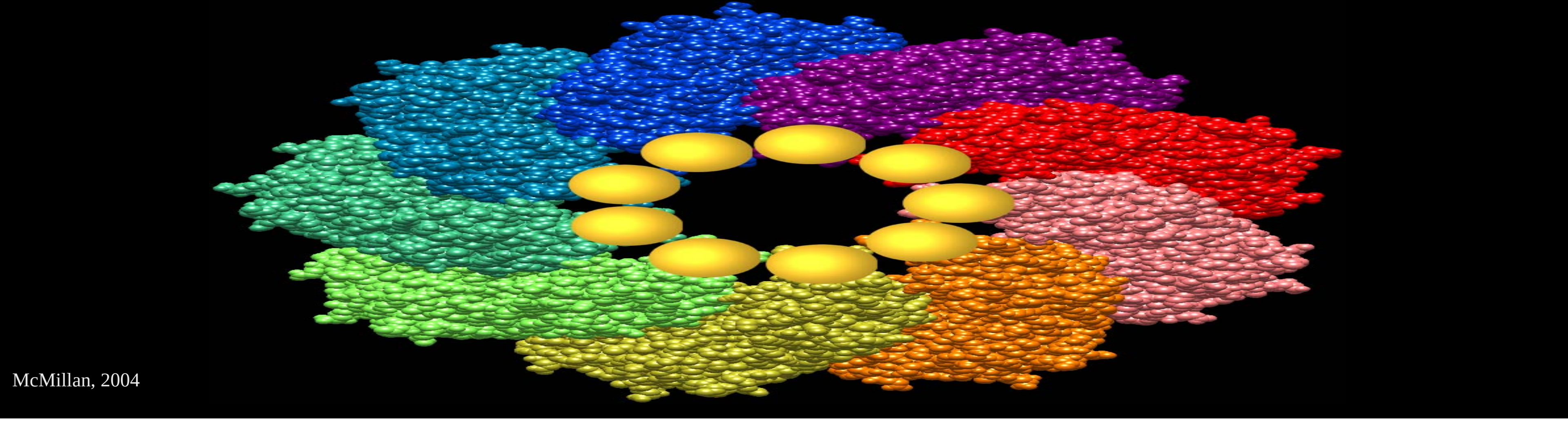


The Future of Nanotechnology

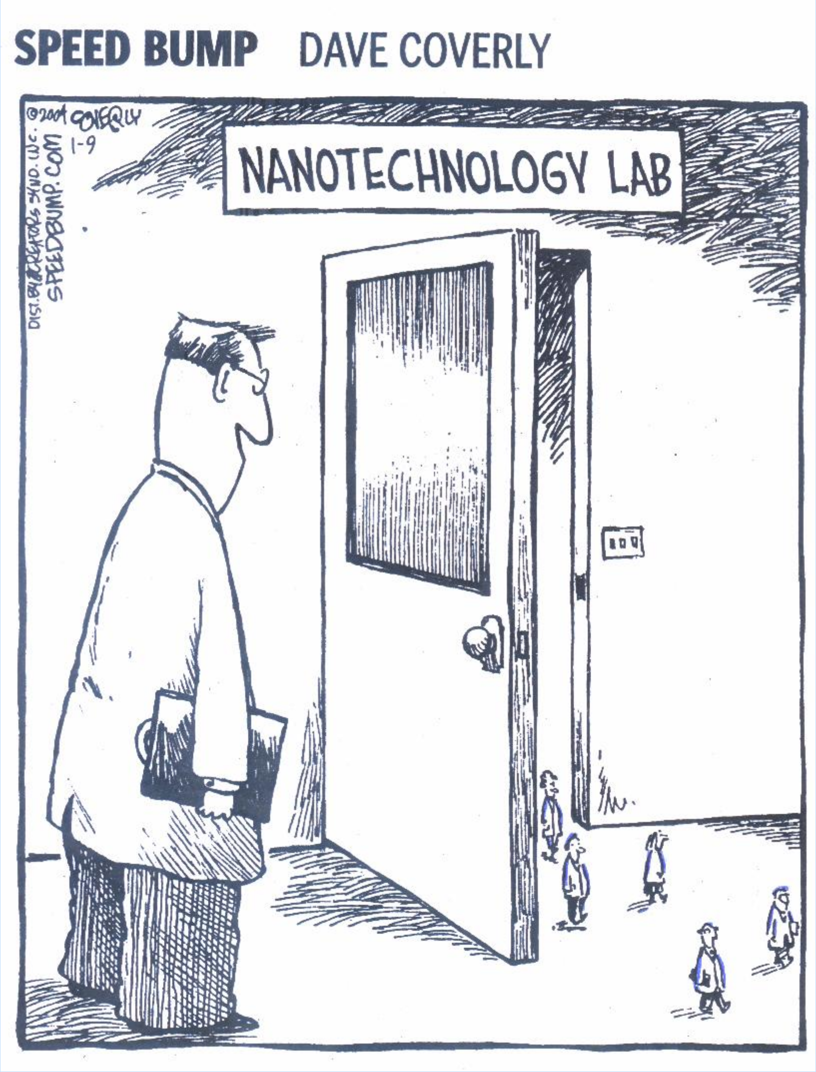
Mike Roco

National Science Foundation and
National Nanotechnology Initiative

WBT, Arlington, TX,
March 17, 2010

Many perceptions of nanotechnology today

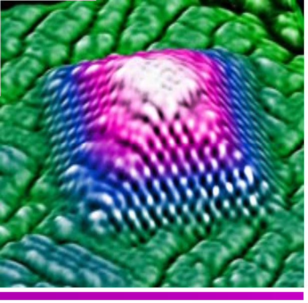
from CAN DO ANYTHING

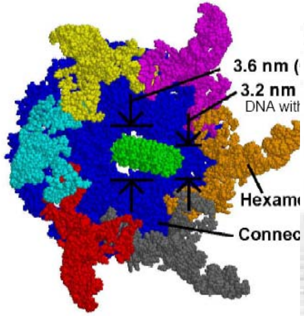


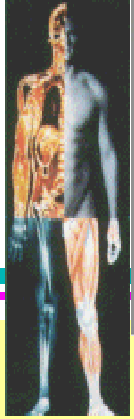
to RISK ANYWHERE

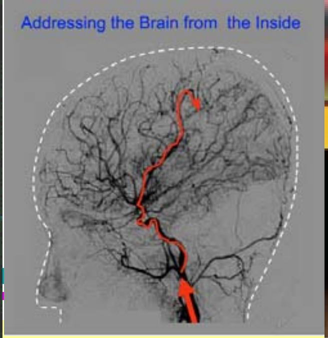
At a nano lunch,
there is a perceived risk

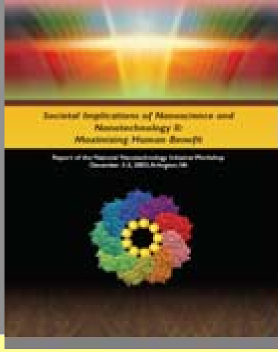
"... nanopizza is taking technology a step too far"











TOPICS

Long view for nanotechnology development

Global progress to date and future opportunities

Increased complexity and dynamics (four generations)
- with increased uncertainty and risk

Corresponding levels of governance (two frameworks)
- with staggered risk management approach (four steps)

Values-driven global governance of nanotechnology

visionary, transformative, responsible, inclusive

Context: Emergence of new technologies - a continuous process

- Knowledge has quasi-exponential growth

  There is an accelerating & non -uniform process of discoveries and innovations leading to emerging technologies

- Need of radically new technologies

  Demographics with limited natural resources

- Particularities in governance of emerging technologies

  - Integration of new tools and separated disciplines, new education skills, partnerships, risk management

  - Need of global governance for development, collaboration and avoiding conflict

More people

9-10 billion by 2050

INCREASED USE OF WATER, FOOD, ENERGY, MATERIALS, AND ENVIRONMENT

NEED OF RADICALLY NEW TECHNOLOGIES

Examples of emerging technologies and corresponding U.S. long-term S&T projects

Justified mainly by societal/application factors

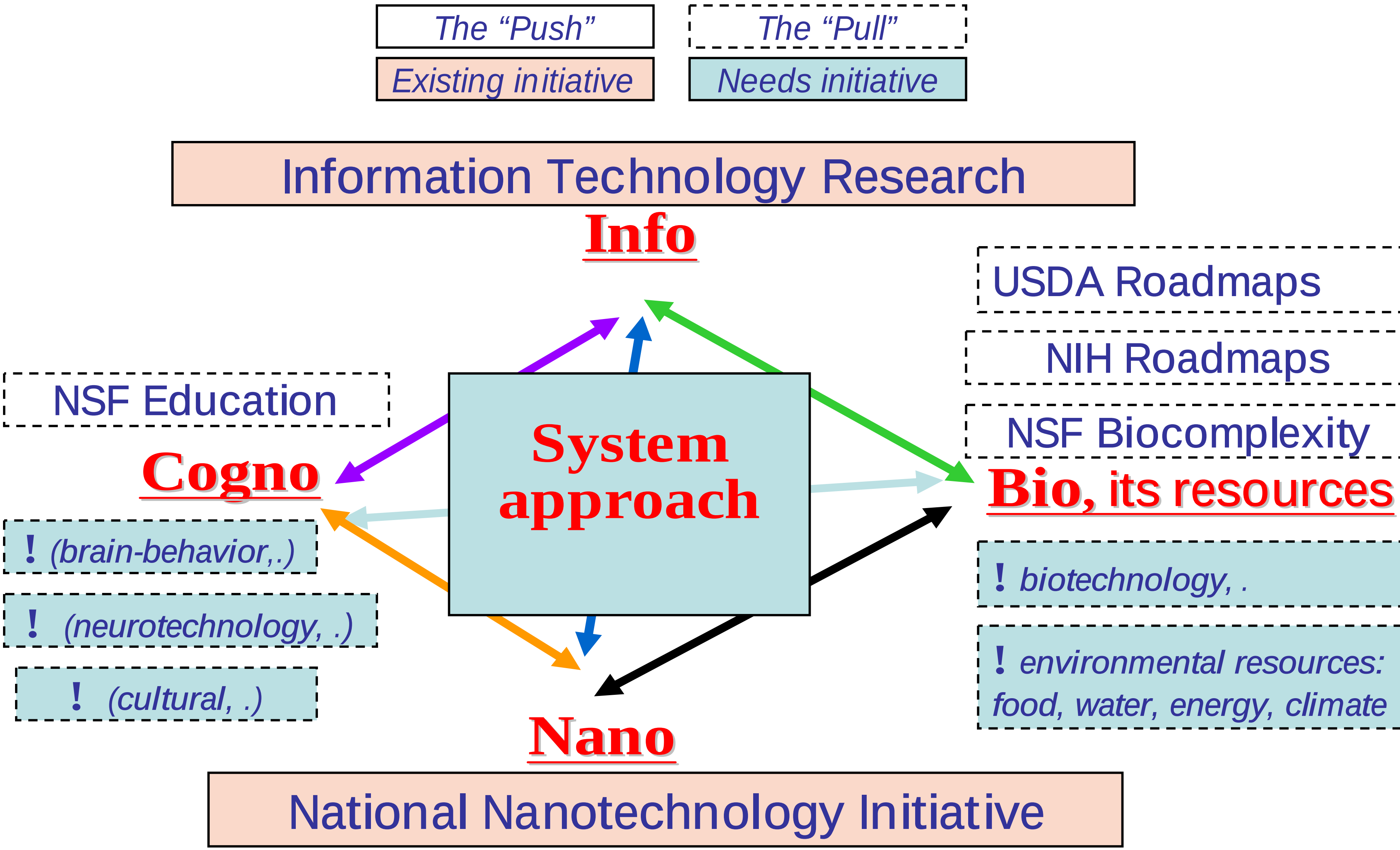
- Manhattan Project, WW2 (centralized, goal focused, simultaneous paths)
- Project Apollo (centralized; goal focused)
- AIDS Vaccine Discovery ("big science" model, Gates Foundation driven)
- IT SEMATECH (Roadmap model, industry driven)
- IT Research (top-down born & managed; application driven)

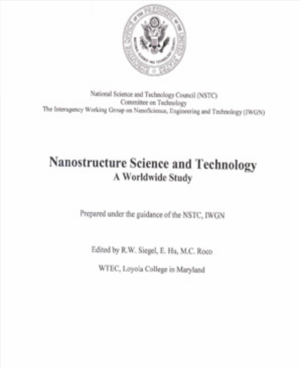
Justified mainly by science and technology potential

- National Nanotechnology Initiative (bottom-up science opportunity born, for general purpose technology)

Converging New Technologies transforming tools

(overview in 2000 ; ~ 50% relevance in NSF awards in 2010 ; convergence has been better developed than for *large-scale systems*)




National Science and Technology Council (NSTC)
Committee on Technology
The Interagency Working Group on NanoScience, Engineering and Technology (IWGN)

Nanostructure Science and Technology
A Worldwide Study

Prepared under the guidance of the NSTC, IWGN

Edited by R.W. Siegel, E. Hu, M.C. Roco

WTEC, Loyola College in Maryland

Benchmark with experts in over 20 countries in 1997-1999

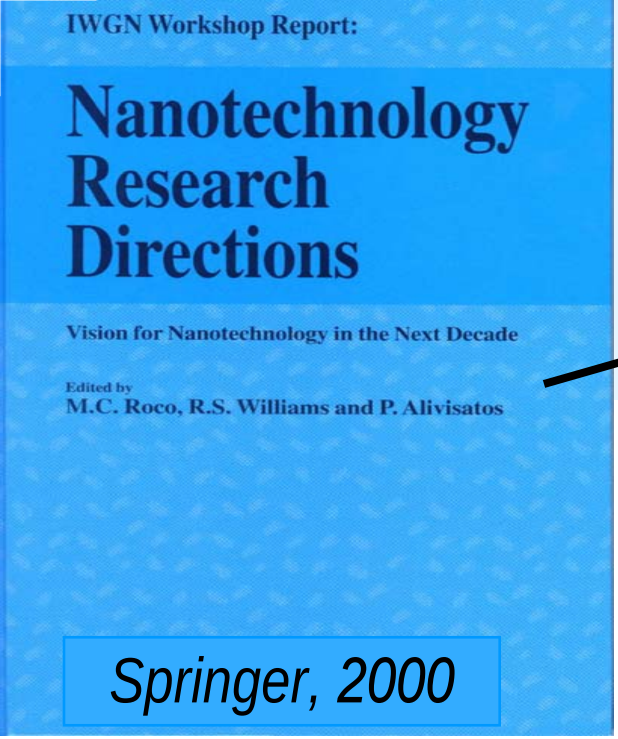
“Nanostructure Science and Technology”

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 fundamentally new properties and functions because of their small structure

- NNI definition encourages new R&D that were not possible before:
  - ***the ability to control and restructure matter at nanoscale***
  - ***new phenomena, properties leading to novel applications***
  - ***integration along length scales, systems and applications***



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

- <u>Change the foundations from micro to nano</u>

- <u>Create a general purpose technology (similar IT)</u>

More important than miniaturization itself:

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

CREATING AN NEW FIELD AND COMMUNITY IN TWO FOUNDATIONAL STEPS (2000~2020)

Mass Application of Nanotechnology after ~ 2020

New area | MATERIA | ELECTRON | HEALTH | ENVIRON | ENERGY | TRANSPO | MANUFACT | SECURITY | INSTRUM

2020

NS&E integration for general purpose technology

~ 2011 ⟷ **~ 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 ⟷ **~ 2010**

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

Infrastructure

Workforce

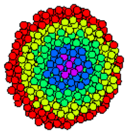
Partnerships

2000

MC Roco, March 9 2010

Introduction of New Generations of Products and Productive Processes (2000-2020)

