Overview of Emerging Nanotechnology

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Nanotechnology

(Nanoscience and Nanotechnology)

- Definition

- World-wide Public Funding

- Evolution of Nanotechnology

Nanoscience & Nanotechnology (Nanotechnology)

Phenomena, Properties, Functions,
Ability to measure, control, and manipulate matter
In a range of 1-100 nm : *"Nano-world"*
(from atomic scale up to ~100 molecular diameter)

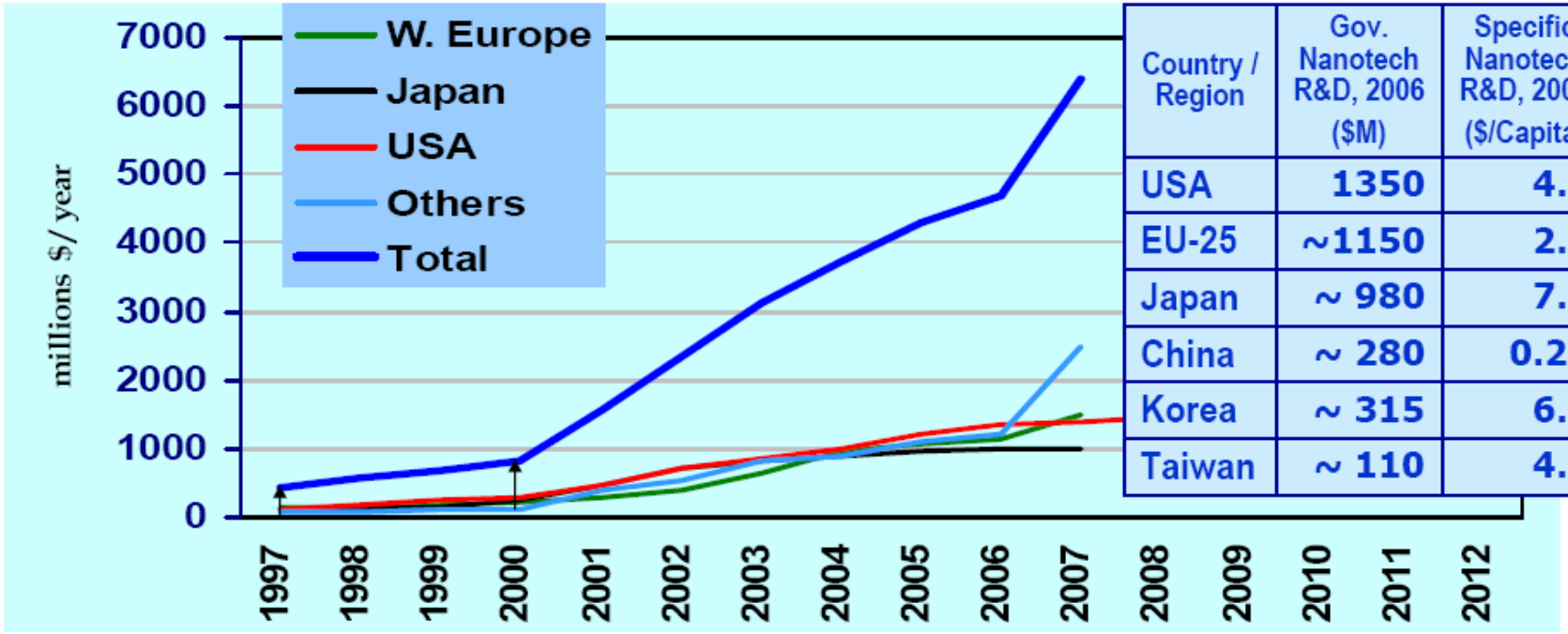
Enabling novel applications:

Nanoelectronics, Nano-biotechnology, Nano-manufacturing, NEMS, and focus will be on Food, Water, Environment, Energy, Materials

World-wide public R&D funding started in 2001, initiated by NNI (USA), and now roughly 30 countries have their own NNI's

Public R&D Funding to Nanotechnology

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

Rapid rise after 2001, and still keeps increasing

Courtesy: MC. Roco

Nanoscience & Nanotechnology before and after the Year of 2001

What's an essential difference between them?

