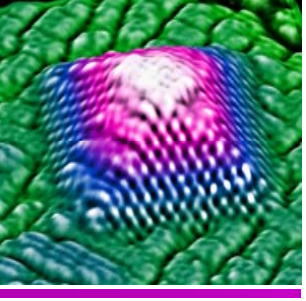
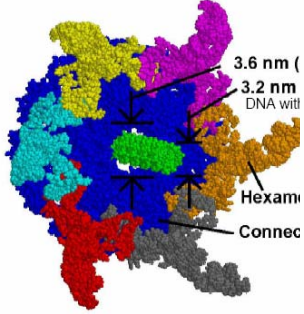
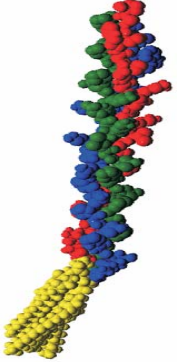
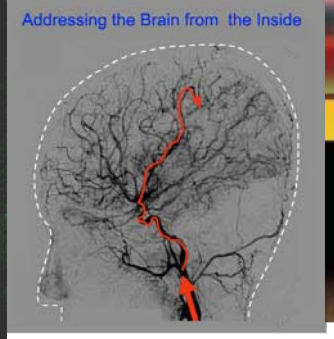
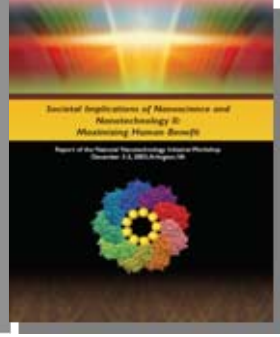









Nanotechnology R&D in the Americas and the Global Context

M.C. Roco

U.S. National Science Foundation and
National Nanotechnology Initiative

International Dialogue 2, Tokyo, June 27, 2006

The Americas and the Global Context

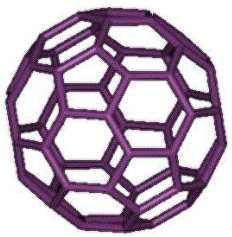
Topics:

- **Connecting to the First Dialogue (Virginia, 2004)**
- **Four generations of nanotechnology products (2000-2020)**
- **Several nanotechnology programs in the Americas**
- **The international context and the need for global risk governance**

First International Dialogue on Responsible R&D of Nanotechnology, Virginia, 2004

Nanotech = no easy Game.

YOU WILL HAVE TO .....



by Manfred Scriba (South Africa) et al.

..... walk briskly to catch up
with the LEADERS

.... wait for your Opportunity

.... and sometimes endure
a bumpy ride. But ....

the rewards will be there ...

... for EVERYONE ...

...late entrants included !
Nano Africa 1 (7 April 2004, Stellenbosch)

Our efforts will change lives!

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

First: June 204, Virginia, USA

Interim: July 2005, Brussels, EC

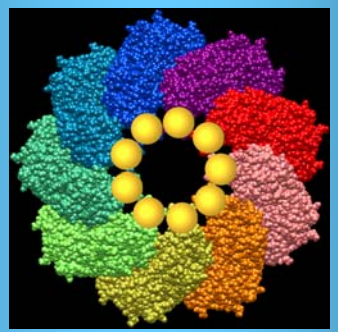
Second: June 2006, Japan

Survey Investments

Current Norms

Recommended measures

International Dialogue



26 countries

Joint Statement

Immediate Actions

June 2004, Virginia

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

MC. Roco, 06/27/06

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

- Recurring themes during the dialogue
  - Nanotechnology and regulatory responses
  - Governance: involving public, global
  - Nanotechnology applications and implications
  - Institutional mechanisms for ongoing dialogue

- Recommended future actions
  - Intention to coordinate activities (next slide)
  - Expanding the dialogue
    to other stakeholders and countries

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 - Preparatory International Dialogue (host: EC)
- **July 2005 - 2nd International Dialogue (host: EC)**
- **October 2005 - OECD Nanotechnology Party in CSTP**
- **2006 Int. awareness for: EHS, public participation, education**

1999 benchmark
Nanostructure
S&T
Springer, 1999

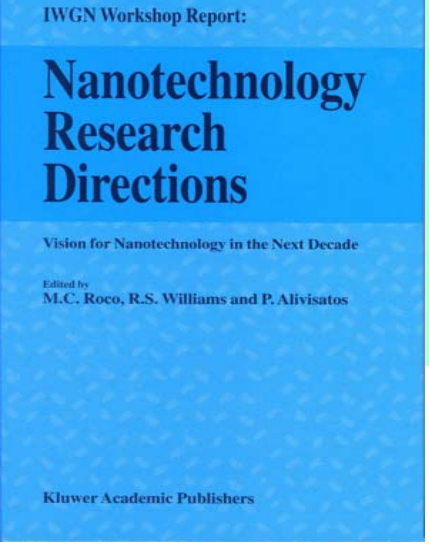
Nanotechnology

Definition after international study > 20 countries, 2000
(Unique term, need for international acceptance, ISO 2006)

- **Working at the atomic, molecular and supramolecular levels, in the length scale of approximately 1 – 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 contributions that were not possible before**

  - the ability to measure, control and restructure matter at the nanoscale in order to change those properties and functions
  - novel phenomena, properties and functions at nanoscale, which are nonscalable outside of the nm domain
  - integration along length scales, and fields of application



WHAT IS SPECIAL ABOUT NANOTECHNOLOGY ?

(drivers)

- **Reaches at the basic level of organization of atoms and molecules**, where properties/functions of manmade and living systems are defined
- **Broad technology platform** (for industry, biomedicine, environment) **with significant societal implications** (improved knowledge, technology, quality of life)
- **Higher purpose goals than development of NT**
  - More basic science and education
  - Higher efficiency processes and novel products
  - Molecular medicine
  - Extend the limits of sustainable development

WHAT IS SPECIAL ABOUT NANOTECHNOLOGY?

(consequences)

- Reverses the trend of specialization of scientific disciplines, providing unifying concepts for research and education, a foundation for converging new technologies
- Has stimulated all developed countries and many countries in development to invest in nanotechnology R&D: in over 60 countries since 2000. Worldwide R&D > $8 billion in 2005
- Has broaden and changed manufacturing/medical capabilities and their implications. Become a main driver for technological / economical change and industrial competition
- Has stimulated the speed and scope of R&D programs that exceeds for now the capacity of regulators to assess human and environmental impact

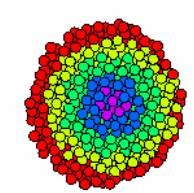
Defining Nanoproducts and Nanomanufacturing

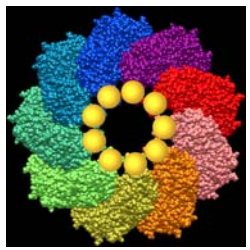
- Fragmentation
- Patterning
- Restructuring of bulk
- Lithography, ..

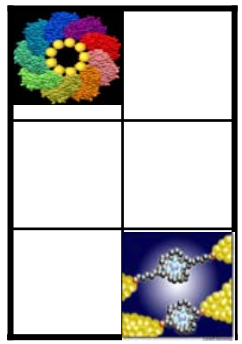
- Interfaces, field & boundary control
- Positioning assembly
- Integration, ..

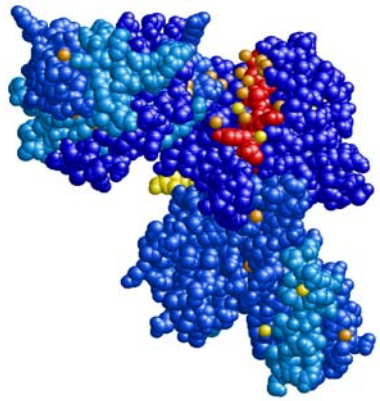
- System engineering
- Device architecture
- Integration, ..

- Nanosystem biology
- Emerging systems
- Hierarchical integration..