Timeline for beginning of industrial prototyping and nanotechnology commercialization

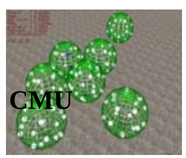


2000

1st: Passive nanostructures (1st generation products)
Ex: coatings, nanoparticles, nanostructured metals, polymers, ceramics

~ 2005

2nd: Active nanostructures Ex: 3D transistors, amplifiers, targeted drugs, actuators, adaptive structures



~ 2010

3rd: Nanosystems
Ex: guided assembling; 3D networking and new hierarchical architectures, robotics, evolutionary

15-2020

4th: Molecular nanosystems
Ex: molecular devices 'by design', atomic design, emerging functions

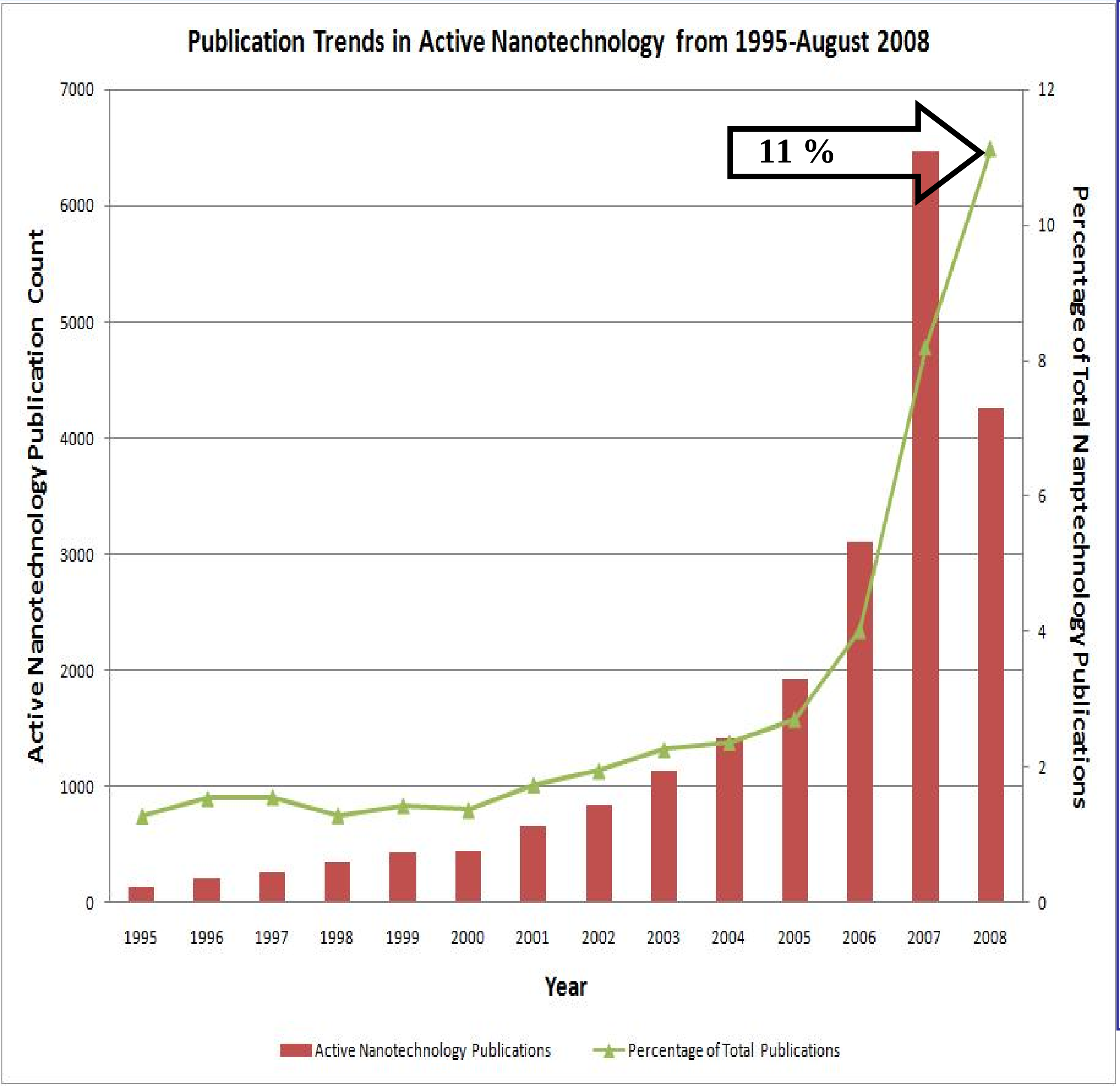
Converging technologies
Ex: nano-bio-info from nanoscale, cognitive technologies; large complex systems from nanoscale

Increased Complexity, Dynamics, Transdisciplinarity

	R&D →		*Broad Use*
IT	1960	-	2000
BIO	1980	-	2010
NANO	2000	-	2020
NBIC	2010	-	2030

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

A shift to “active nanostructures” after 2006



On active nanostructures

21,000+ articles from WOS/SCI from 1995 to 2008

Exemples:

- Transforming (e.g., self-healing materials)
- Remote actuated (e.g., magnetic, electrical, light and wireless tagged nanotechnologies)
- Environmentally responsive (e.g., actuators, drug delivery)
- Miniaturized device (e.g., molecular electronics)
- Hybrid (e.g., uncommon material combinations, biotic-abiotic, organic-inorganic in chips)
- Drug delivery

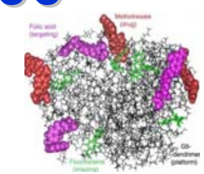
Source: Vrishali Subramanian, Jan Youtie, Alan L. Porter, and Philip Shapira (2009). Is there a shift to "active nanostructures?" *Journal of Nanoparticle Research*, 2009 http://dx.doi.org/10.1007/s11051-009-9729-4.

Perceived Higher Risks Areas (2000-2020; 2020-)

as a function of nanotechnology generation

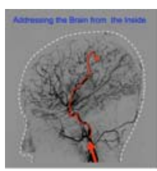
1st: Passive nanostructures *Ex: Cosmetics (pre-market tests), Pharmaceuticals (incomplete tests for inflammatory effects, etc.), Food industry , Consumer products*

~ 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

Converging technologies *Ex: Hybrid nano-bio-info-medical-cognitive application*

~ 2020-

Higher uncertainty & risk

Highest perceived risks in 2009:
- in air - car combustion
- in water - industrial pollution
- in food and cosmetics

MC Roco, Nov. 18, 2009

Examples of 3rd and 4th generation

- Artificial organs using nanoscale control of growth
- Subcellullar intervention for treatment of cancer
- Bioassembly (ex. use of viruses) of engineered nanomaterials and systems
- Evolutionary systems for biochemical processing
- Sensor systems with reactive mechanisms
- Nanoscale robotics on surfaces and 3-D domains
- Simulation based experiments and design of engineered nanosystems from basic principles
- New molecules designed as devices
- Hierarchical selfassembling for micro or macro products

Four generations of products and productive processes *in nanoelectronics*

- First generation - scaling down with nanoscale components with new physics. Ex: passive nanoscale layers in production - since 2003

- Second generation - with device state change during operation. Ex: “Integrated-CMOS” with carbon-nanotubes, single-electron transistors; “directed self-assembly” leading to CMOS scaled to its ultimate limits

- Third generation - "Novel logical switch": Nanosystem solutions based on state variables other than electric charge.   Ex: electron-spin, photonic states, graphene-based

- Fourth generation - Molecular and supramolecular components of nanoelectronic systems “by design”; guided assembling nanosystem

- Converging techn. – integration with applications; hybrid architectures

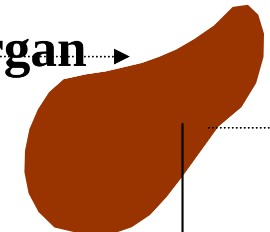
Examples of levels for intervention of nanobiotechnology

4 generations of products for human life extension

Human

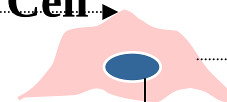
- **(1st)** Joint replacement
- Non-invasive and invasive diagnostics for rapid patient monitoring
- Cognitive-assist devices
- Targeted cancer therapies

Organ



- **(2nd)** Sensors for in vivo monitoring
- Localized drug delivery
- Neural stimulation
- Cardiac therapies
- Artificial organs

Cell



- **(3rd)** Improved cell-material interactions
- Scaffolds for tissue eng.
- **(4th)** Genetic therapies
- Cell ageing
- Stem cell therapies

Molecule

- Localized drug delivery
- Fast diagnostic techniques
- Gene therapy devices
- Self-assembly structures

(NBIC Report, 2002)

Nanotechnology convergence with bio, info and cogno, and bifurcation of nanosystem architectures: 2010-2020

New nanosystem architectures, more

- Guided assembling
- Nanobio evolutionary
- Molecular design and guided hierarchical selfassembling
- Robotics based
- Reconfigurable sensorial systems
- Biomimetics . . . .

and less defines

- ? New carrier of information instead of electron charge
- ? Manufacturing by nanomachines
- ? Extending use of human potential
- ? Use of virtual reality and intelligent environments
- ? Collective cognitive capabilities . . . .

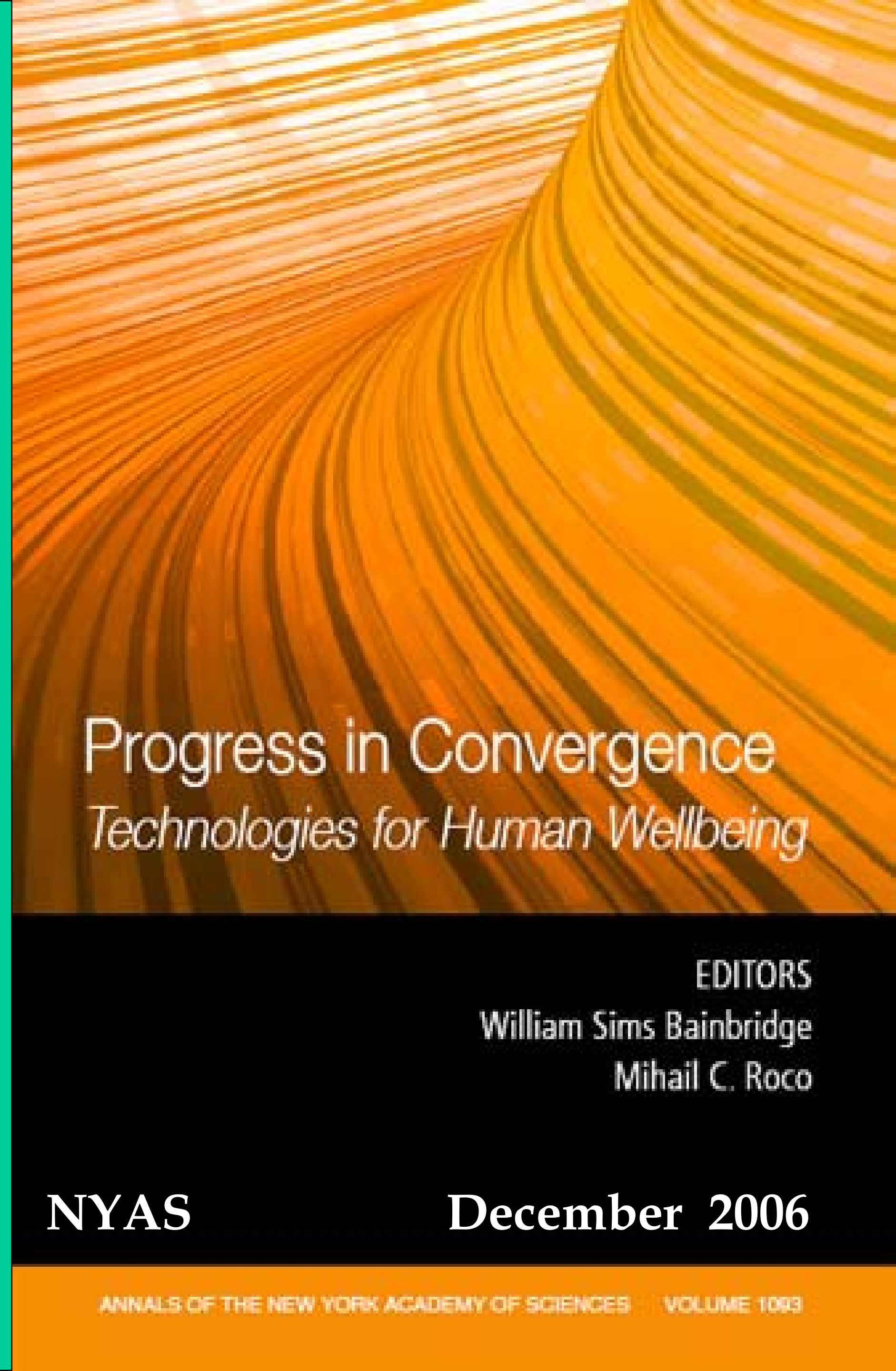
CT: Improving Human Health and Physical Capabilities

- Bio nanosystem approach for healthcare, regenerative and biocompatible body replacements, and physiological self-regulation
- Brain-machine interfaces, and neuromorphing engineering
- Improving sensorial capacities and expanding sensorial functions
- Improving quality of life of disabled people
- Aging with dignity, and average life extension

CT: Enhancing Societal Outcomes
(including new technologies and products)

- Methods for enhancing group interaction and creativity
- Cognitive engineering and enhancing productivity
- Revolutionary manufacturing processes, products and services. Ex: hybrid manufacturing, bio-inspired nanoelectronics, bio-robotics (muscles), “aircraft of the future”, bio-chem lab on a chip, adaptive and emerging intelligence systems, multiphenomena software from the nanoscale, pharmaceutical genomics, neuromorphic engineering, intel. env.
- Networked society, with bio-inspired culture
- Business as agents of change for human perfomance

Five volumes on science and technology convergence (2003-)



2000-2009
Expanding nanotechnology domains

2000-2001: nano expanding in almost all disciplines;
by 2009: 11% of NSF awards; 5% papers; 1-2% patents

2002-2003: industry moves behind nano development
by 2009: ~ $200B products incorporating nano worldwide