R&D projects on nanoscience & nanotechnology from early 1980's up to 2001 / ***A challenge to nano-world within a framework of each independent discipline***

National Nanotechnology Initiatives after 2001 /
Integrative projects with huge R&D budget (Investment)
Interdisciplinary collaboration is strongly encouraged in order to create new frontiers of nanoscience & nano-technology towards "Innovation" (Funding Policy)

R&D Outcome ← Investment + Funding Policy

How to promote interdisciplinary collaboration

Evolution of Nanotechnology

First generation (~1990~) ***Independent Nano***

Access to Nano-world (1-100nm) in each independent discipline; via top-down, bottom-up or combination

TEM, STM, ALE, lithography, CNT, supra-molecule

Second generation (~2000~) ***Fusion Nano***

Interdisciplinary fusion of Nano-worlds of different disciplines

low-k material via block-copolymer process, graphene on Si, DNA transistor, nano-DDS

Third generation (~2010~) ***Integration Nano***

Integration of various Nano-worlds into functional sytems

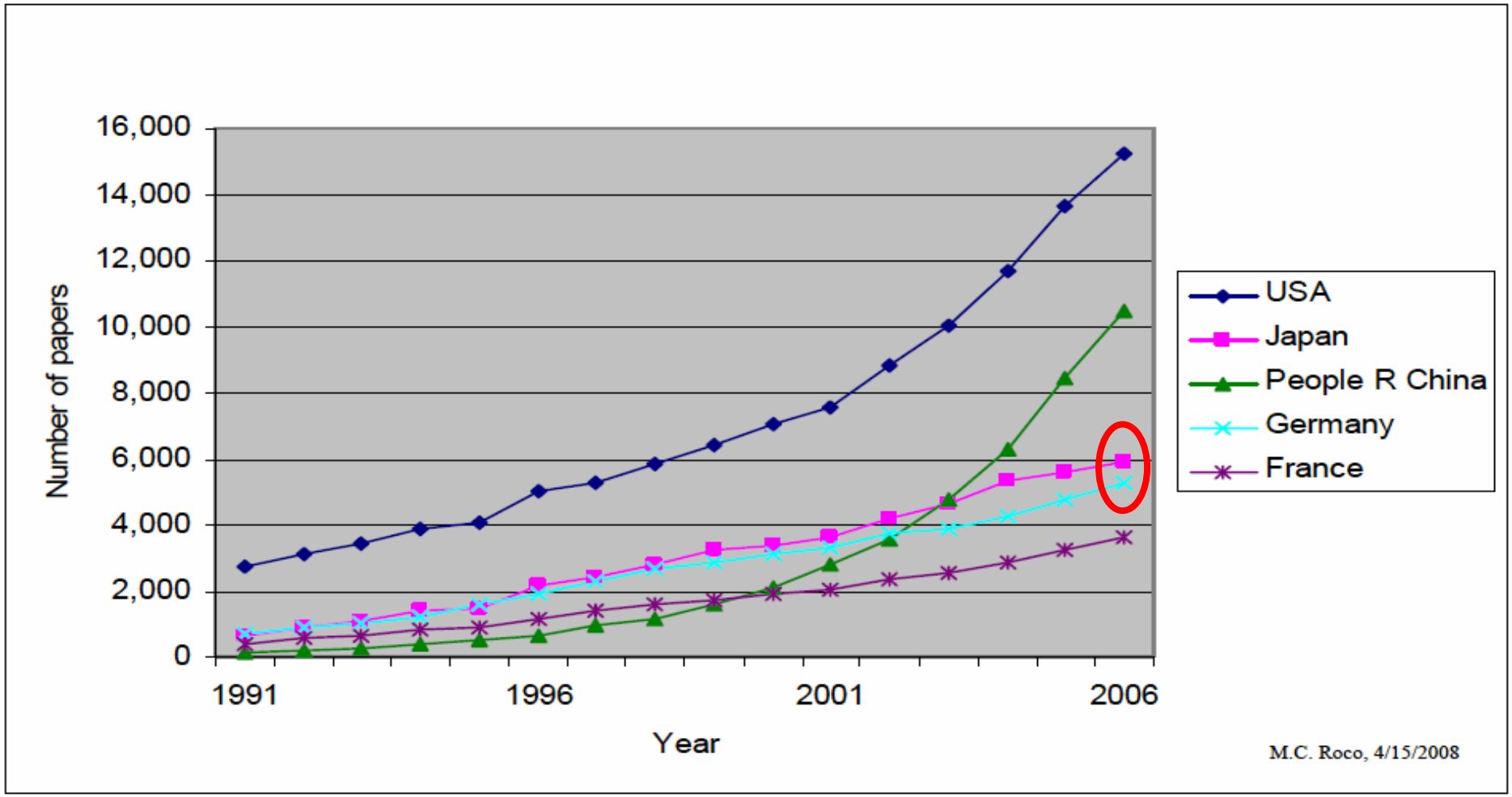
molecular E, nano-bot, hierarchical self-assembly