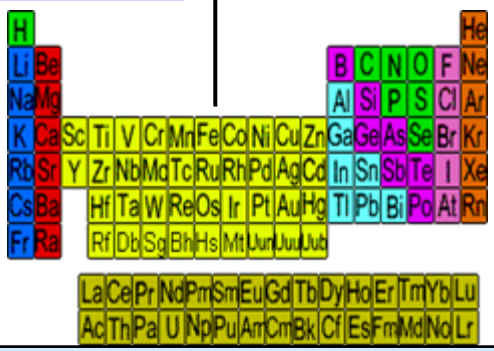








Assembling



- Directed selfassembling,
- Templating,
- New molecules

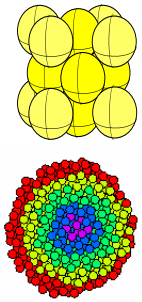
- Multiscale selfassembling,
- In situ processing, ..

- Eng. molecules as devices,
- Quantum control,
- Synthetic biology..

PASSIVE NANOSTRUCTURES	ACTIVE NANOSTR.	SYSTEMS OF NANOSYSTEMS	MOLECULAR NANOSYSTEMS

NANOPRODUCTS

Four generations of nanoproducts and productive processes

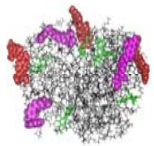


1st: Passive nanostructures (1st generation products)

a. *Dispersed and contact nanostructures*. Ex: aerosols, colloids

b. *Products incorporating nanostructures*. Ex: coatings; nanoparticle reinforced composites; nanostructured metals, polymers, ceramics

~ 2000

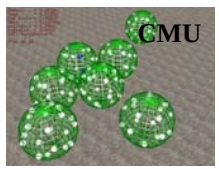


2nd: Active (evolving function) nanostructures

a. *Bio-active, health effects*. Ex: targeted drugs, biodevices

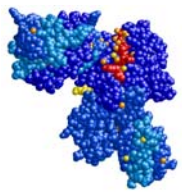
b. *Physico-chemical active*. Ex: 3-D transistors, amplifiers, actuators, adaptive structures

~ 2005



3rd: Systems of nanosystems Ex: guided assembling; 3-D networking and new hierarchical architectures, robotics, evolutionary biosystems

~ 2010



4th: Molecular nanosystems

Ex: molecular devices 'by design', atomic design, emerging functions

~ 2015-2020

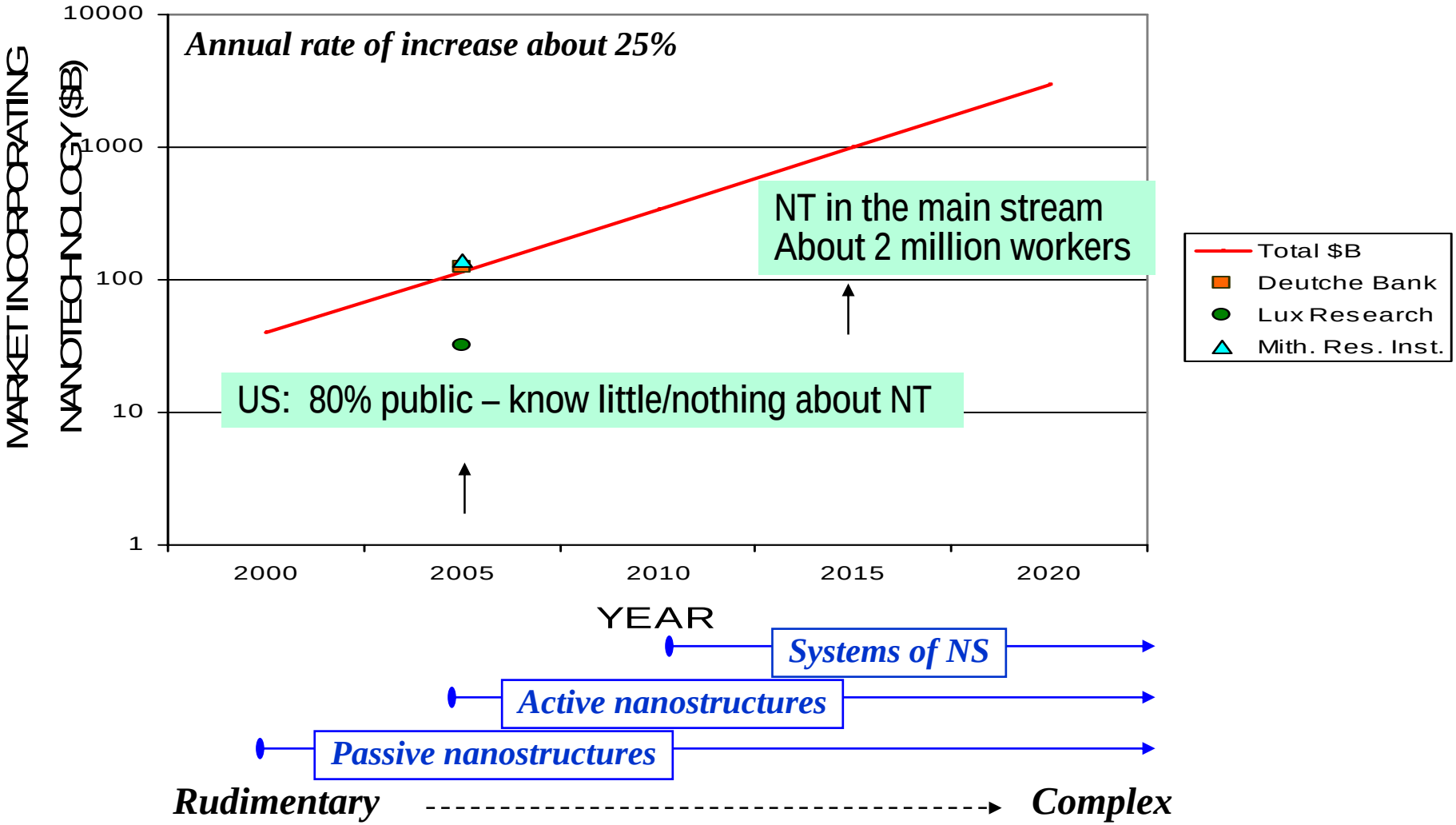
In production

New R&D challenges

Timeline for beginning industrial prototyping and nanotechnology commercialization

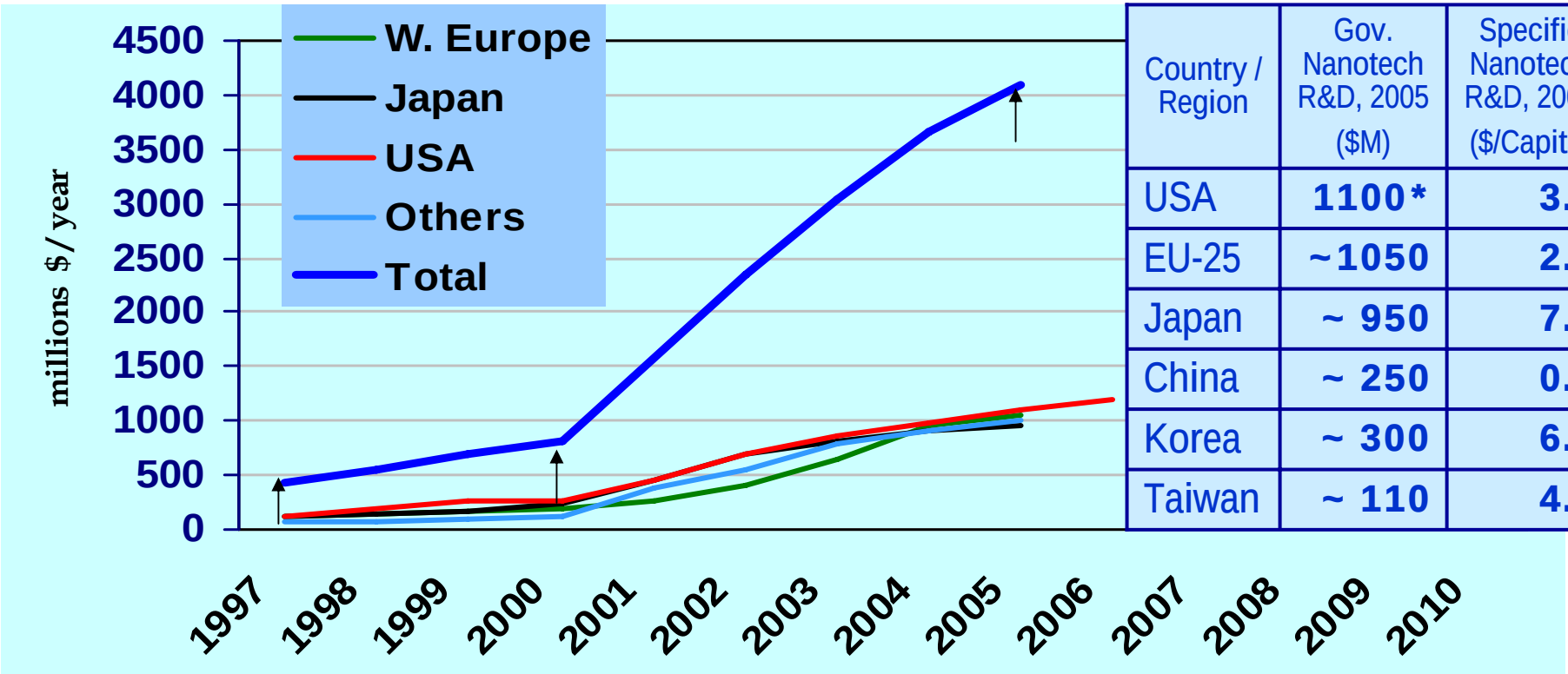
WORLDWIDE MARKET INCORPORATING NANOTECNOLOGY