2003-2004: medical field sets up new goals

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

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

2008-2009: increased relevance to
economy – policies - sustainability

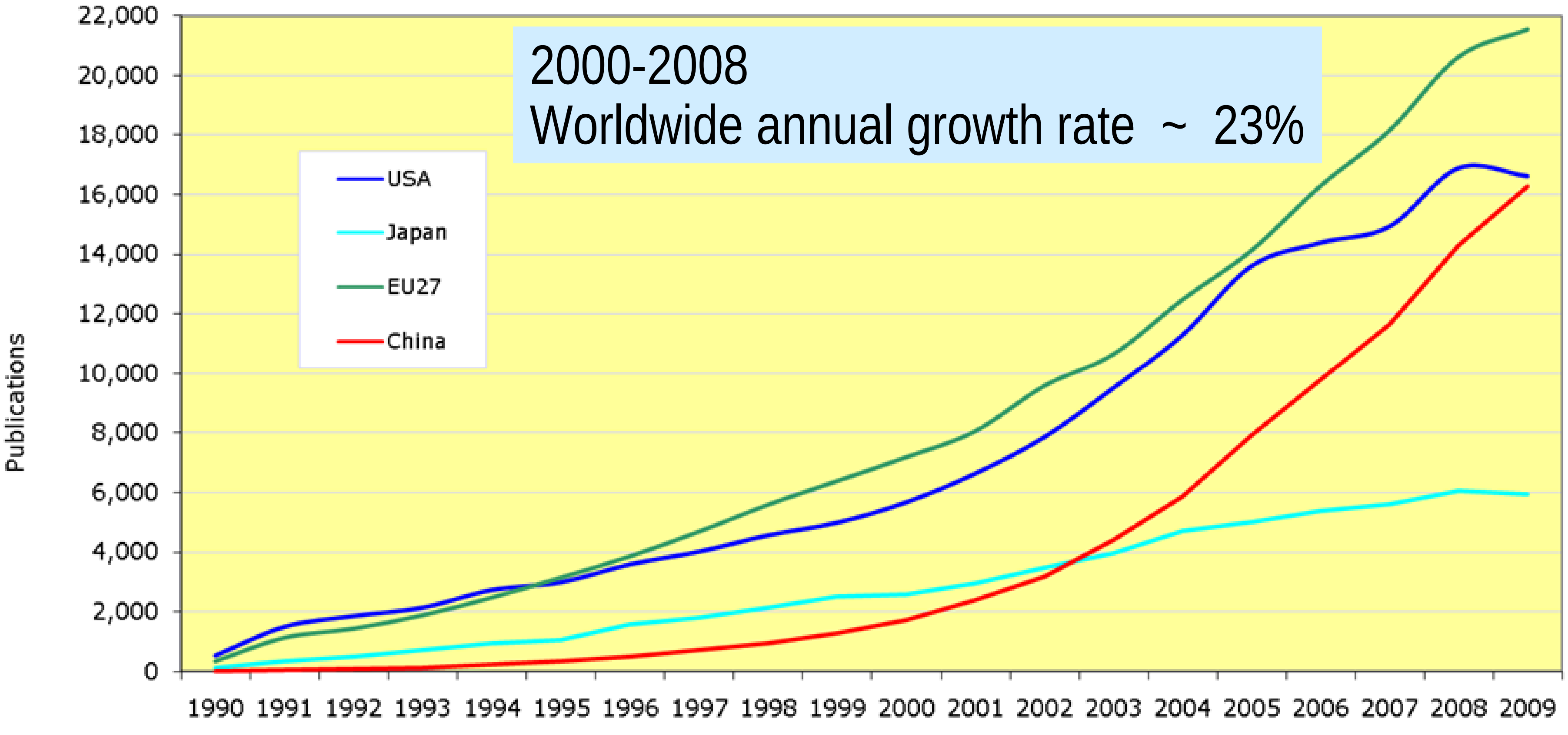
Ten highly promising products incorporating nanotechnology in 2009

- Catalysts
- Transistors and memory devices
- Structural applications (coatings, hard materials,.)
- Biomedical applications (detection, implants,.)
- Treating cancer and chronic diseases
- Energy storage (batteries), conversion and utilization
- Water filtration
- Video displays
- Optical lithography
- Environmental applications

With safety concerns: cosmetics, food, disinfectants,..

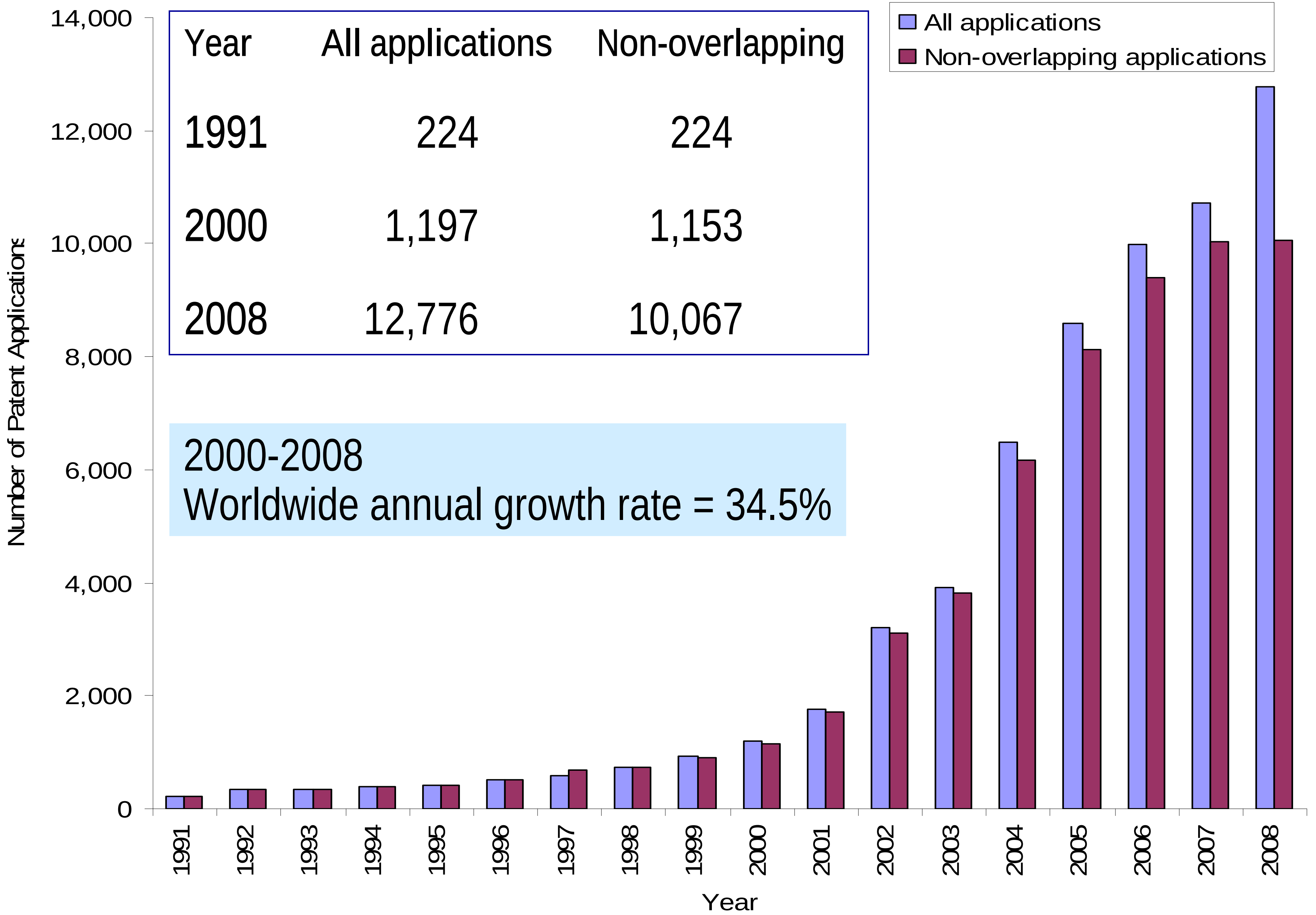
Nanotechnology publications in the Science Citation Index (SCI)

Data was generated from online search in Web of Science using “Title-abstract” search in SCI database for nanotechnology by keywords (Chen, Dang and Roco, 2010)



Note: CHINA = PRC

WORDWIDE NUMBER OF NANOTECHNOLOGY PATENT APPLICATIONS



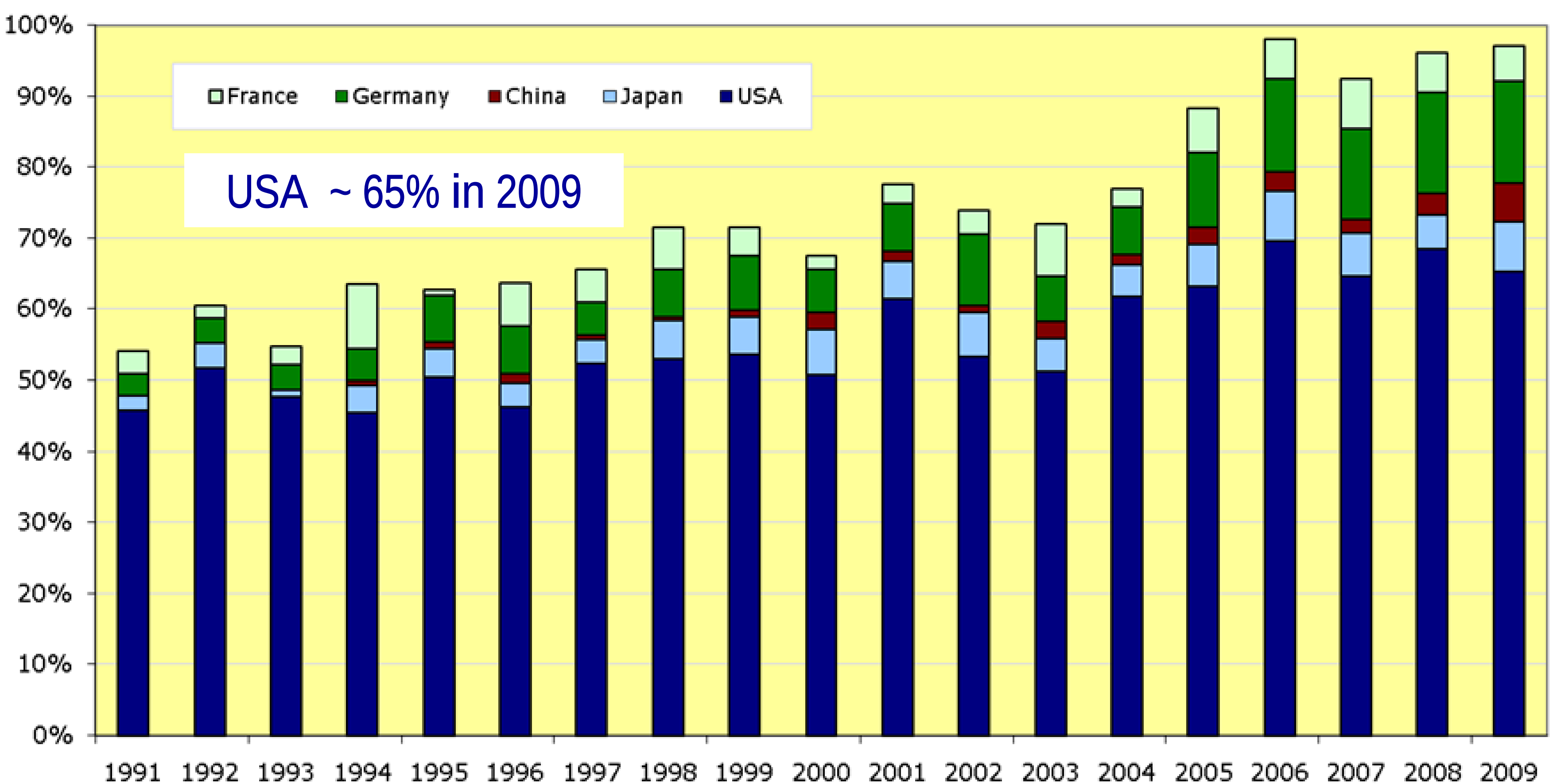
Year	All applications	Non-overlapping
1991	224	224
2000	1,197	1,153
2008	12,776	10,067

2000-2008
Worldwide annual growth rate = 34.5%

MC Roco, March 9 2010

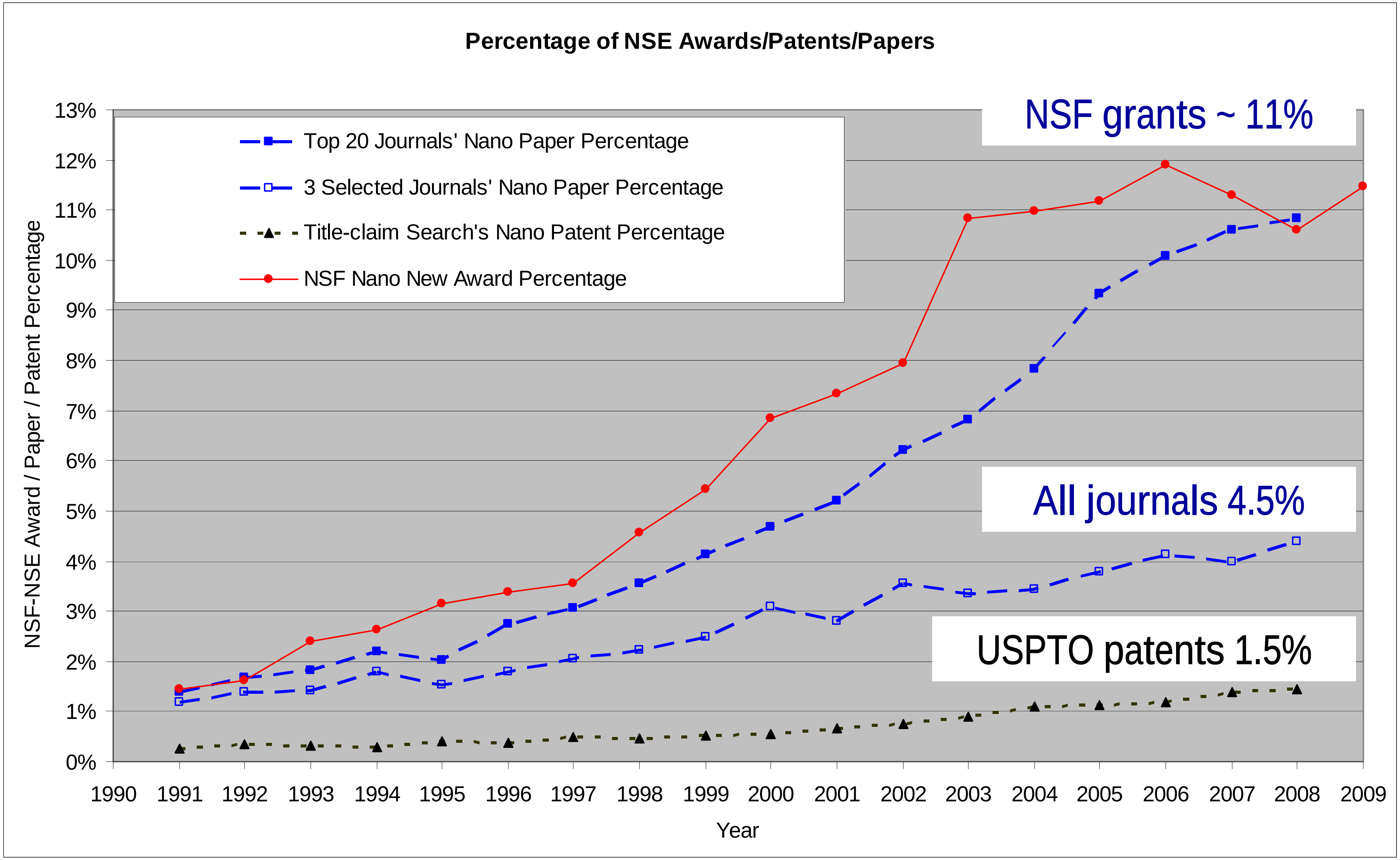
Percent contribution by country to nanotechnology publications by title-abstract search in Science, Nature, and Proceedings of the National Academies of Science (top 3 journals based on citation index by other nanotechnology papers and patents)

2007-2009 data was generated from online search in Web of Science (Chen, Dang and Roco, 2010)



