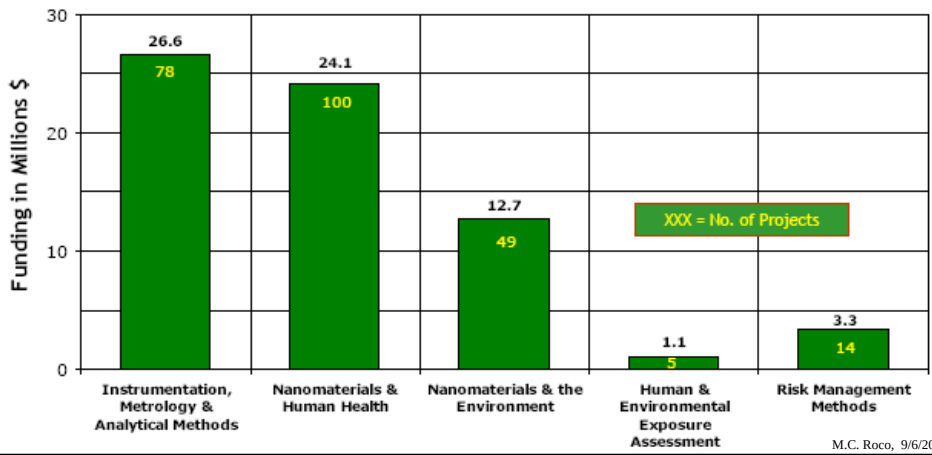
1: World market 2005 source: Uni Ulm; **2**: World market 2005 source : Line Strategic Management; **3**: World market 2000 source NNI Study;
4: World market 2000 source Market Letter; **5**: World market 2005 source : SkyePharma

Study by German Federal Ministry of Education and Research

M.C. Roco, 9/6/2008

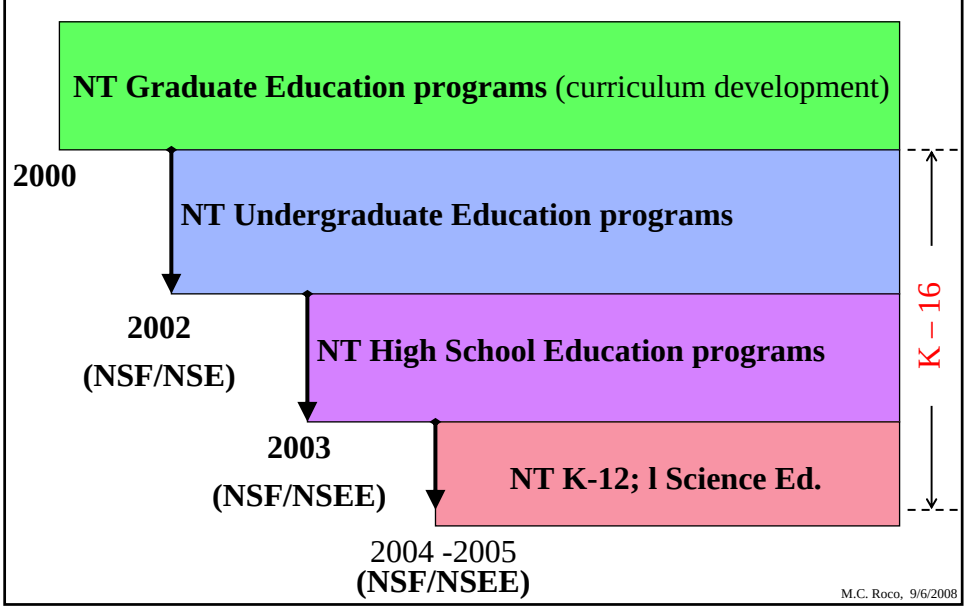
Overview of NNI EHS funding in 2006

- $68 million funding for 246 nanotechnology-related EHS research projects at seven NNI member agencies
- *Consensus among NEHI Working Group that instrumentation, metrology, and analytical methods category is cross-cutting and generally a high priority*