(NSF estimation made in 2000 after international study in > 20 countries)



Context – Nanotechnology in the World

Past government investments 1997-2005 (est. NSF)



Country / Region	Gov. Nanotech R&D, 2005 ($M)	Specific Nanotech R&D, 2004 ($/Capita)
USA	1100*	3.7
EU-25	~1050	2.3
Japan	~ 950	7.4
China	~ 250	0.2
Korea	~ 300	6.2
Taiwan	~ 110	4.7

Seed funding (1991 -)

NNI Preparation (vision / benchmark)

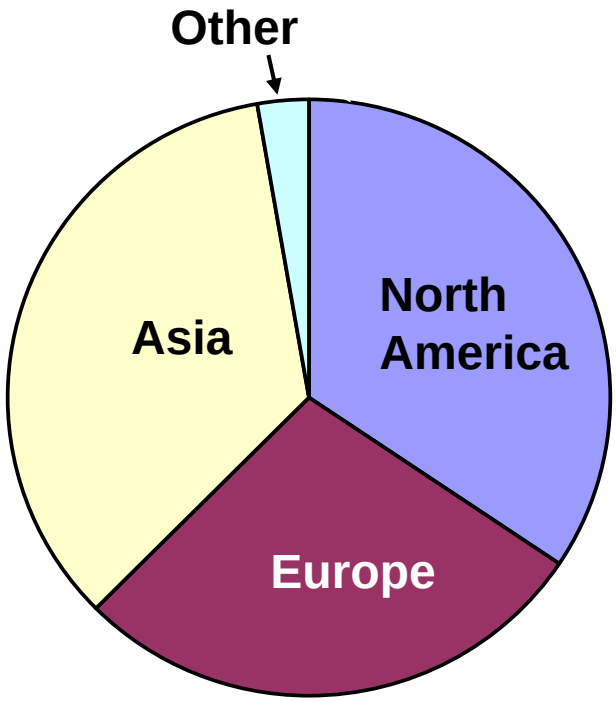
1st Strategic Plan (passive nanostructures)

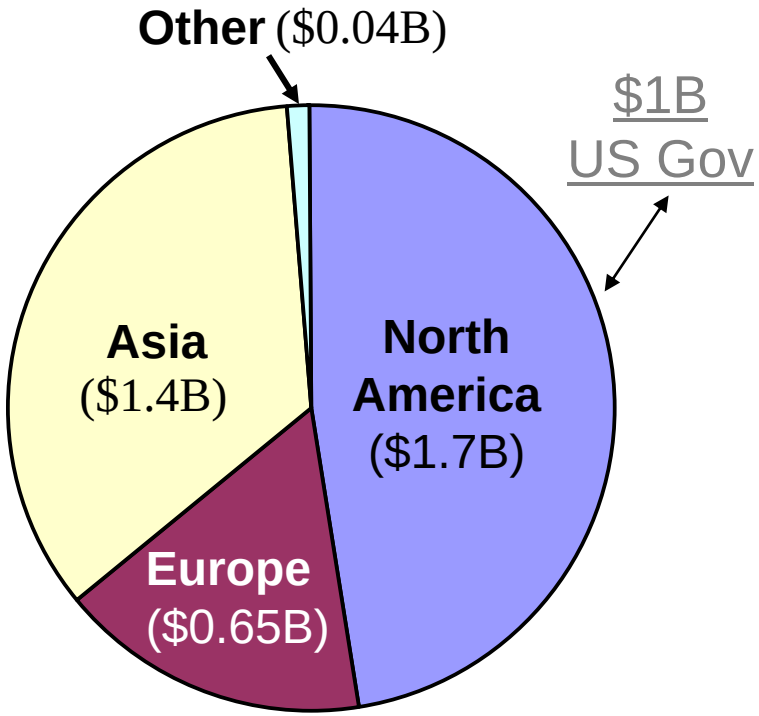
2nd Strategic Plan (active ns. & systems)

Total government expenditure in FY 2005 – about $4.1 billion

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

Where do we stand?
Global R&D investments in 2004 (Total = $8.6 billion)





Public (National, regional, state)

Focused on long-term research

Total = $4.6 B

(less than $0.5 B in 1997, NSF survey)

Private (Corporate + VC)