MC Roco, March 9 2010

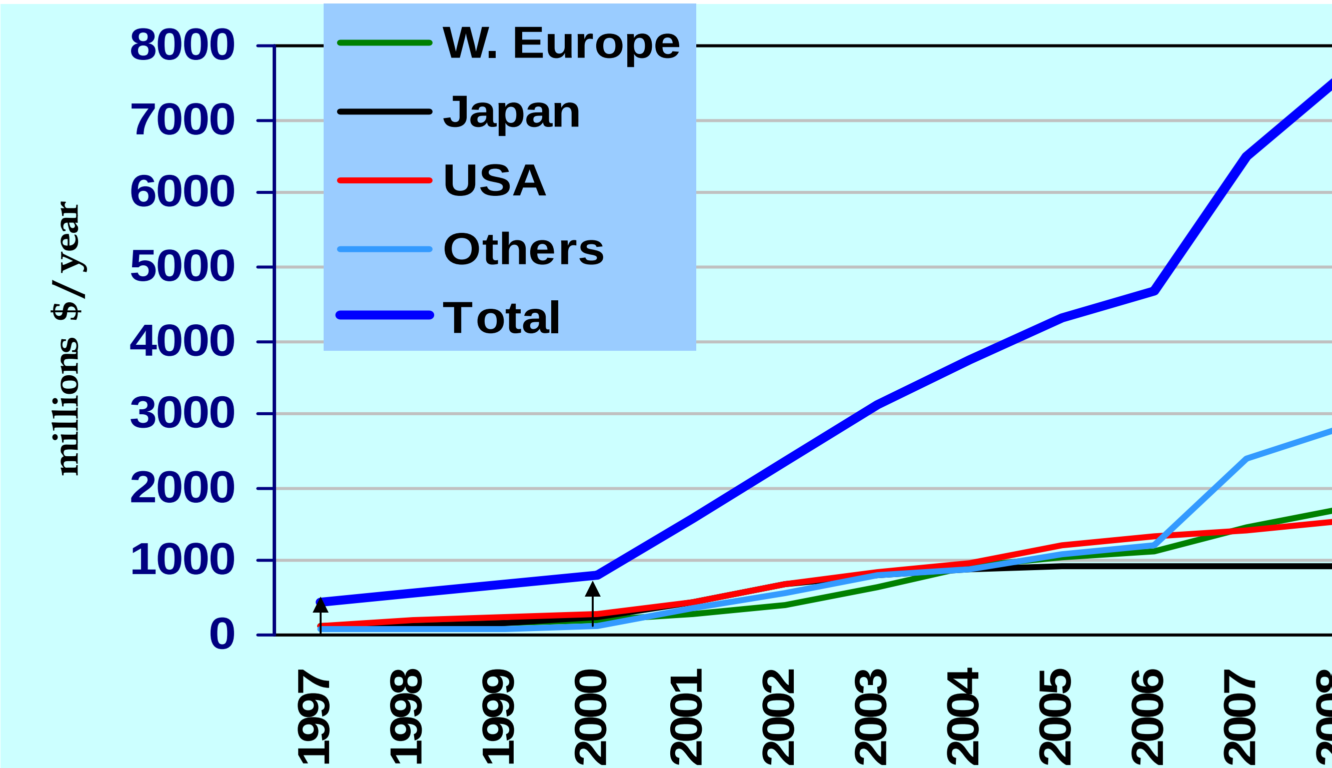
Proportion of nanotechnology contents in NSF awards, ISO papers and USPTO patents (1991-2008)



Searched by keywords in the title and abstract/claims

MC Roco, 3/17/2010

2000-2009
Changing international context: government funding



Country / Region	Gov. Nano R&D 2007 ($M)	Specific Nano R&D 2007 ($/Capita)
USA	1500	5.0
EU-25	~1450	4.0
Japan	~ 980	7.5
China	~ 350	0.3
Korea	~ 315	6.0
Taiwan	~ 110	4.5

Seed funding (1991 -)

NNI Preparation (vision / benchmark)

1st Strategic Plan (passive nanostructures)

2nd Strategic Plan (active ns. & systems)

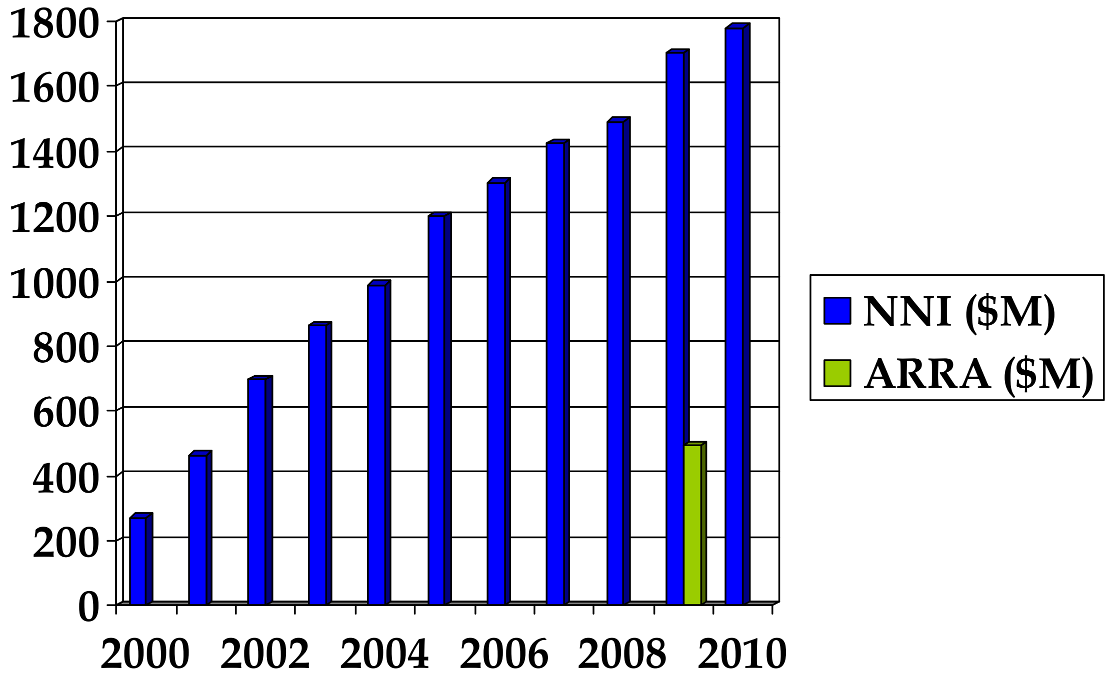
Industry R&D ($7.3B) has exceeded national government R&D ($6.5B) in 2007

2001-
2010

Changing national investment

FY 2010 NNI Budget Request $1,640 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
2009	$1,703M
2010	$1,781M



+ $494M ARRA = $2,197M

(Request in FY 2011 $1,776M; nano EHS $117M)

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

2001-
2010

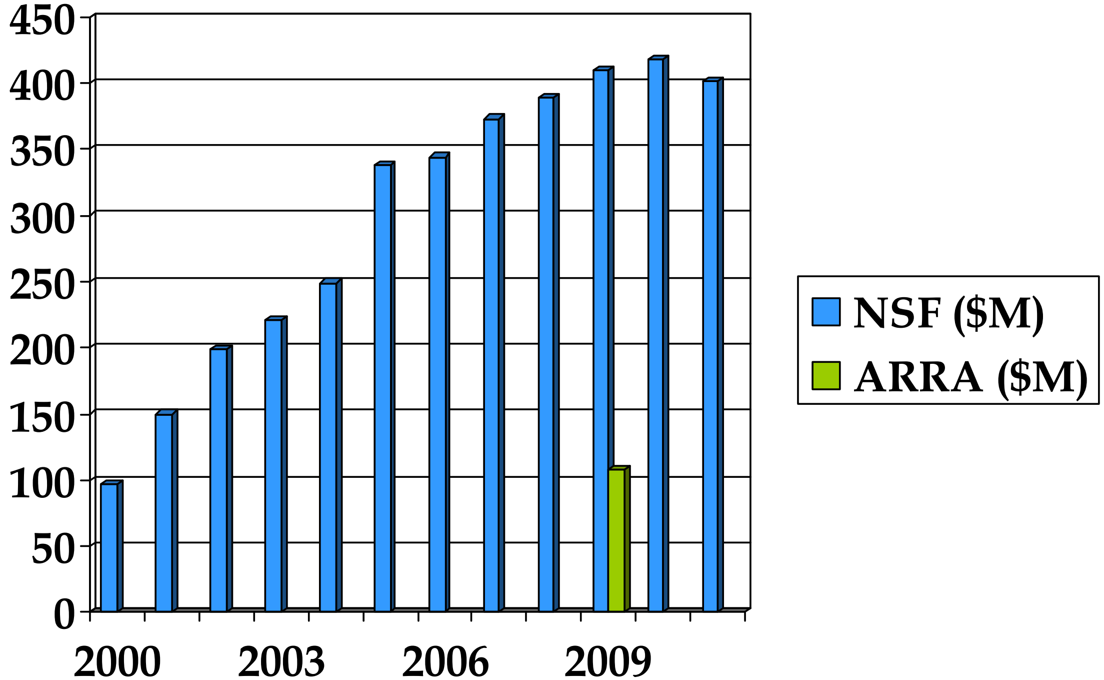
NSF – discovery, innovation and education in Nanoscale Science and Engineering (NSE)

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

FY 2010 Budget Request $423M

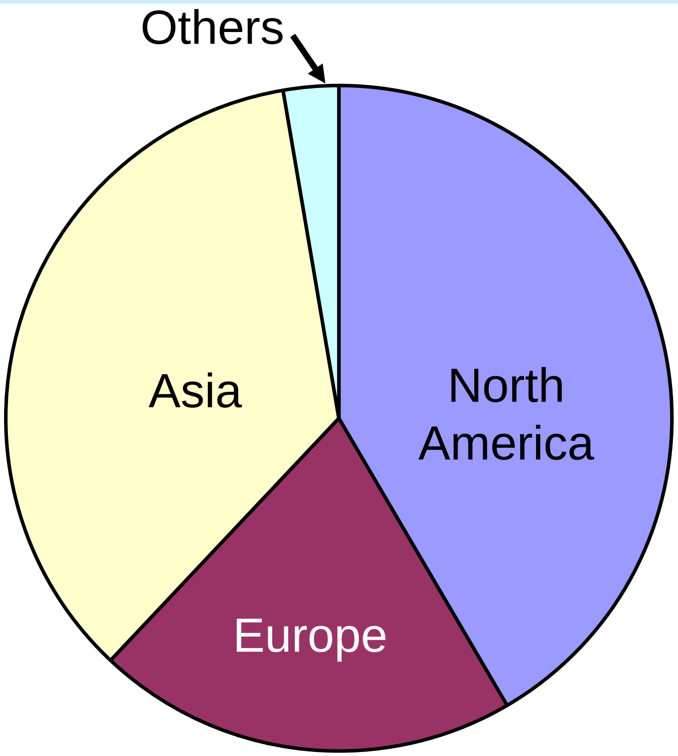
- Fundamental research ~ 5,000 active projects
- Establishing the infrastructure - 26 large centers, 2 user facilities, teams
- Training and education >10,000 students and teachers/y; ~ $30M/y

Fiscal Year	NSF
2000	$97M
2001	$150M
2002	$199M
2003	$221M
2004	$254M
2005	$338M
2006	$344M
2007	$373M
2008	$389M
2009	$409M + $108M (ARRA) = $517M
2010	$418M

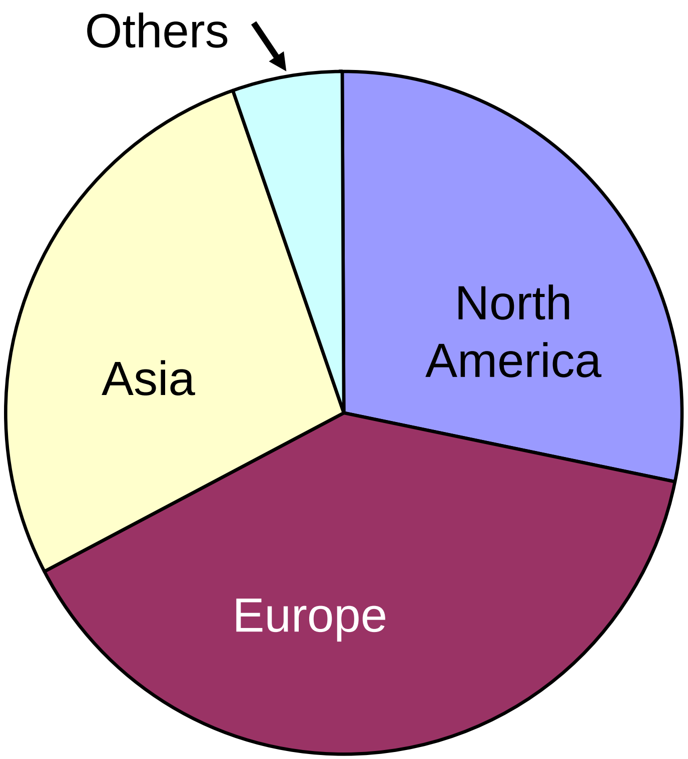


(Request in FY 2011: $401M, nano EHS $33M)

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

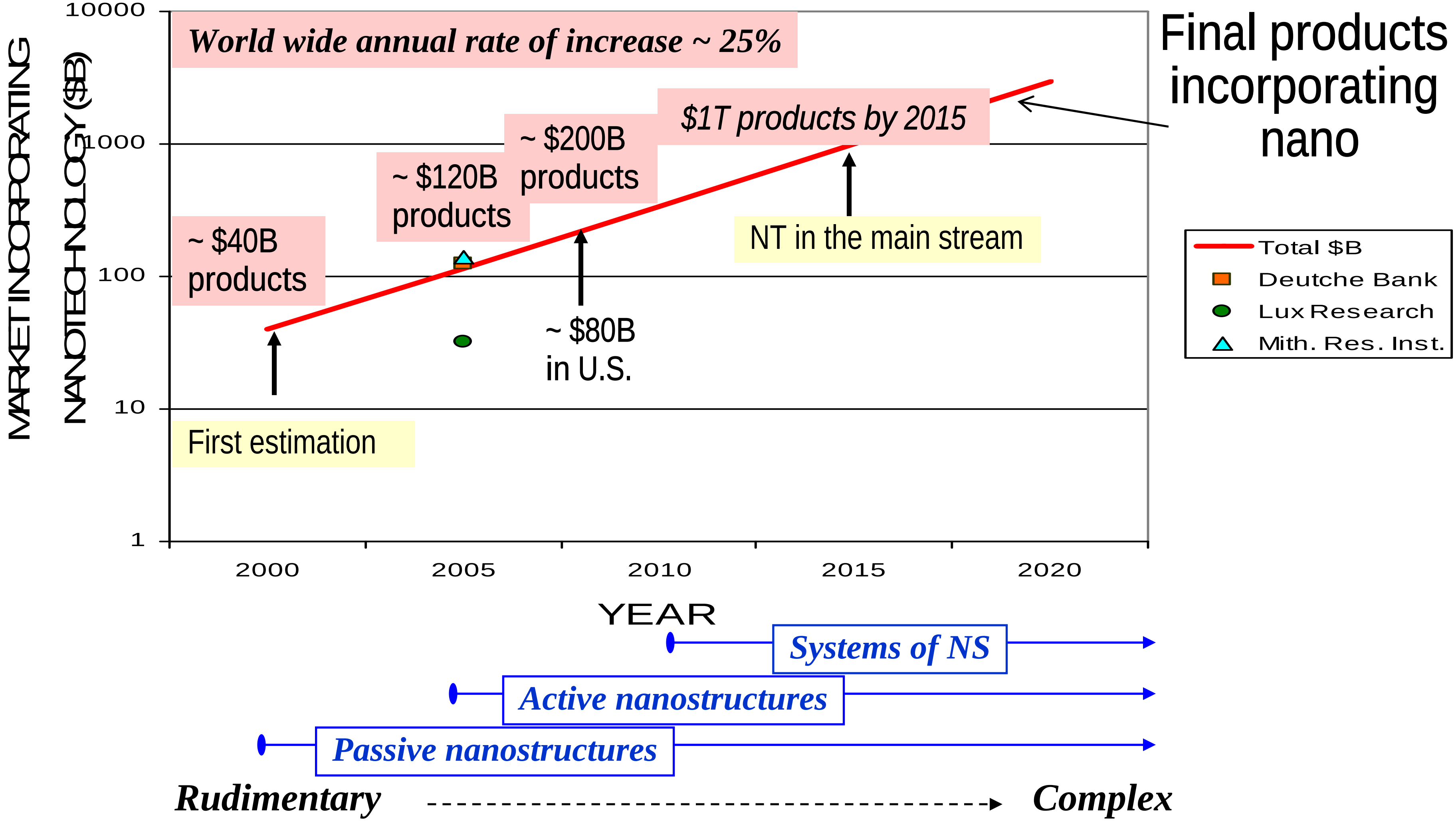
National governments ~ $4.7 billion
Local governments and organizations ~ $1.8 billion