M.C. Roco, 9/6/2008

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



M.C. Roco, 9/6/2008

Changing R&D infrastructure since 2000
Ex: US - NNI Infrastructure

- Over 80 nanotechnology research centers, networks, and user facilities linked in a world-class interdisciplinary infrastructure
- Over 4500 active research projects in 2007 at over 500 universities, Government labs, and other research institutions in all 50 states

Source: NNCO

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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*

MC Roco, 5/6/2008

NNI Accomplishments

- Developed foundational knowledge for control of matter at the nanoscale: about 4,500 active projects in > 500 universities, private sector institutions and gov. 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 patents[2], and
  - ~ 70% of startups[3] in nanotech.
    Over 2,300 U.S. nanotech companies in 2007;
    ~ $70B products incorporating essential nano components
- Infrastructure:
  over 80 new large NT research centers, networks and user facilities;
  ~ 10,000 students and teachers educated and trained each year

([1]) NSF Committee of Visitors; ([2]) Journal of Nanoparticle Research, 2006; ([3]) NanoBusiness Alliance, 2006

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Changing international context since 2000

~ *2000*: Focus on discovery , 'wait & see' if applied

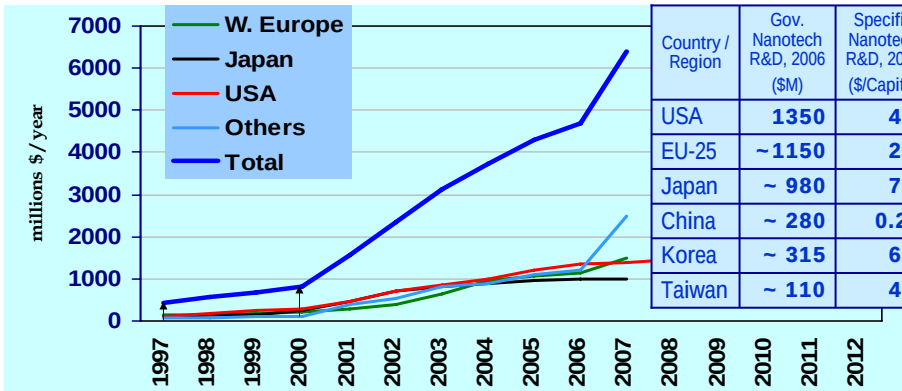
> *2005*: Nano as a technological, economical and strategic advantage for nations and large businesses

Expanding
- open-source
- horizontal growth
- communication
- governance

M.C. Roco, 9/6/2008

Context – Nanotechnology in the World

National government investments 1997-2007 (estimation NSF)



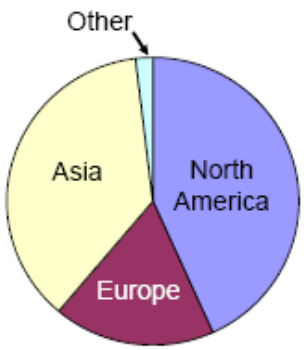
Country / Region	Gov. Nanotech R&D, 2006 ($M)	Specific Nanotech R&D, 2006 ($/Capita)
USA	1350	4.5
EU-25	~1150	2.5
Japan	~ 980	7.6
China	~ 280	0.23
Korea	~ 315	6.5
Taiwan	~ 110	4.7

Seed funding (1991 -) | NNI Preparation (vision / benchmark) | 1st Strategic Plan (passive nanostructures) | 2nd Strategic Plan (active ns. & systems)

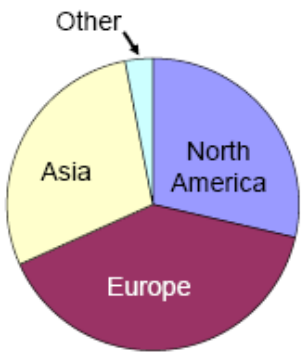
Industry R&D ($6B) has exceeded national government R&D ($4.6B) in 2006