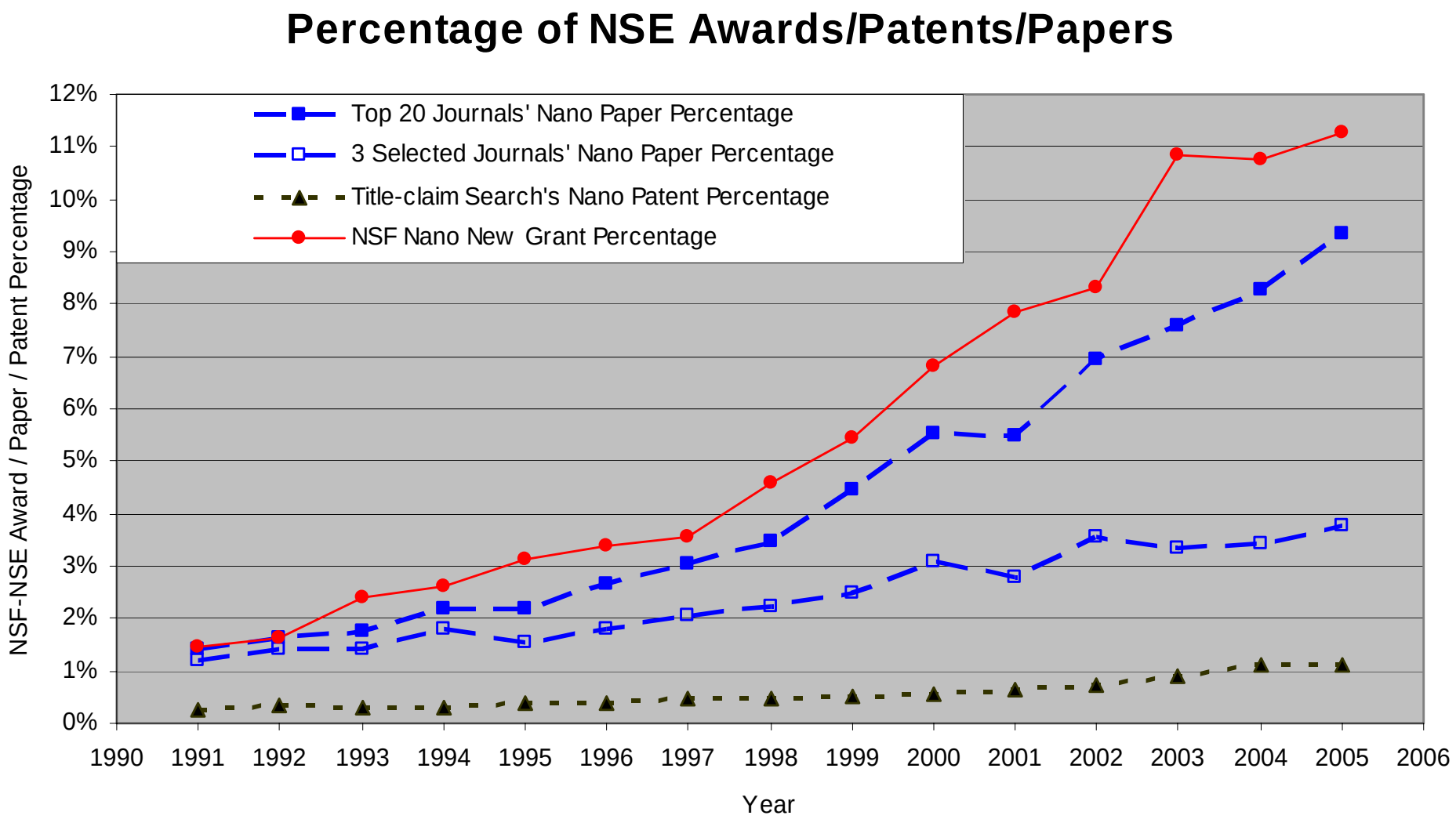
Focused on 1st Gen. R&D applications

Total = $4 B (Lux Research)

(less than $0.1 B in 1997)

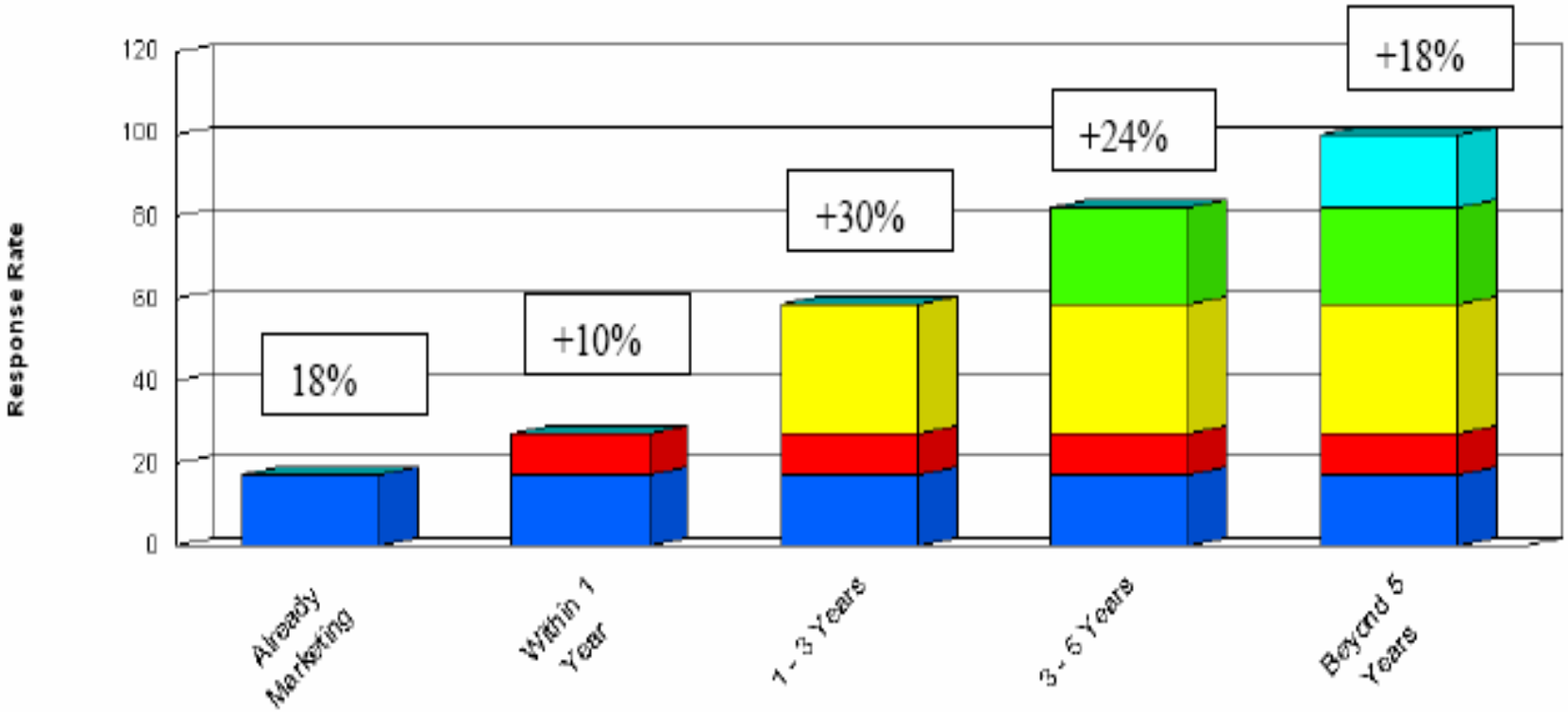
Source: Lux Research & NSF

Keyword search for nanotechnology contents: NSF awards, USPTO patents and ISO papers



MC. Roco, in Handbook of Nanoscience, Engineering and Technology, Taylor and Francis, 2006

2005 NCMS Survey on nanotechnology in manufacturing industry (594 companies)



Commercialization timelines indicate many new nanoproducts introductions in 2007-2011, and the high level of expectation in long-term

(National Center for Manufacturing Systems, Jan 2006)

International Grand Challenges
(suggestions)

- **Focus on single molecules and single cell**
- **Nanoscale instrumentation and metrology**
- **Theory, modeling and simulation at nanoscale**
- **Tools for manufacturing at the nanoscale**
- **Improving resources: water, energy, food**
- **Improving human performance and education**
- **Enhancing societal implications, env & health**

References:
MC Roco, "International Strategy for Nanotechnology R&D", J. Nanoparticle Res., 2001
MC Roco, "International Perspective of Nanotechnology R&D", J. Nanoparticle Res., 2005

The Americas: Significant national nanotechnology R&D

- Argentina
- Brazil
- Canada
- Chile
- Mexico
- USA

Pan American collaborations

- Various partnerships, such as Materials Institute, PASI
- Funding bilateral; regional groups (PASI, S. America)

Argentina
R&D programmes related to nanotechnology

- **CONICET, the National Research Council**:
  - Supports 7 centers, 60 researchers, 40 PhD and post-docs
  - Twelve research projects on nanosciences were financed as national projects for a three-year period
  - Public investment over 500k/year

- **Inter-American Materials Collaboration** (CIAM) together with the US (NSF), Canada, Mexico, Colombia, Costa Rica, Chile and Brazil.