Source: Lux Research

MC Roco, 3/17/2010

WORLDWIDE MARKET INCORPORATING NANOTECNOLOGY

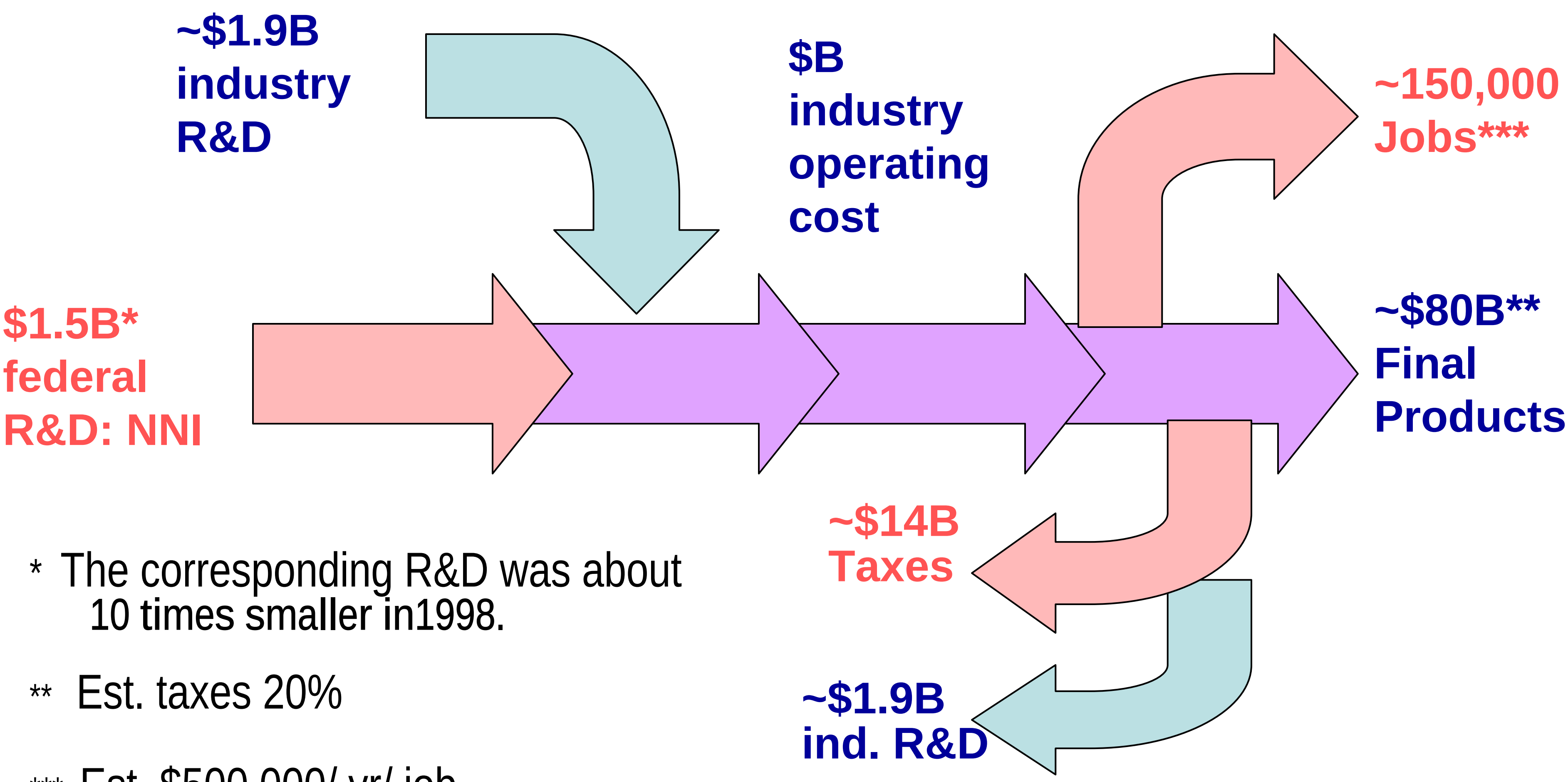
(Estimation made in 2000 after international study in > 20 countries)



Reference: Roco and WS Bainbridge, Springer, 2001

MC Roco, 3/17/2010

Estimation of Annual Implications of U.S. Federal Investment in Nanotechnology R&D (2008)



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

** Est. taxes 20%

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

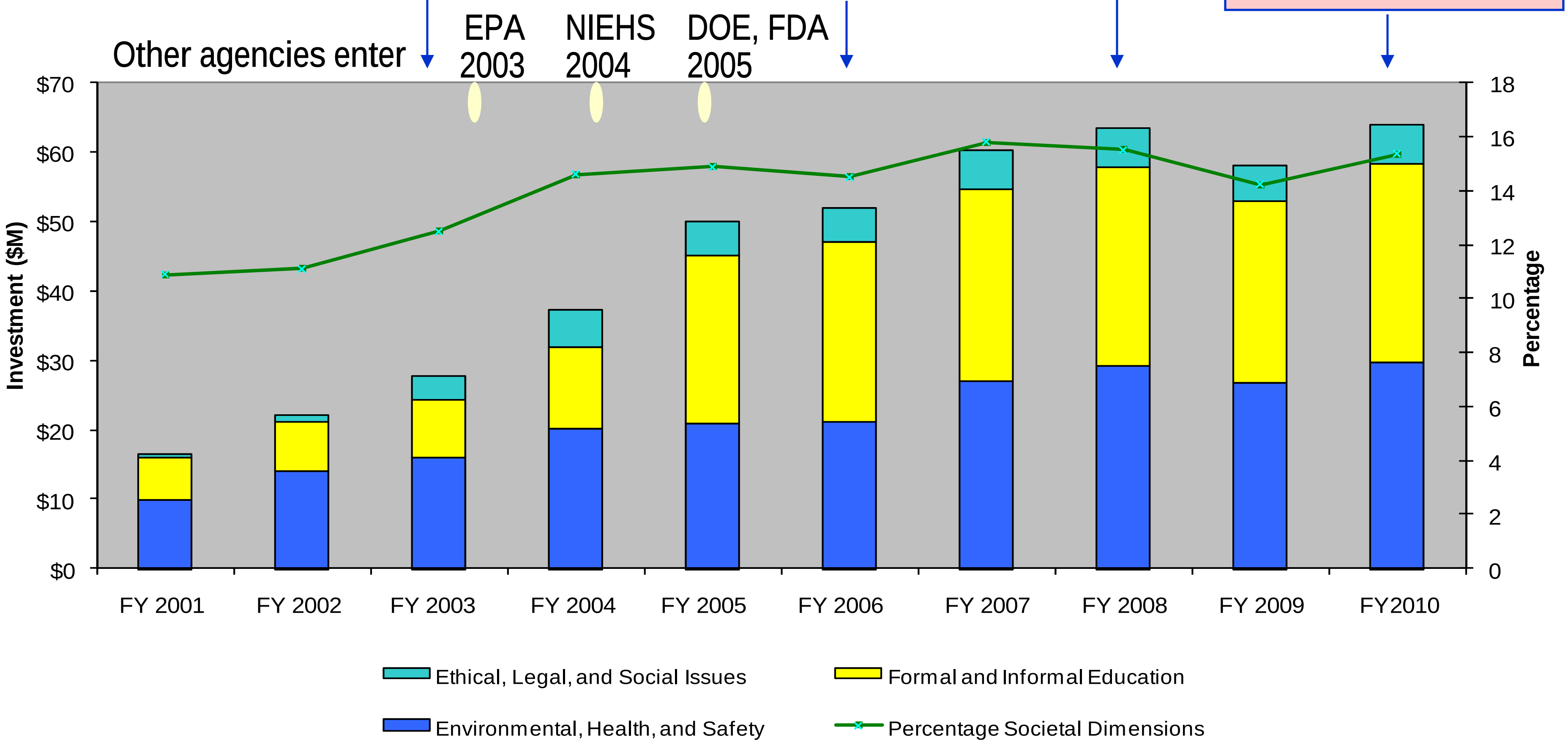
NSF Investment in Nanotechnology Implications for Safety and Society

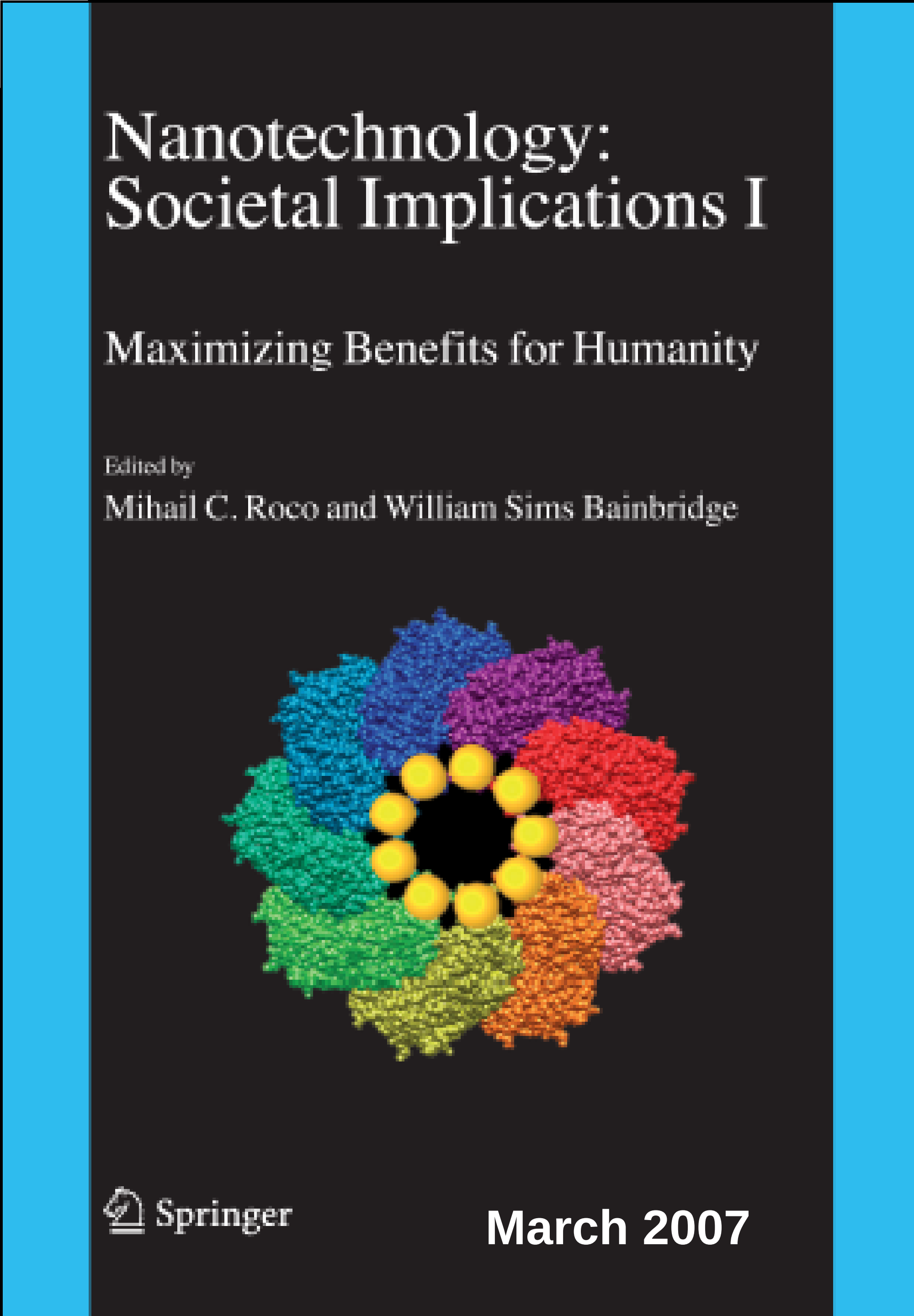
Nano-manufacturing safety added in 2003

Focus on future nano-generations added in 2006

New CEIN in 2008

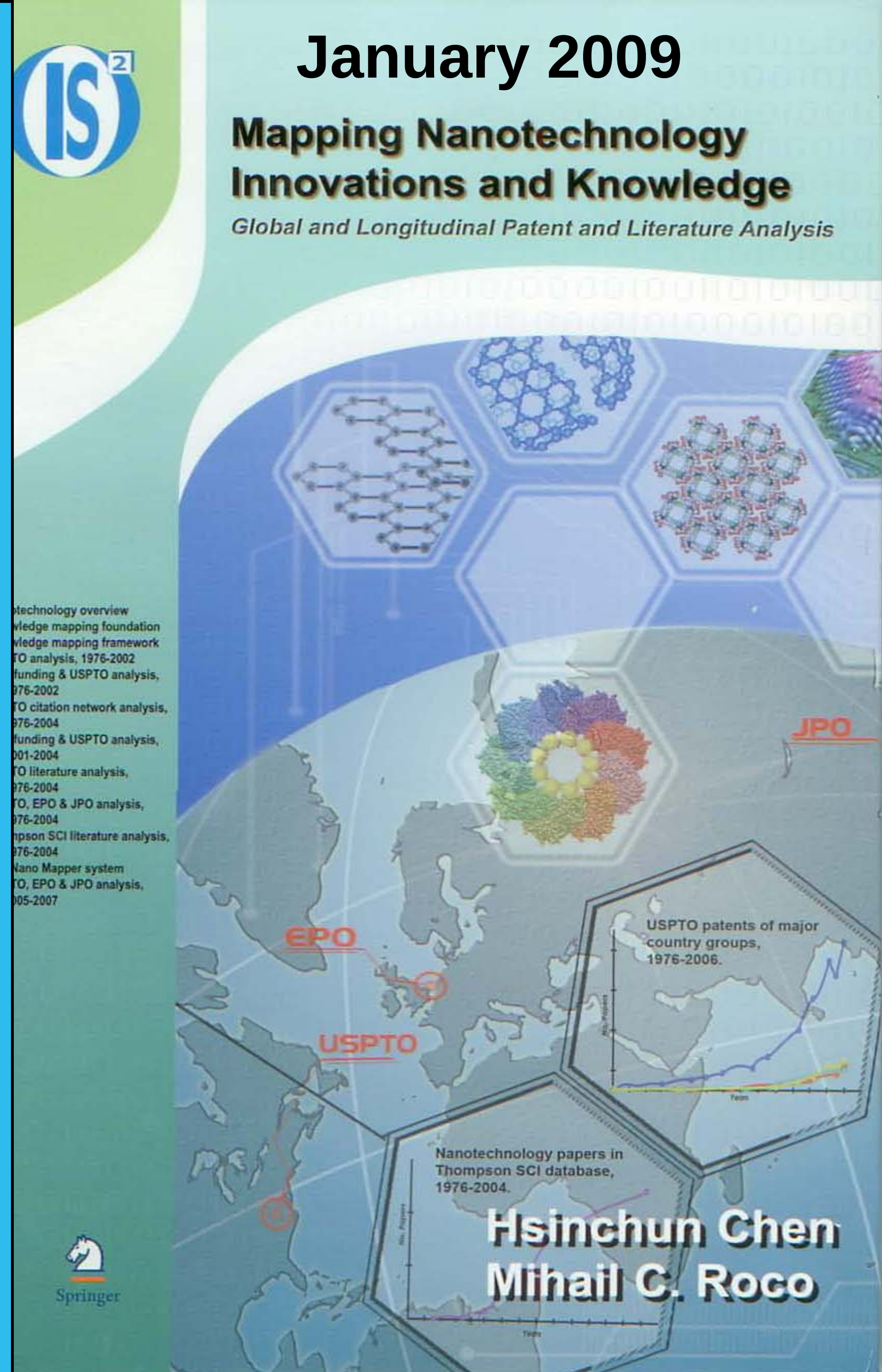
Focus on nanosystems >2010





March 2007

January 2009



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;
  - at four levels: program, agency, national executive, legislative