J. Nanoparticle Research, 7(6), 2005, MC. Roco

Growing nanotechnology R&D investment - $12.6 billion in 2006



Private (Corp. + VC)
Total = $6 billion



Public (National, regional, state)
Total = $6.4 billion

National governments ~ $4.6 billion
Local governments and organizations ~ $1.8 billion

Source: Lux Research

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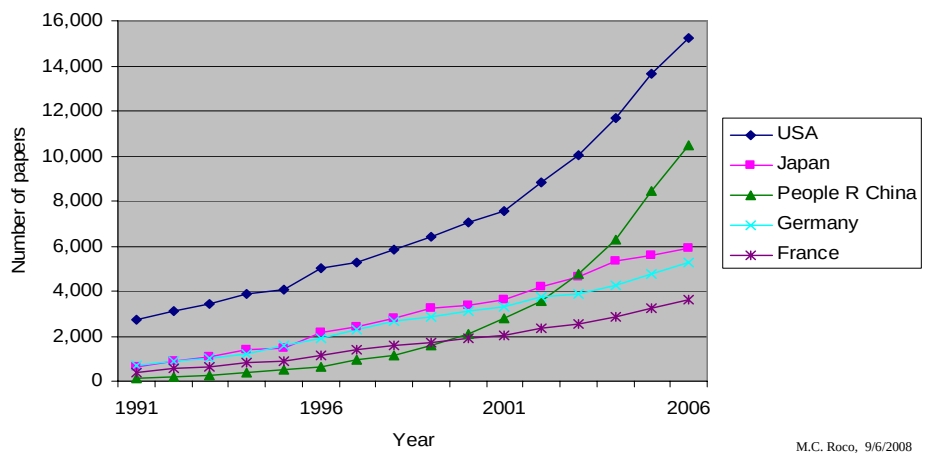
Nanotechnology research publications
Top five countries in 2006: USA, China, Japan, Germany, France

using "Title-claims" search in SCI database for nanotechnology by keywords
(using intelligent search engine, update J. Nanoparticle Research, 2004, 6 (4))



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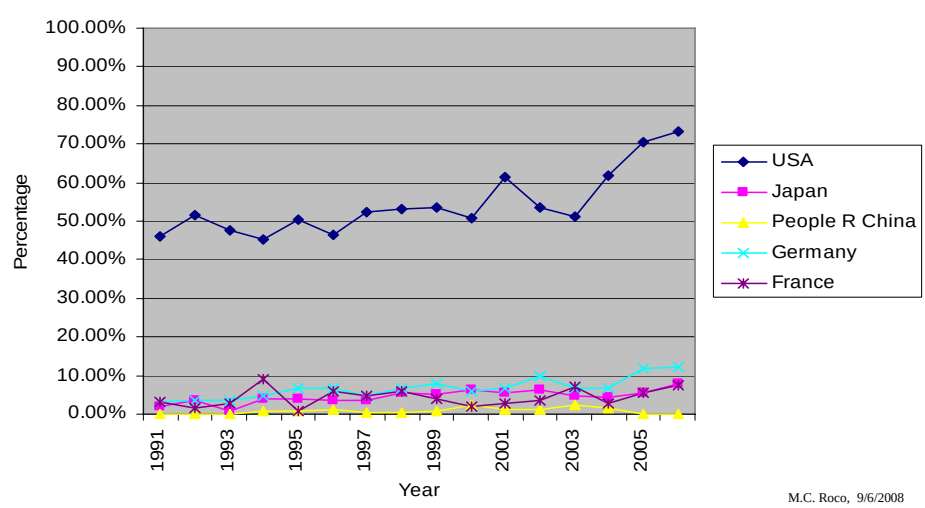
Highly cited nanotechnology related papers published in Science, Nature and PNAS

using "Title-abstract" search in SCI database for nanotechnology by keywords
(using intelligent search engine, update J. Nanoparticle Research, 2004, 6(4))