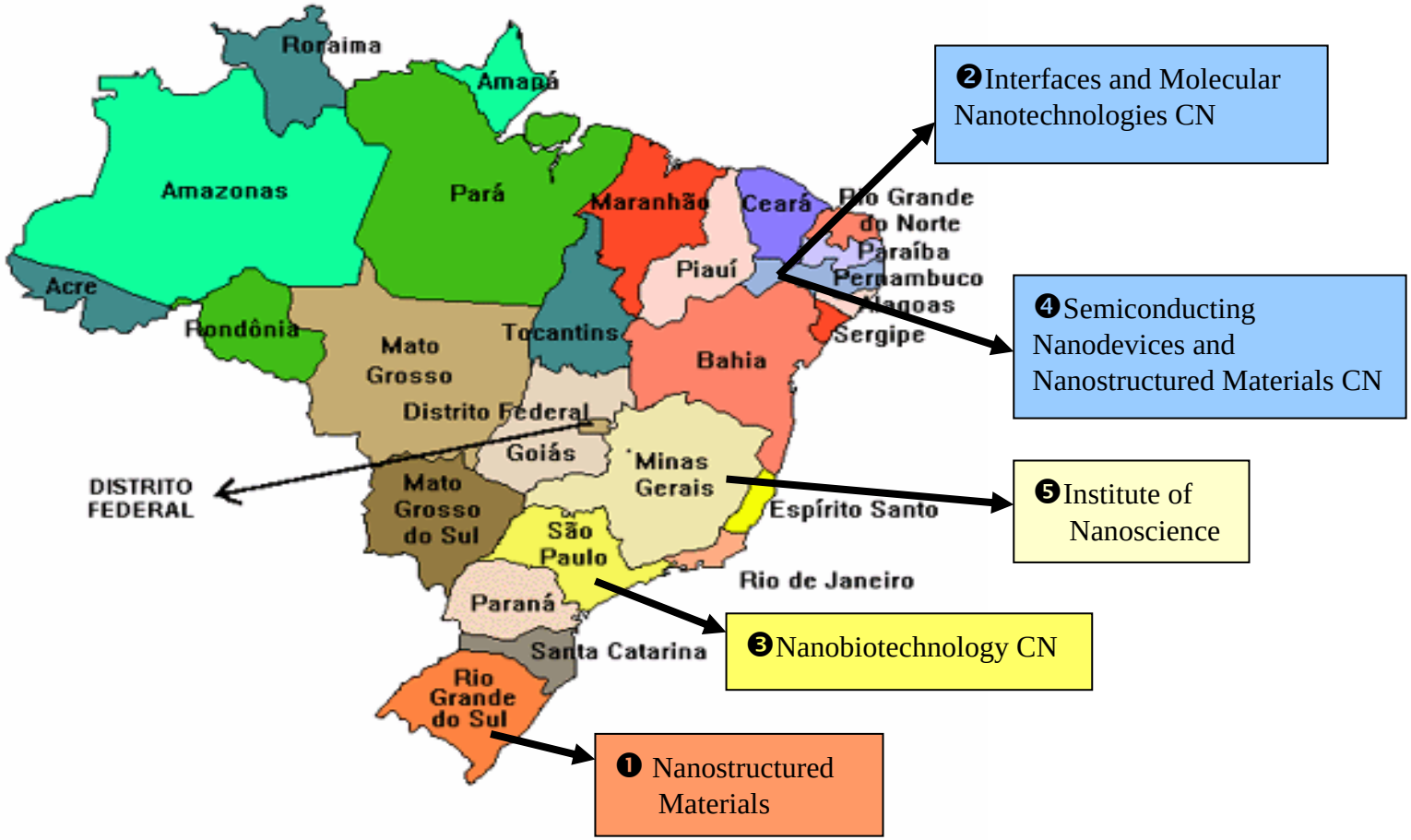
- **Bi-lateral collaborations with US (NSF) and EU (EC)**

- **Independent nanotechnology initiatives** are at:
  - Universities of Buenos Aires
  - Mar del Plata and La Plata
  - The Atomic Energy Commission

Brazil
R&D programmes related to nanotechnology (1)

- The Brazilian initiative towards a **national program in nanoscience and nanotechnology (N&N)** started in 2001
- **Four research networks** have been created by the Ministry of Science and Technology (MCT) through the National Council for Scientific and Technological Development (CNPq)
- **Three "Millennium institutes"** for Science and Technology
- **Around 400 scientists are involved**. The main foci of these programs are in nanobiotechnology and nanostructured materials
- For 2004-2007 it is estmated a budget of **US$ 25 millions**

Brazil
R&D centers related to nanotechnology (2)



❷Interfaces and Molecular Nanotechnologies CN

❹Semiconducting Nanodevices and Nanostructured Materials CN

❺Institute of Nanoscience

❸Nanobiotechnology CN

❶ Nanostructured Materials

CANADA
R&D programmes related to nanotechnology (1)

- **Main granting bodies supporting nanotechnology**
  - the Natural Sciences and Engineering Research Council (NSERC)
  - the Canada Foundation for Innovation (CFI)
  - the Canadian Institutes for Health Research (CIHR); in 2003 – program on regenerative medicine and nanomedicine
- **In 2004 estimated research funding:** NSERC - $15 million; CIHR - $7 million; the Canada Foundation for Innovation and its matching partners (provincial government, foundations, other) - funding for major capital equipment grants totalled $115 million
- **Over 55 Canada Research Chairs** have been awarded to leading nanotechnology researchers in Canadian Universities since 2000
- Funding for salaries, buildings, and equipment to universities is provided by provincial governments based on their teaching component: **Quebec** - 10 million four-year program in 2001-2005 to build nanotechnology; **Alberta** - build expertise and research infrastructure in nanotechnology

National Research Council Canada (NRC)
R&D programmes related to nanotechnology (2)

- NRC in collaboration with the Province of Alberta it launched the **National Institute for Nanotechnology** (NINT, 2001) for five years. The institute is focused on research in integrated circuit technology, energy and biology that has significant commercialization potential.

- **NRC has other research institutes in molecular sciences, microelectronics, materials science and engineering, aerospace, metrology, and biotechnology** with active nanotechnology research programs related to their specific focus area. Total NRC spending on nanotechnology including NINT was estimated at $20 million for operating expenses and $10 million in capital investments in FY 2004-05.

Canada -Mission Oriented Research

R&D programmes related to nanotechnology (3)

- **Natural Resources Canada, Environment Canada, Health Canada, and National Defence** identified the potential of nanotechnology to impact regulatory functions, defence and security, and economic and social benefits for Canadians. In 2003 Natural Resources Canada identified $2 million in expenditures on nanotechnology research.

- There are varying estimations of **Canadian private sector** involvement in Canada, ranging from between 50 to over 100 (depending on the source of information and the definition) that are involved in nanotechnology R&D and adoption of technology.

Mexico
R&D programmes related to nanotechnology

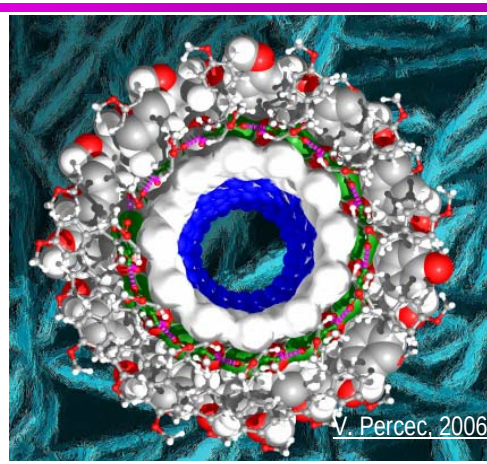
- **The government support is for academic R&D**

  15 Centers and Universities with research programs on novel structures, nanofilms, nanoparticles, and polymer nanostructures