National Nanotechnology Initiative

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

OSTP
OMB
NIH
NSF
DOD
DOE
NIST
FDA
NASA
USDA
NIOSH
USDA FS
DOS
EPA
DOTr
NRC
DOT
USPTO
ITIC
USGS
DOJ
DOL
DOC TA
DOEd
DOC BIS
DHS
CPSC
ITC

2009 Nanotechnology Regional, State, and Local Initiatives (34)

http://www.nano.gov/html/funding/businessops.html#RSLI

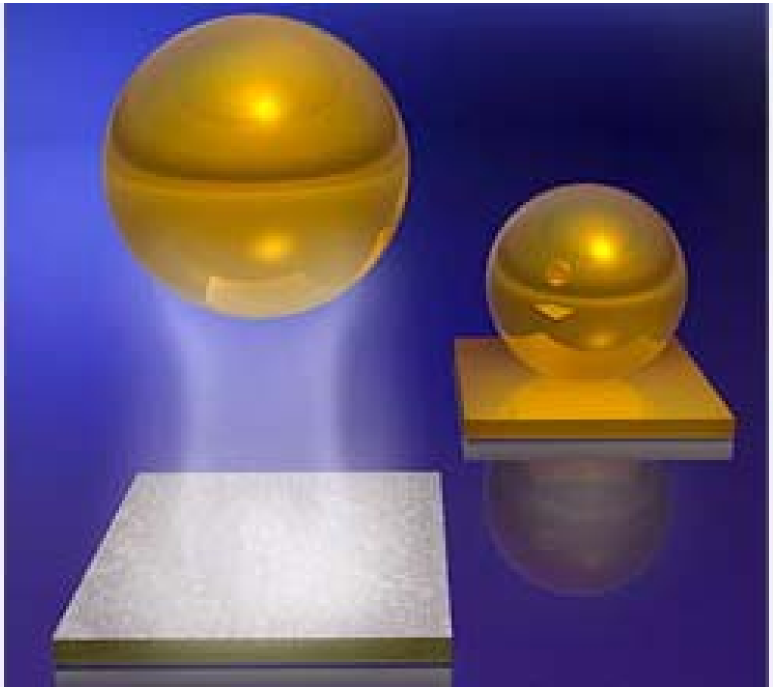
MC Roco, March 9 2010

Nanotechnology in 2009 - 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

Discovery of Nanoscale Repulsion

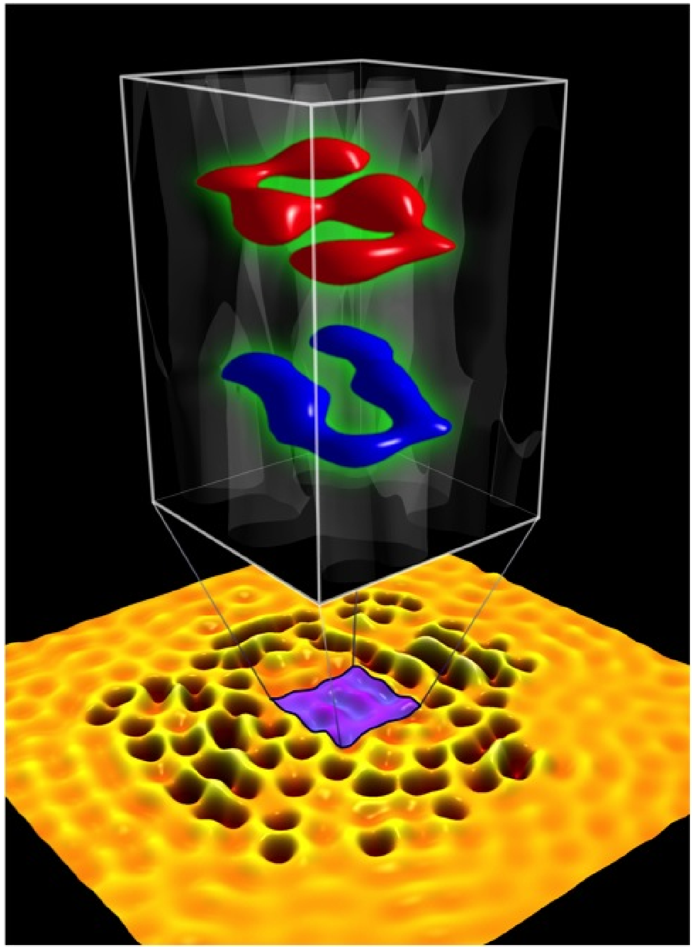
Federico Capasso, Harvard University

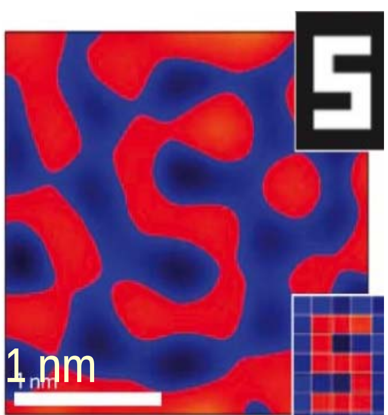


A repulsive force arising at nanoscale was identified similar to attractive repulsive Casimir-Lifshitz forces.

As a gold-coated sphere was brought closer to a silica plate - a repulsive force around one ten-billionth of a newton was measured starting at a separation of about 80 nanometers.

For nanocomponents of the right composition, immersed in a suitable liquid, this repulsive force would amount to a kind of quantum levitation that would keep surfaces slightly apart





Creating the World's Smallest Letters

Hari Manoharan, NSF – 0425897, NSEC Stanford U.

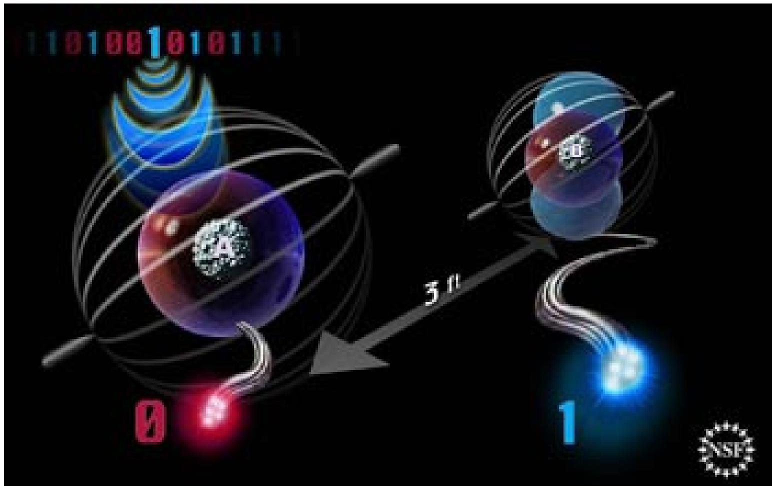
A STM is used to position CO molecules on a copper (111) surface and to read out by 2D illumination the **molecular holographic encoding** spelling the **letters SU of about 1 nm (0.8 by 1.5 nm) size in 3D**

The letters with features as small as 3 A are formed in the interference pattern generated by the 2D surface state electrons from the (111) face of the copper crystal and confined by the CO molecules acting as local gates (quantum holographic encoding)

C. Moon et al., Nature Nanotechnology, 4, (2009)

How to Teleport Quantum Information from One Atom to Another

Chris Monroe, University of Maryland, NSF 0829424



Teleportation carries information between entangled atoms.

Teleportation to transfer a quantum state over a significant distance from one atom to another was achieved.

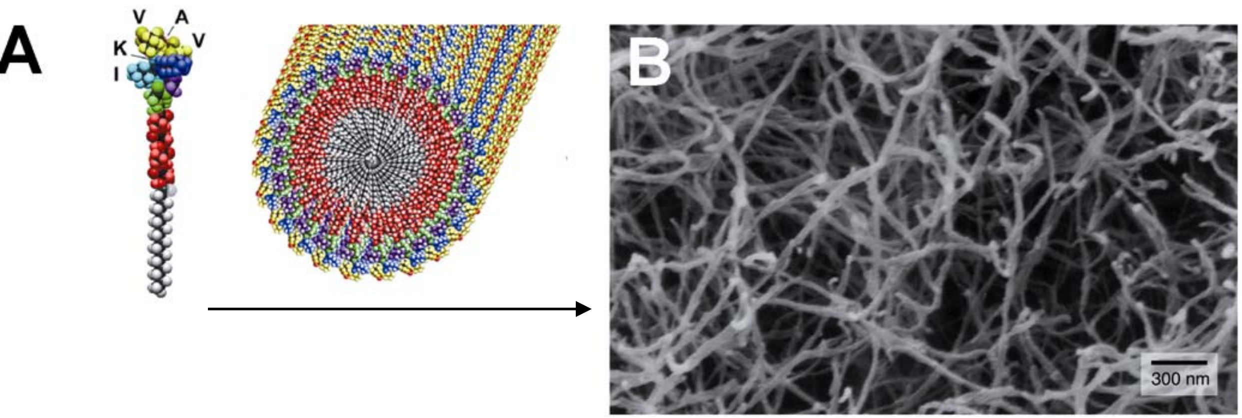
Two ions are entangled in a quantum way in which actions on one can have an instant effect on the other

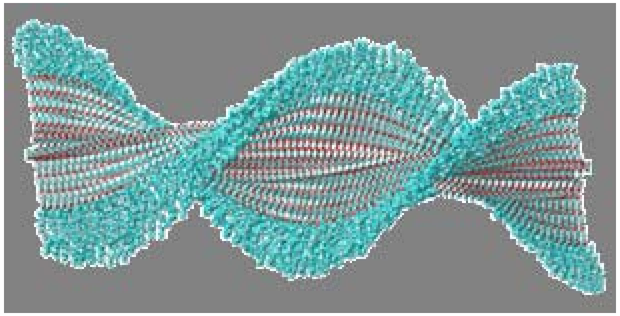
Experiments have attempted to teleport states tens of thousands of times per second. But only about 5 times in every billion attempts do they get the simultaneous signal at the beam splitter telling them they can proceed to the final step.

Example 4th generation (in research)

Designing molecules for hierarchical selfassembling

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

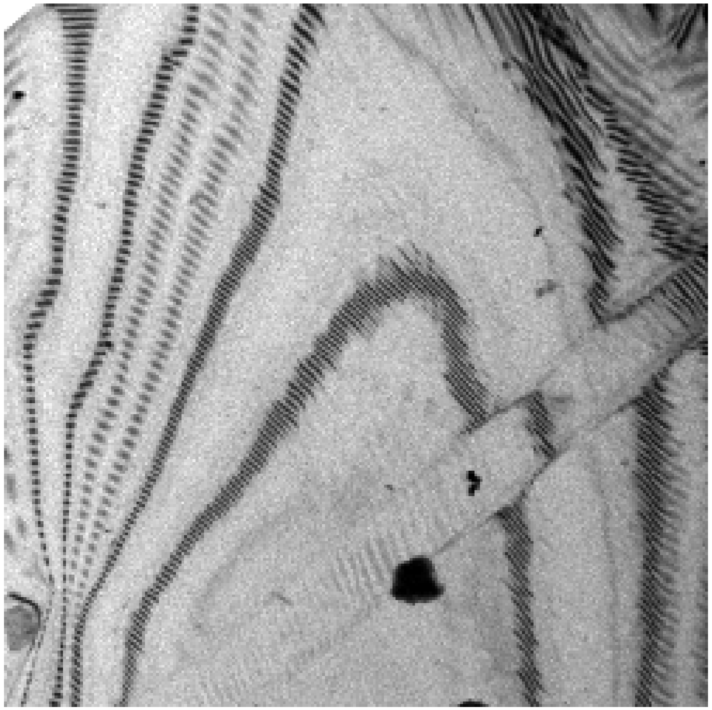




- New nanomachines, robotics - DNA architectures (Ned Seeman, Poly. Inst.)
- Designed molecules for self-assembled porous walls (Virgil Percec, U. PA)
- Self-assembly processing for artificial cells (Matt Tirrell, UCSB)
- Block co-polymers for 3-D structures on surfaces (U. Mass, U. Wisconsin)

4D Microscope Revolutionizes the Way We Look at the Nano World

A. Zewail, Caltech, and winner of the 1999 Nobel Prize in Chemistry



Nanodrumming of graphite, visualized with 4D microscopy.

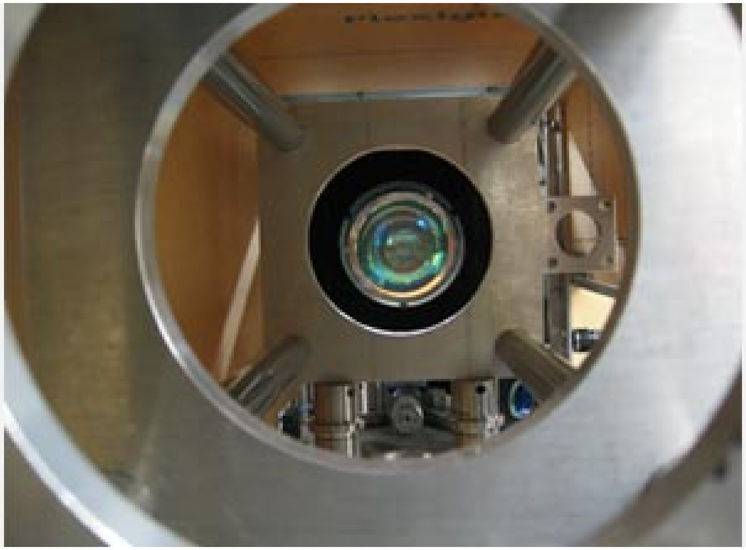
Use of ultra short laser flashes to observe fundamental motion and chemical reactions in real-time (timescale of a femtosecond, 10^{-15}s), with 3D real-space atomic resolution.

Allows for visualization of complex structural changes (dynamics, chemical reactions) in real space and real time. Such visualization may lead to fundamentally new ways of thinking about matter

http://ust.caltech.edu/movie_gallery/

Excited Atoms to Advance Quantum Computing

Mark Saffman, University of Wisconsin-Madison



End-on view of high numerical aperture custom lens system used to trap and image single atoms.

- Use a single atom to control another atom: potential to create working logic devices, similar to transistors in an electronic circuit, which could eventually be used in a quantum computer.
- Experiment performed to prove Rydberg blockade effect for quantum logic gates.