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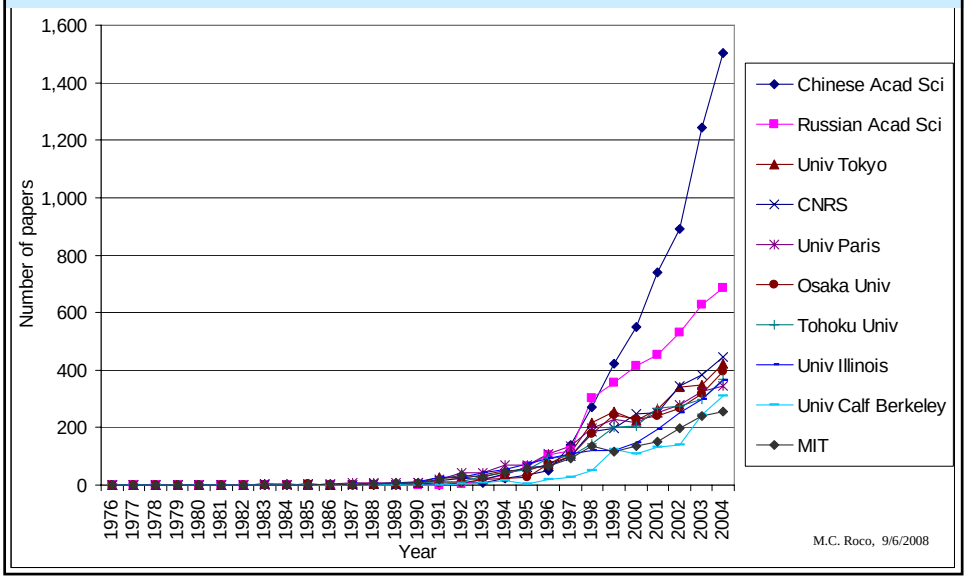
Top 10 institutions in nanotechnology paper publications (1976-2004)



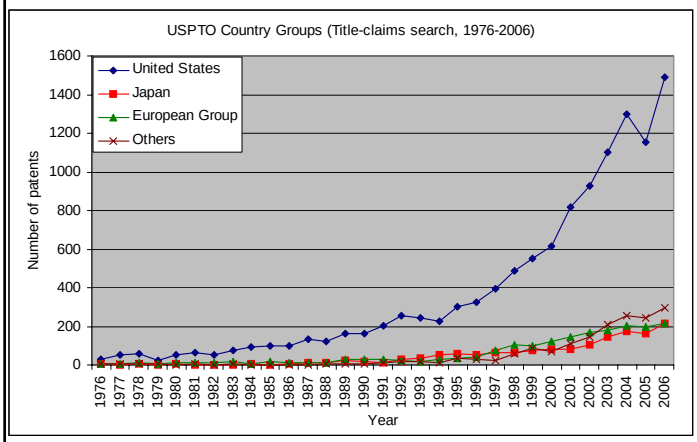
Top 20 institutions with more than 100 papers (1976-2004) based on the average number of cites by Dec. 2004

Rank	Institution	Country/Region	No. of Papers	Average No. of Cites
1	AT&T Bell Labs	USA	221	44.22
2	European Mol Biol Lab	Germany	108	42.17
3	Harvard Univ	USA	1292	40.97
4	Inst Charles Sadron	France	113	38.79
5	Scripps Res Inst	USA	271	36.80
6	Rice Univ	USA	623	34.25
7	IBM Corp	USA	1191	34.20
8	Univ Calif San Francisco	USA	257	33.82
9	NCI	USA	248	30.02
10	Univ Calif Santa Barbara	USA	1322	28.83
11	Stanford Univ	USA	904	26.71
12	Max Planck Inst Biochem	USA	136	25.96
13	Colorado State Univ	USA	207	25.62
14	Lawrence Berkeley Lab	USA	172	25.38
15	Univ Strasbourg	France	431	23.83
16	Univ Calif Berkeley	USA	1809	23.68
17	Indiana Univ	USA	231	23.66
18	Michigan State Univ	USA	461	22.91
19	MIT	USA	1597	22.90
20	Univ Miami	USA	178	22.86