Interdisciplinary fusion, Integration - Key issues

Nanotechnology research publications

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

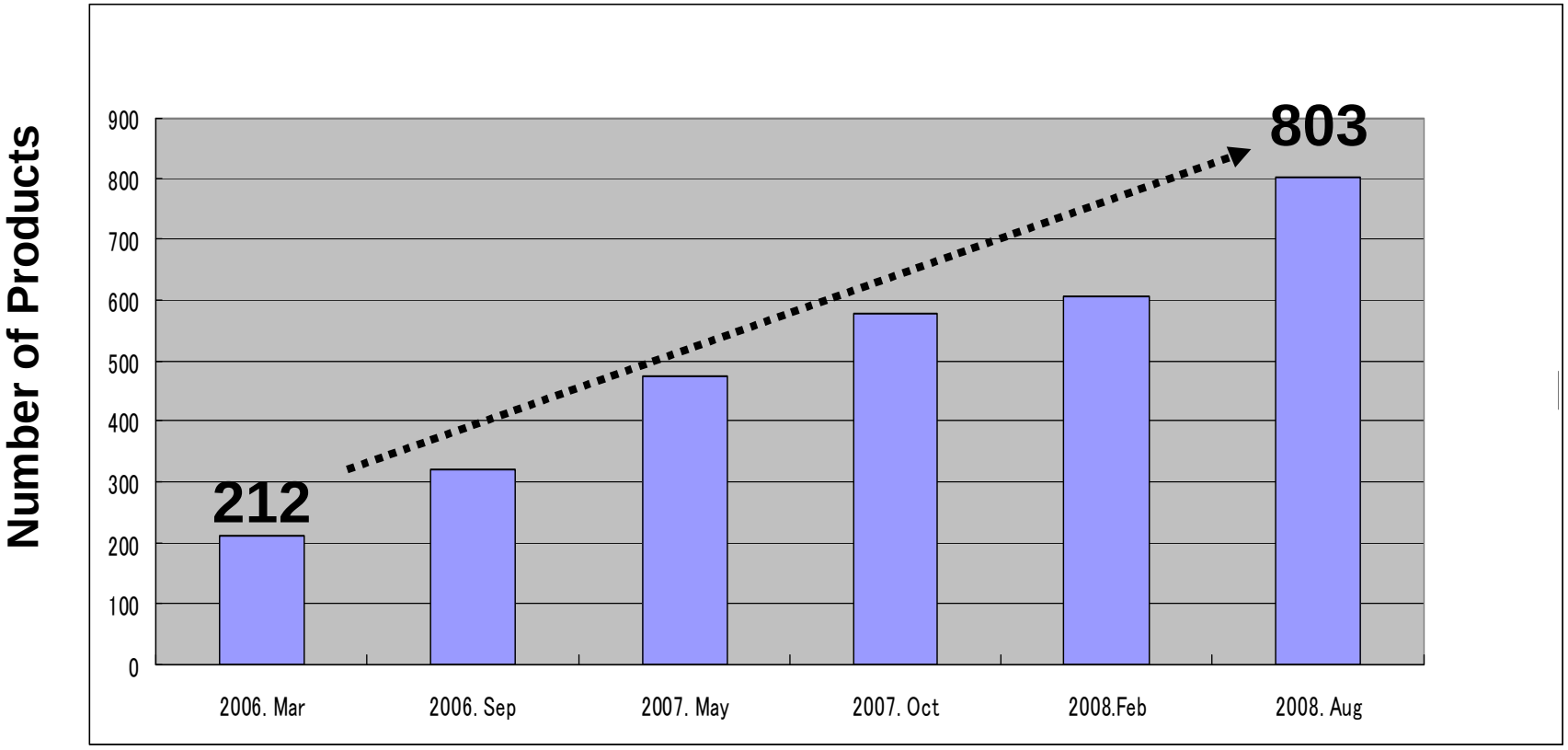
using "Title-claims" search in SCI database for nanotechnology by keywords
(using intelligent search engine, update J. Nanoparticle Research, 2004, 6 (4))