Nature Physics, 2009

Nanoelectronics Research Initiative (NRI)

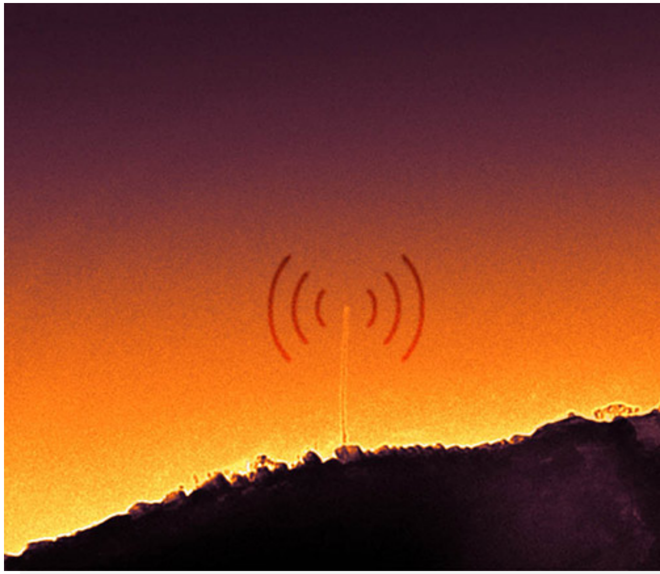
NRI Mission: Demonstrate novel computing devices capable of replacing the CMOS FET as a logic switch in the 2020 timeframe.

To meet these goals, NRI pursues five research vectors:

- **NEW DEVICE:** Device with alternative state vector
- **NEW WAYS TO CONNECT DEVICES:** Non-charge data transfer
- **NEW METHODS FOR COMPUTATION:** Non-equilibrium systems
- **NEW METHODS TO MANAGE HEAT:** Nanoscale phonon engineering
- **NEW METHODS OF FABRICATION:** Directed self-assembly of devices

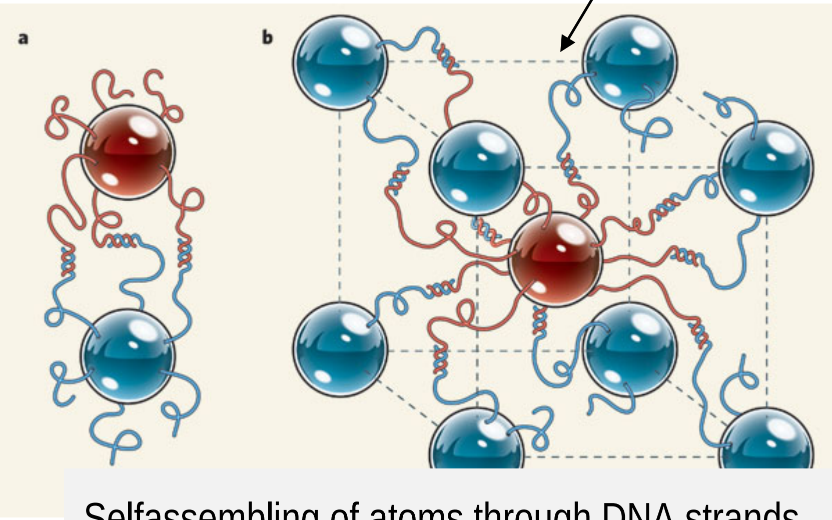
Examples new topics in 2008
Nanodevices and components of nanosystems

- A. Zettl (UCB), J. Rogers (U Illinois): nano radio = antenna, filter, amplifier



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

- C. Mirkin (NU), O. Gang (BNL) Architectures for new, designed crystals



Selfassembling of atoms through DNA strands

The World is NOT Currently Achieving Sustainable Development

Every major ecosystem is under threat at different time scales: food, water, risk of climate change, energy, biodiversity, mineral resources

Nanotechnology may offer efficient manufacturing with less resources, less waste, better functioning products

Need for global governance of converging technologies

.

Converging technologies (NBIC) - Examples of new transdisciplinary domains

- **Quantum information science** (IT; Nano and subatomic physics; System approach for dynamic/ probabilistic processes, entanglement and measurement)
- **Eco-bio-complexity** (Bio; Nano; System approach for understanding how macroscopic ecological patterns and processes are maintained based on molecular mechanisms, evolutionary mechanisms; interface between ecology and economics; epidemiological dynamics)
- **Neuromorphic engineering** (Nano, Bio, IT, neurosc.)
- **Cyber-physical systems** (IT, NT, BIO, others)
- **Synthetic & system biology** (Bio, Nano, IT, neuroscience)
- **Cognitive enhancers** (Bio, Nano, neuroscience)

Examples of new transdisciplinary domains (2)

- Nano sensors in the environment (Nano, bio, IT networking, environment)
- Emerging technologies for sustainable development (energy conversion and storage using nano, filtration of water using nano, using exact nanomanufacturing for reducing environmental quality and weather implications, using nanotechnology to reduce consumption of raw materials, energy from fusion, etc.)
- Adaptive systems engineering (neuroscience, cognitive technologies, adaptive systems for unpredicted events, etc.)
- Enhanced virtual reality (using nano, IT, cognitive, BIO; personalized learning, reverse engineer the brain)

NT Governance and Risk Governance

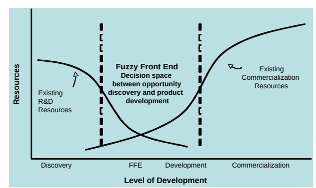
NANOTECHNOLOGY GOVERNANCE

- Investment policy
- Science policy
- Risk management
- Others . . . .

Four key functions:

Visionary

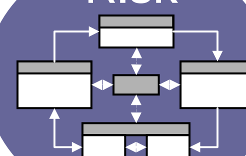
Transformative



Responsible

Benefit society

Risk



→ Risk Governance

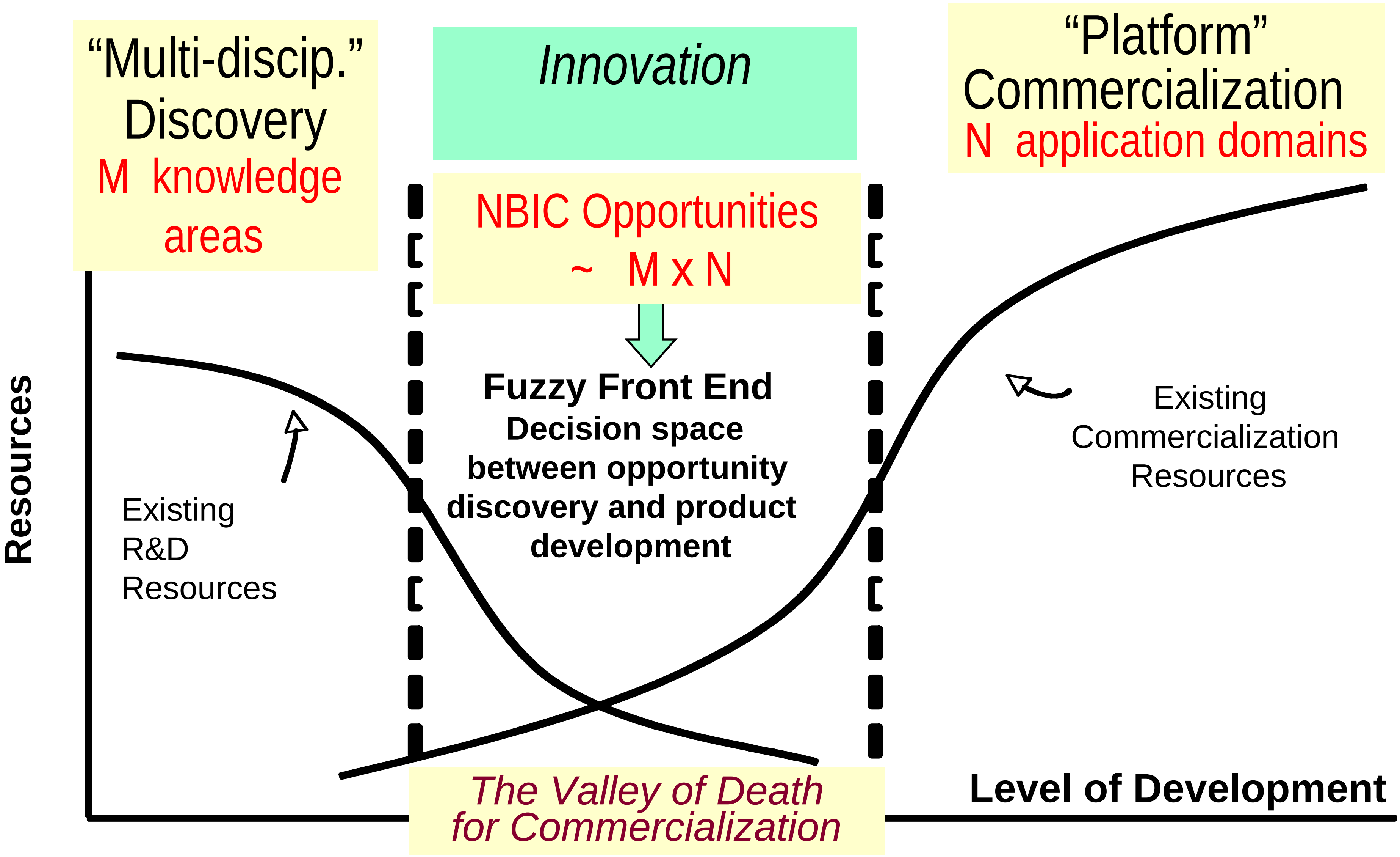
Inclusive

MC Roco, 3/17/2010

Governance of nanotechnology: four main functions

- Visionary
  Long-term and global view in planning, including setting R&D priorities and human development / progress
- Transformative
  investment and S&T policy, support innovation, tools, informatics, prepare pipeline in education, facilitate commercialization; management (build-up, solicitations)
- Responsible development
  EHS, ELSI+, risk governance, evaluation, communication & participation, regulations and oversight including voluntary measures
- Inclusive, collaborative
  Building national capacity; national and international structure, multi-sector partnerships and leveraging

Transformative: enhance innovation



INNOVATION opportunities increase ~ M x N times

MC Roco, 3/17/2010

Example of emerging technology organization: **Semiconductor Research Corporation**

SRC

- **GRC** — Global Research Collaboration
  Ensuring vitality of current industry
- **FCRP** — Focus Center Research Program
  Breaking down barriers to extend CMOS to its limits
- **NRI** — Nanoelectronics Research Initiative
  Beyond CMOS – identify next information element
- **Education Alliance** for Science, Engineering & Technology
  Attracting and educating the next generation of innovators and technology leaders
- **TRC's** — Topical Research Collaborations
  Topic(s) chosen by participants

The World is NOT Currently Achieving Sustainable Development

Every major ecosystem is under threat at different time scales: food, water, risk of climate change, energy, biodiversity, mineral resources

Nanotechnology may offer efficient manufacturing with less resources, less waste, better functioning products

Need for global governance of converging technologies

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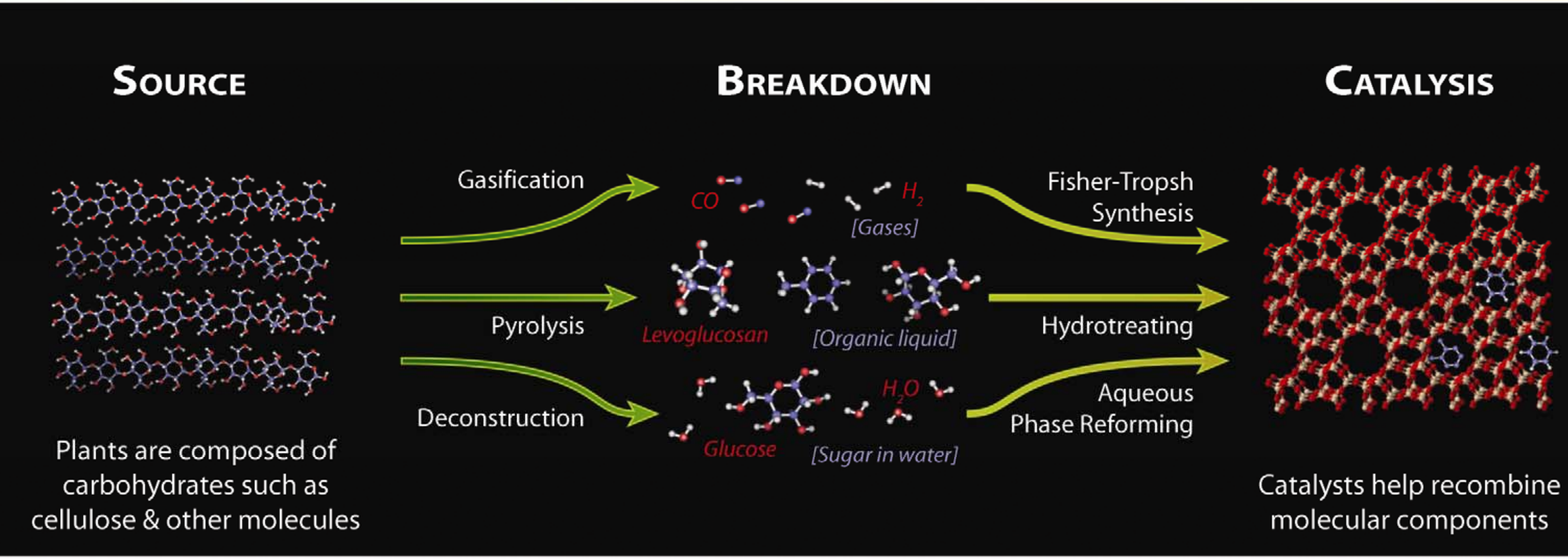
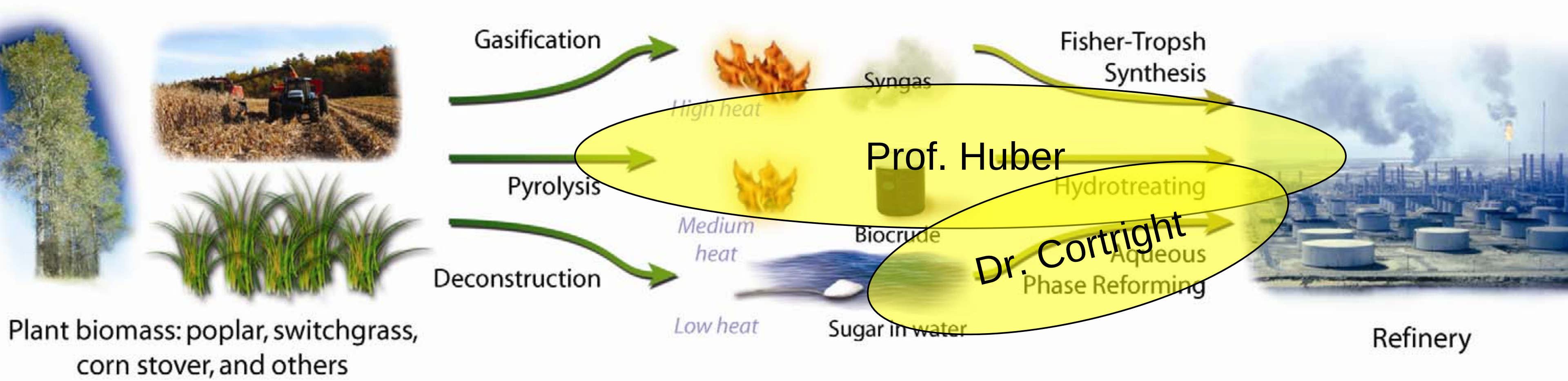
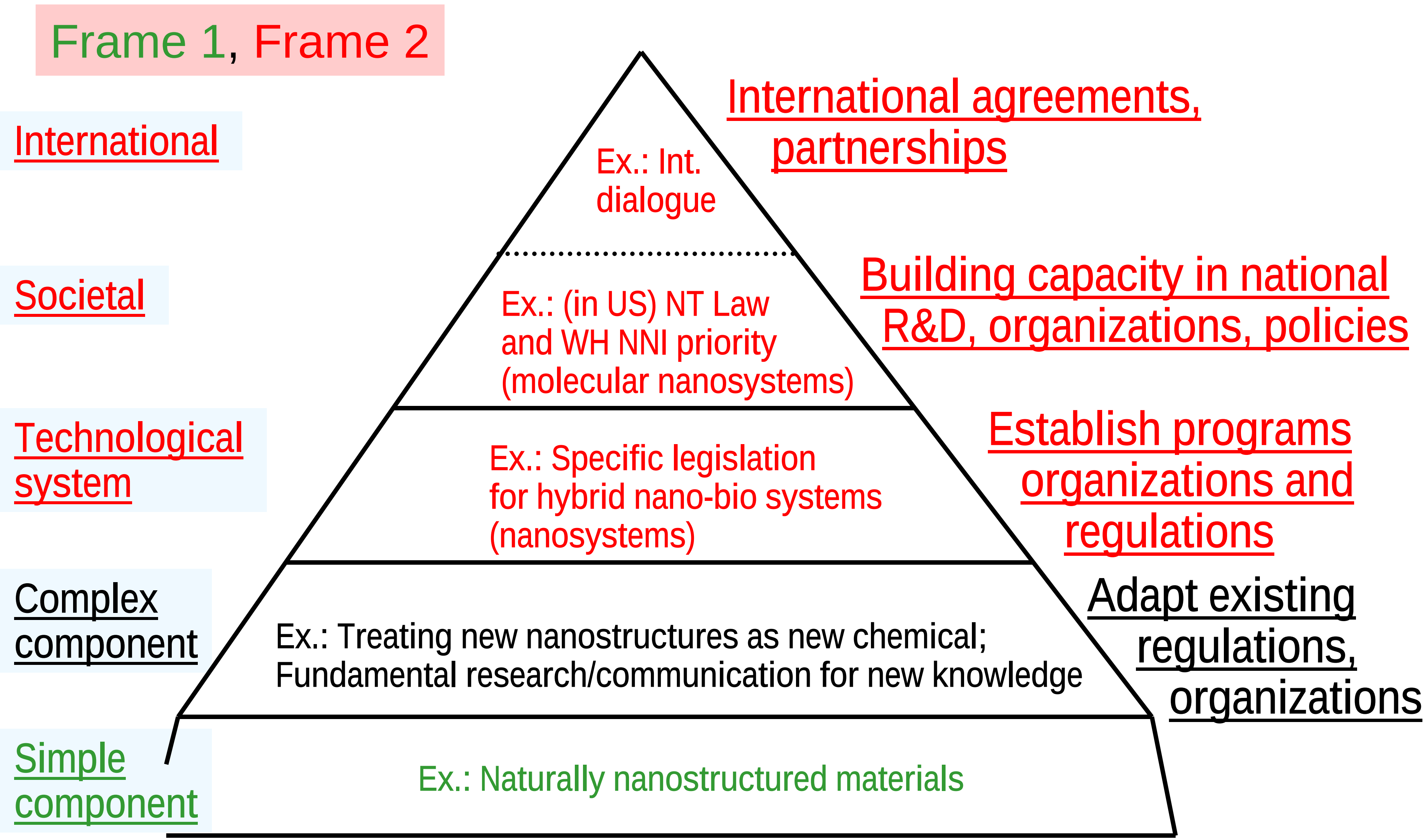
Green Gasoline: A Renewable Petroleum Alt