MC Roco, 9/6/2008

NSE patents at USPTO by country group

Assignee country group analysis by year, 1976-2006 ("title-claims" search)



Year	United States	Japan	European Group	Others
1976	30	3	3	6
1977	53	2	3	3
1978	58	3	9	3
1979	26	2	7	3
1980	50	3	9	0
1981	61	1	10	3
1982	51	1	13	1
1983	73	1	15	4
1984	93	4	8	0
1985	97	2	16	1
1986	100	6	11	1
1987	132	12	11	0
1988	124	10	10	6
1989	162	21	28	4
1990	164	17	28	7
1991	204	14	28	9
1992	256	31	26	19
1993	244	36	20	18
1994	227	51	28	10
1995	302	57	33	36
1996	325	52	40	27
1997	393	62	73	25
1998	486	65	103	56
1999	548	75	96	85
2000	612	81	122	68
2001	818	84	147	112
2002	926	102	168	144
2003	1103	143	182	207
2004	1300	172	203	257
2005	1155	160	198	245
2006	1488	212	214	298
Total	11661	1485	1862	1658

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Technological Comparison

Europe; Japan; U.S.

This is an extension in 2004 survey of the WTEC Nanotechnology Workshop's first evaluation in 1999

Synthesis & Assembly	U.S.	Europe	Japan	BASIC APPROACHES
Biological Approaches & Applications	U.S.	Europe	Japan	
Dispersions and Coatings	U.S./Eur	Japan		R&D for PRODUCTS 1st Generation
High Surface Area Materials	U.S.	Europe	Japan	
Consolidated Materials	Japan	U.S./Eur		
Nanodevices	Japan	U.S./Eur		2nd Generation
Nanosystems/ Molecular systems	U.S.	Jap/Eur		3rd and 4th Generation
Instrumentation	Japan	U.S./Eur		TOOLS
Simulations	U.S.	Eur/Jap		
Level	1	2	3	
	Highest			

MC Roco, J. Nanoparticle Research, Vol. 7(6), 2005

Five Possibilities for Global Nanotechnology Governance

1. *Establish models for the global self-regulating ecosystem* to enhance discovery, education, innovation, informatics, commercialization and broad societal goals
2. *Create and leverage S&T nanotech platforms* (ind., med.) for new products in areas of highest societal interest
3. Develop NT for *common resources and EHS requirements*
4. Support *global communication and international partnerships*, facilitated by international organizations
5. Commitment to *long-term, priority driven, global view* using scenarios and anticipatory measures

Reference: "Global Governance of Converging Technologies", M Roco, J. Nanoparticle Research, 2008, 10

Reserves

Changing public perception since 2000

Before 2000: Is anything special at nanoscale?
Is nanotechnology important?
When the first products?

2000-2003: Are there self-duplicating nano-bots?
Could they create "grey-goo"?

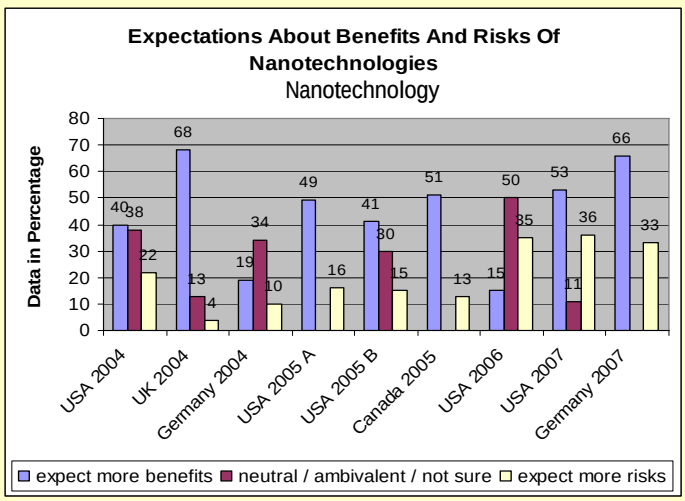
> 2003: What are the risks of "long-term / catastrophic environmental and health events" of nanoparticles?