- **CONACyT, JesúsGonzález: Coordinator of the National Nanotechnology Program**

- **Collaboration in NAFTA**

US/National Nanotechnology Initiative
Agencies with major NNI contributions



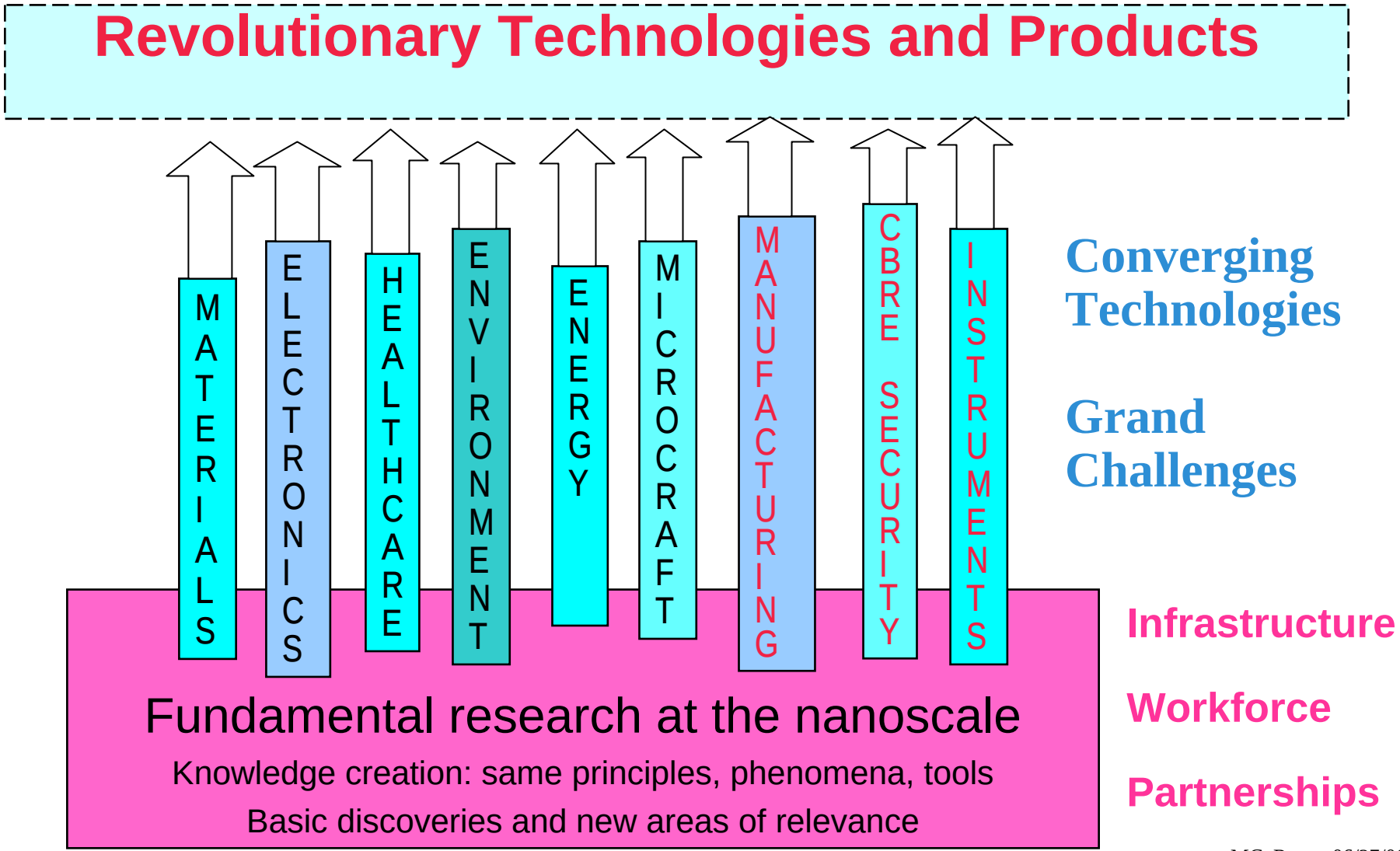
Total: 25 federal departments and agencies in 2006

Agency presentations at this Conference:

- **National Science Foundation (NSF)**
- **Department of Defense (DOD)**
- **Department of Energy (DOE)**
- **National Institute of Health (NIH)**
- **National Aeronautical and Space Agency (NASA)**
- **National Institute of Science and Technology (NIST)**
- **Environmental Protection Agency (EPA)**
- **National Inst. for Occupational Safety and Health (NIOSH)**
- **US Department of Agriculture (USDA)**

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

National Nanotechnology Initiative, FY 2006: $1.3 billion with Congressional adds-on
Industry, state and local organizations: about 2 times NNI budget in FY 2005



Outcomes of 2001-2005: R&D Networks and User Facilities

- **Network for Computational Nanotechnology** (NCN)
  - **7** universities (Purdue as the central node)
  - Nanoelectronic device simulation/modeling
- **National Nanotechnology Infrastructure Network (NNIN)**
  - 13 universities with user facility (Cornell as central node)
  - Development measuring & manufacturing tools
  - Education and societal implications
- **Oklahoma Nano Net (EPSCoR award)**
- **DOE network for large scale facilities**
- **NASA academic research network**
- **NIH centers of excellence in nanotechnology**

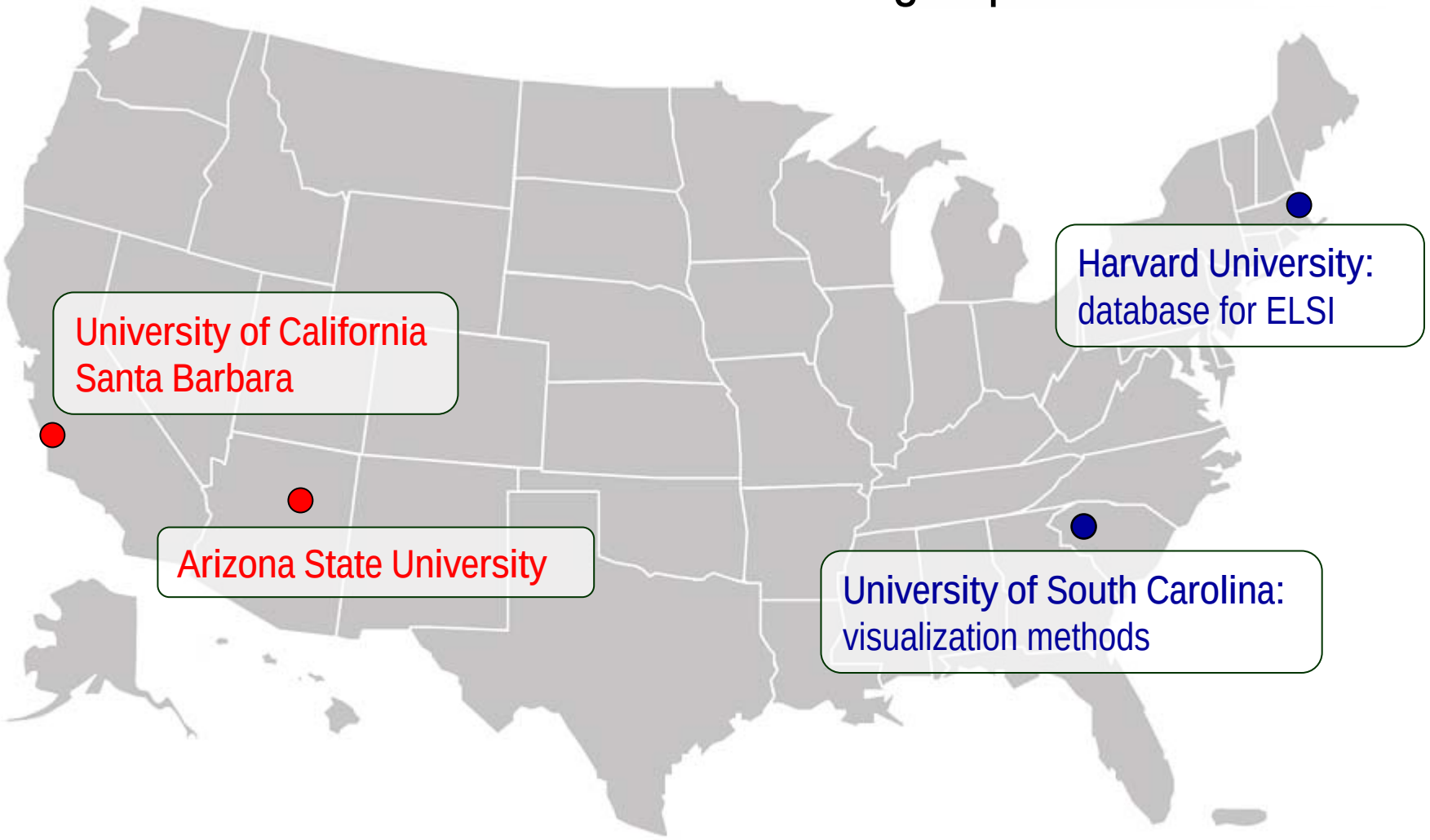
59 new centers and networks created by NNI since 2001:

24 NSF, 3 DOD, 5 DOE, 4 NASA (academic), 2 NIST, 21 DHHS

NSEC: Nanotechnology in Society

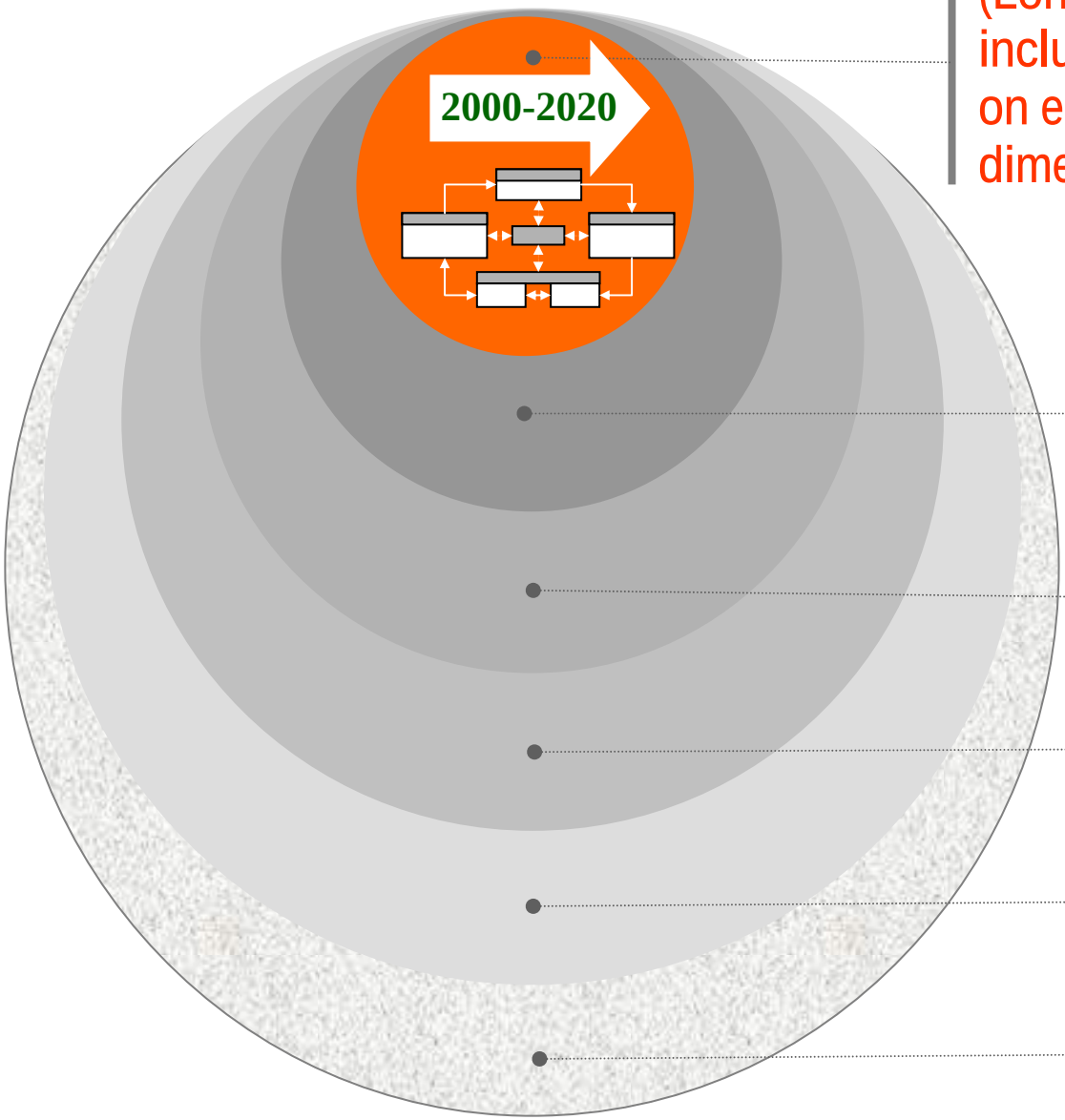
Four nodes established in September 2005:

● 2 centers and ● 2 small-groups



To address Ethical, Legal and other Social Issues related to Nanotechnology

NANOTECHNOLOGY GOVERNANCE OVERVIEW



Core Governance Process
(Long-term view, transforming, inclusive, horizontal/vertical, priority on education, addressing societal dimensions, risk governance)

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

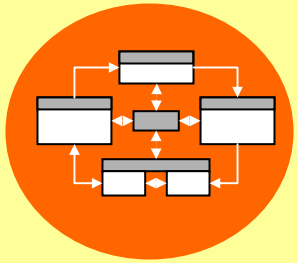
MC. Roco, in Handbook of Nanoscience, Eng. and Techn., Taylor and Francis, 2006

Nanotechnology Governance and Risk Governance

NANOTECHNOLOGY GOVERNANCE

- Investment policy
- Science policy
- Risk governance
- Others

SCOPE
- Conceptual framework for integrated approach to analyze and manage risks and challenges
- For decision-makers



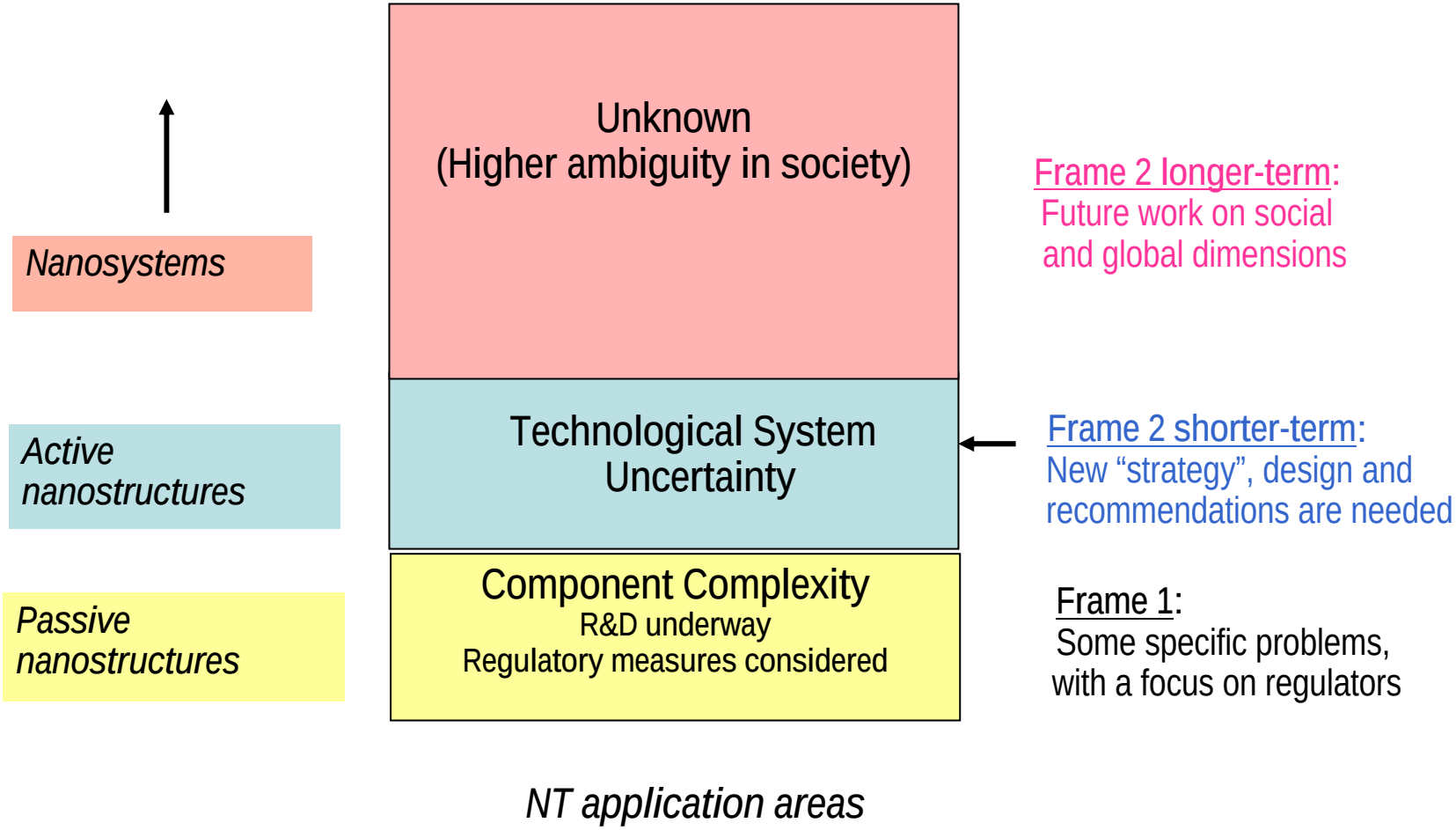
NANOTECHNOLOGY RISK GOVERNANCE

GOALS
- Cross stakeholders
- Multiple authorities
- Cross-boundary, global
- Long-term view