Responsible development

Multi-level structure for risk governance



MC Roco, 3/17/2010

Naturally nanostructured materials	Engineered nanostructured materials	Active nanostructures and systems	Large and molecular nanosystems
			Risk Trade -off Analysis & Deliberation necessary + Risk Balancing + Probabilistic Risk Modelling
		Risk Balancing Necessary + Probabilistic Risk Modelling	
		Remedy	**Remedy**
	Probabilistic Risk Modelling	• Cognitive • Evaluative	• Cognitive • Evaluative • Normative
	Remedy	**Type of Conflict**	**Type of Conflict**
Statistical Risk Analysis	Cognitive	• Agency Staff • External Experts • Stakeholders - Industry - Directly affected groups	• Agency Staff • External Experts • Stakeholders - Industry - Directly affected groups - General public
Remedy	**Type of Conflict**		
• Agency Staff • External Experts	• Agency Staff • External Experts • Stakeholders		
Actors	**Actors**	**Actors**	**Actors**
Instrumental	Epistemological	Reflective	Participative
Type of Discourse	**Type of Discourse**	**Type of Discourse**	**Type of Discourse**
Simple	Component Complexity induced	System uncertainty induced	Ambiguity induced
Risk Problem	**Risk Problem**	**Risk Problem**	**Risk Problem**

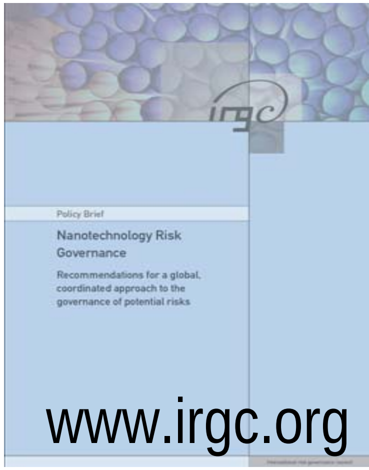
Frame 1 **Frame 2**

The Risk Management Escalator and Stakeholder Involvement

(from Simple via Complex and Uncertain to Ambiguous Phenomena) with reference to nanotechnology

IRGC

Address changing <u>public perception</u> since 2000



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

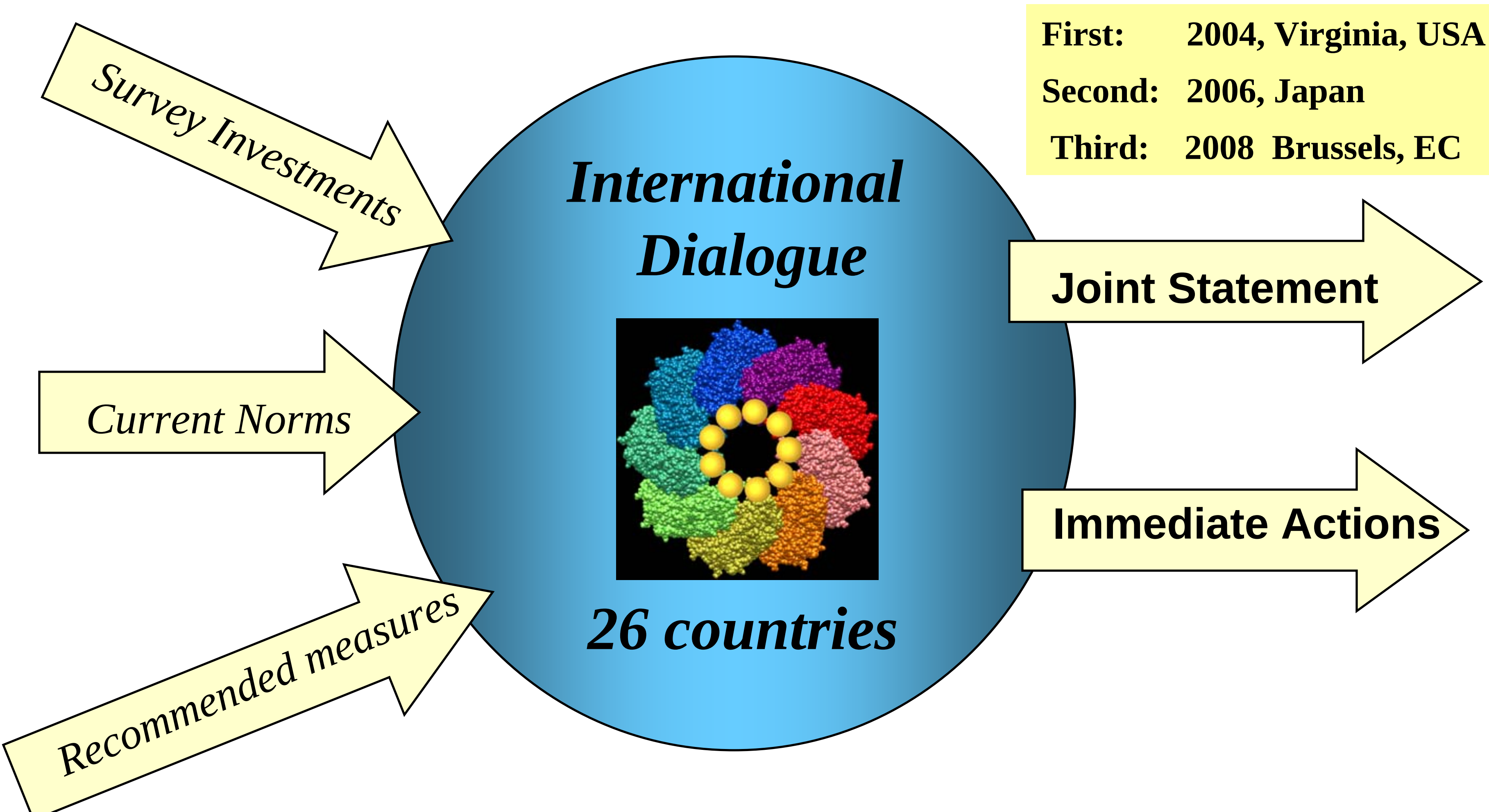
2000-2003: Are there self-duplicating nano-bots?
Could they create “grey-goo”?

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

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

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

Inclusive governance - Ex: International Dialogue on Responsible Nanotechnology R&D since 2004



June 2004, Virginia

http://www.nsf.gov/home/crssprgm/nano/dialog.htm

First International Dialogue on Responsible Nanotechnology R&D (2004)

Coordinated activities after the June 2004 International Dialogue

- October 2004 / October 2005 - Occupational Safety Group (UK, US,.)
- November 2004 - OECD / EHS group on nanotechnology begins
- December 2004 - Meridian study for developing countries
- December 2004 - Nomenclature and standards (ISO, ANSI)
- February 2005 - North-South Dialogue on Nanotechnology (UNIDO)
- May 2005 - International Risk Governance Council (IRGC)
- May 2005 - “Nano-world”, MRS (Materials, Education)
- July 2005 - Interim International Dialogue (host: EC)
- **October 2005 - OECD Nanotechnology Party in CSTP**
- **June 2006 - 2nd International Dialogue (host: Japan)**
- **2006 Int. awareness for: EHS, public participation, education**
- **2007-2009 - new activities**

Foster suitable international organizations

Ex: International standards organizations working on nanotechnology

National Body International Standards Organizations

ISO

IEC

Treaty-Based International Standards Organizations

ITU

OECD

Standards Development Orgs. With Global Reach

IEEE

semi

ASTM INTERNATIONAL

ASME International

OECD, Chemicals Committee, WPMN

2005- (**http://www.oecd.org/env/nanosafety/**)

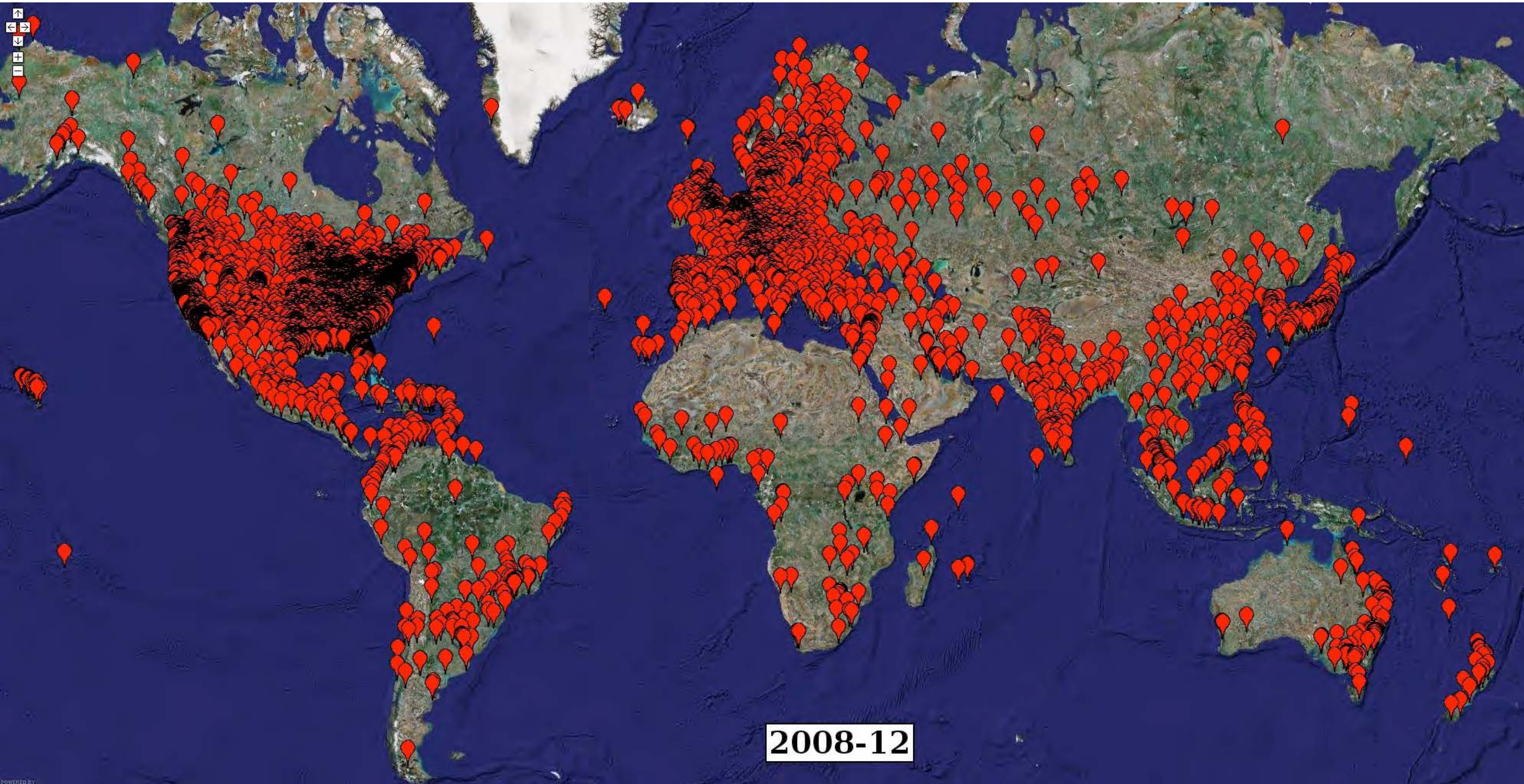
OECD: Working Party on Nanotechnology (WPN)

Working Party on Nanotechnology, 2007- (http://www.oecd.org/sti/nano)

A. Statistics and Measurement
B. Impacts and Business Environment
C. International Research Collaboration
D. Outreach and public engagement
E. Dialogue on Policy Strategies
F. Contribution of Nanotech to Global Challenges

Support global eco-systems via COLLABORATION

NETWORK FOR COMPUTATIONAL NANOTECHNOLOGY
nanoHUB.org is a resource for the global Nanotechnology Community.
The map below indicates a red-peg for every nanoHUB user on the planet.



Five Possibilities for Global Nanotechnology Governance

1. *Establish open-source 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 institutional capability to address sustainability of resources, *EHS and unexpected consequences*

4. Support *global communication and international partnerships*, facilitated by international organizations

5. Commitment to *long-term, priority driven gov., global view* using scenarios, anticipatory and adaptive measures

Several background references

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in Global Risk Governance Framework, Springer (2007)

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