> 2005: Nanotechnology can help sustainable management of global resources (water, energy, ..)
Concerns on using nanotech in food, reaction to accidents, perception of transhumanism, buzz word

2008: ~ 30% know something; ~ 70% benefits > concerns

MC Roco, 9/6/2008

International Surveys On Public Perception: Public Expectations



Expectation of risks climbed to ~ 30 %, independent of the knowledge

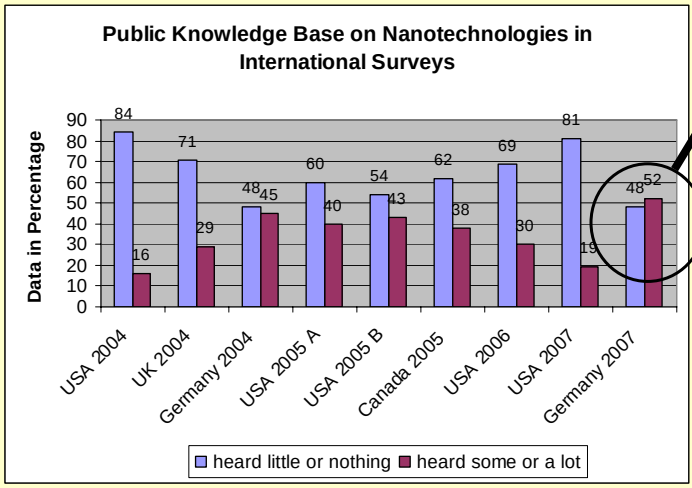
The more information is reached - the more consumers are positive

(*IRGC, A. Grobe et al., 2008)*

USA 2004 Cobb & Macoubrie; UK 2004 Royal Society; Germany 2004 komm.passion; USA 2005 A Einsiedel; USA 2005 B Macoubrie; Canada 2005 Einsiedel; USA 2006 Hart; USA 2007 Kahan et al.; Germany 2007 BfR

MC. Roco, 6/23/2008

International Surveys On Public Perception: Public Knowledge



Consumers know applications mainly from Science Shows on TV and advertising

(*IRGC, A. Grobe et al., 2008)*

USA 2004 Cobb & Macoubrie; UK 2004 Royal Society; Germany 2004 komm.passion; USA 2005 A Einsiedel; USA 2005 B Macoubrie; Canada 2005 Einsiedel; USA 2006 Hart; USA 2007 Kahan et al.; Germany 2007 BfR

MC Roco, 6/23/2008

Five way nanotechnology is changing academia

1. *Reverse the pyramid of learning:* learning first (earlier) unifying concepts of matter/ biology/ information systems
2. *More basic science and engineering:* increased opportunities for discovery and innovation
3. *Brings together disciplines and departments and colleges*: Convergence - NT, biomedical, electronics and cognition
4. *New organization models in university:* nanoscale interdisciplinary laboratories (this lab), "horizontal" and "universal" information system, closer with industry (NRI)
5. *Global governance*: collaboration and competition, multi-stakeholders, long-term planning, responsible development

MC Roco, 9/6/2008

Five ways nanotechnology will change business

1. *Competitive advantage* - by improved products now
2. *Create S&T nanotech platforms* - for revolutionary new products (over 50% of new chemical/ electronic/ pharmaceutical/ advanced materials products by 2015)
3. *Opportunities for innovation -* convergence with biomedical, electronics and cognition
4. *New organization and business models* – "horizontal" organization, S&T clusters, distributed production, new information system, voluntary systems for risk management
5. *Global governance* - strong collaboration and competition; address multi-stakeholders and responsible development; long-term planning; responsible development

M.C. Roco, 9/6/2008