WHAT IS DIFFERENT
- Structure NT development: 4 generations; 2 frames
- Include social context: concern assessment
- Governance approach: corrective and adaptive

RISK GOVERNANCE APPROACH
- Begin with the IRGC framework
- Methodologies for 2 risk frames
- Focus: EHS, ELSI, ED, PSI, HDI
- Stakeholder engagement
- Risk communication
- Risk governance methods

EX: Strategies as a function of the generation of nanoproducts: Application to Frame 1 and Frame 2



Management Sphere: Decision on & Implementation of Actions

Assessment Sphere: Generation of Knowledge

To be defined before most nanoproducts are known

Knowledge development is critical for nanotechnology

Pre-Assessment

- Problem Framing
- Early Warning
- Screening
- Determination of Scientific Conventions

Two frames for NT

Risk Management

Implementation
- Option Realisation
- Monitoring & Control
- Feedback from Risk Mgmt. Practice

Decision Making
- Option Identification & Generation
- Option Assessment
- Option Evaluation & Selection
- Option Risk Reduction

Specific to 4 nanoproduct generations

Risk Appraisal

Risk Assessment
- Hazard Identification & Estimation
- Exposure & Vulnerability Assessment
- Risk Estimation

Concern Assessment
- Risk Perceptions
- Social Concerns
- Socio-Economic Impacts

Applied to specific NT areas

Communication

Multidimensional in nanotechnology

Tolerability & Acceptability Judgement

Risk Evaluation
- Judging the Tolera-bility & Acceptability
- Need for Risk Reduction Measures

Risk Characterisation
- Risk Profile
- Judgement of the Seriousness of Risk

Specific to natural, manufactured and bi-products NS

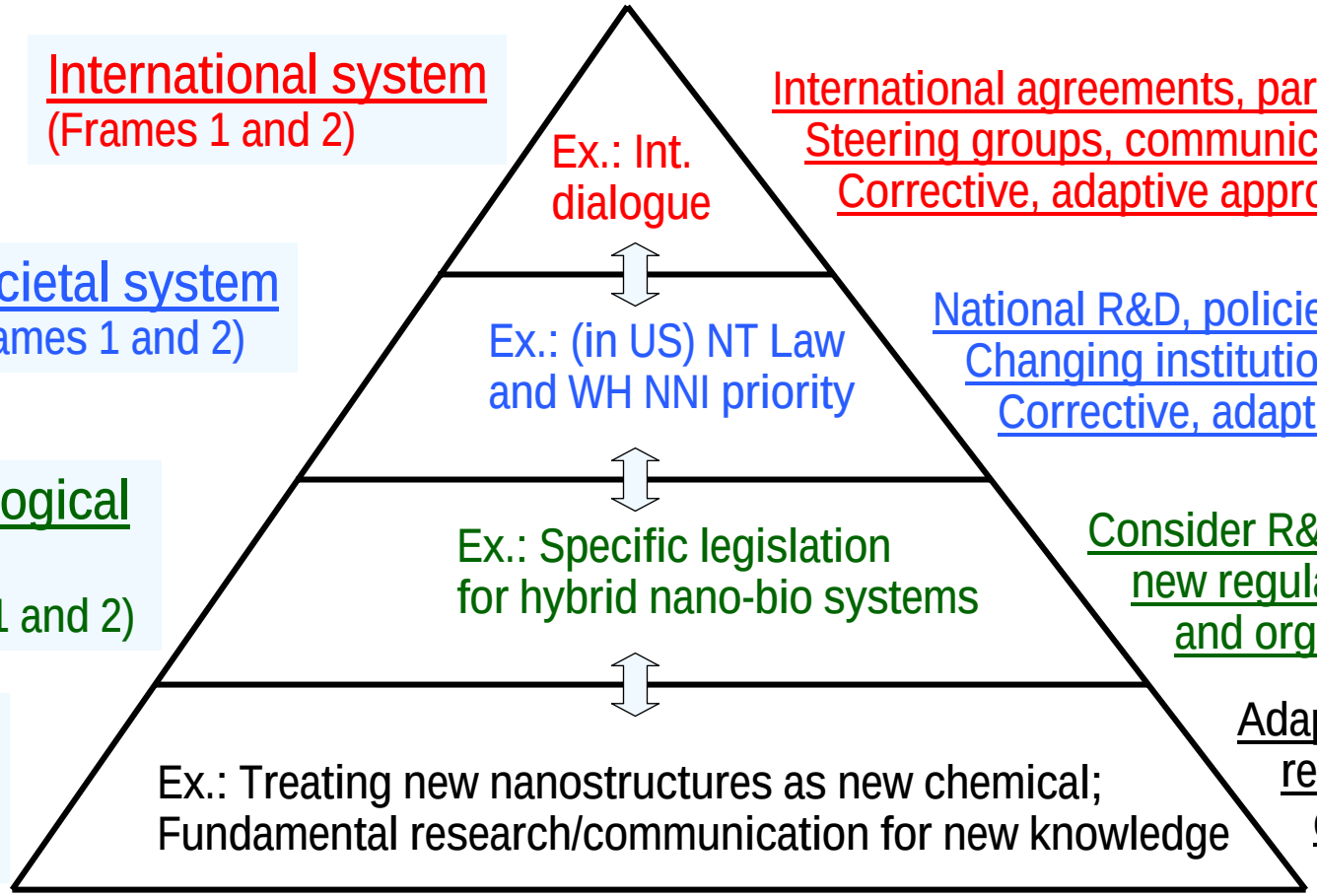
The Risk Management Escalator and Stakeholder Involvement

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

Naturally nanostructured materials	Engineered nanostructured materials	Active nanostructures and systems	Large and molecular nanosystems
		Risk Balancing Necessary + Probabilistic Risk Modelling	Risk Trade -off Analysis & Deliberation necessary + Risk Balancing + 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**	

Hierarchical approach for NT risk governance

Implication Domain / Examples of RG activities / Implementation approach



International system
(Frames 1 and 2)

International agreements, partnerships, Steering groups, communication links Corrective, adaptive approach

Societal system
(Frames 1 and 2)

National R&D, policies and laws Changing institutional system Corrective, adaptive approach

Technological system
(Frames 1 and 2)

Consider R&D programs new regulations and organizations

System component
(Frames 1)

Adapting existing regulations and organizations

Key issue: reaching all levels with proper interfaces

Transforming and Responsible Development of Nanotechnology

Reaching at the building blocks of matter for manmade and living systems, and access to global information system - makes transforming tools more powerful and unintended consequences more important than for other technologies

The integration of NT with BT, IT and CT increases the transforming power and potential risks even further

In long-term, a concern is a possible instability in human development, because perturbations created at the foundation of life and of the transforming tools may have implications (perturbations) that could be difficult to be controlled (damped) after the fact; need system approach

There is a need for an anticipatory and corrective approach in

- **planning, to be both transforming and responsible**
- **in addressing societal implications for each major R&D program or project from the beginning**