Courtesy: MC. Roco

Rapid Increase of Nanotech-Based Consumer Products

As of August 2008; the inventory has grown by nearly 279% (from 212 to 803 products) since it was released in March 2006. (Woodrow-Wilson Int'l Center)



Reference: Analysis by Woodrow Wilson International Center, 2008

Nanotechnology-based Products
Rapid increase after 2006

Nanotechnology-based goods in the world
PEN (W-W Int'l Center, USA) 803 (Aug, 2008)

Practical Use of Nanotechnology in Japan
Surveillance Study (JST-CRDS, Japan) 386 (Dec, 2007)

"Nanomark" commercial goods in Taiwan
"Nanomark" system (2005,Taiwan) >100 (Jan, 2008)

World market prediction corrected
– from US$1T to US$3.1T (in 2015)

Practical Use of Nanotechnology in Japan

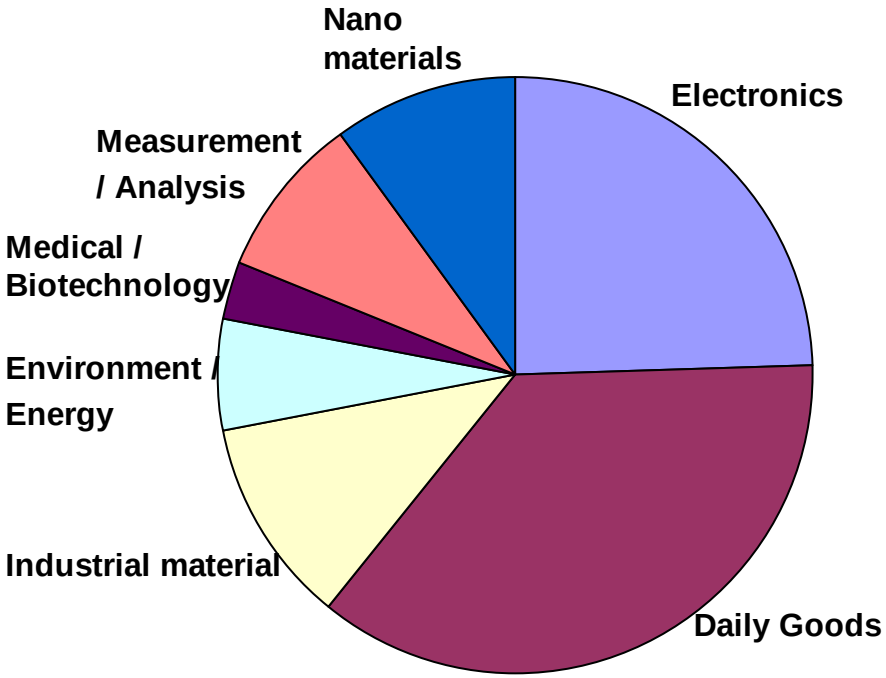
Articles on the nanotechnology published in newspapers and magazines, etc. were retrieved, and classified into "Research stage", "Development stage", and "Practical use stage".
Period covered: 2004-2007
Retrieval object: Nikkei high technology, Nikkei Nano business, weekly nanotech, and Report of Funding (NEDO/JST)

Stage	Electronics	Life	Indust. material	Environ. / Energy	Medical / Biotech	Meas./ Analysis	Nano materials	Total
R	147	41	57	56	103	43	32	479
D	201	94	113	54	39	28	60	589
Practical use	**94**	**141**	**43**	**23**	**12**	**34**	**39**	**386**
Total	442	276	213	133	154	105	130	1454

Practical use of nanotechnology (2004 – 2007)

Total 386

Daily goods 141
Electronics 94
Indust. Materials 43



From the investigation at 2008.12 by JST_CRDS

Status of Japan National R&D Program on Nanotechnology / Materialas

Courtesy: CSTP

Promotion System of S&T Policy in Japan

Image: Office of Prime Minister

Prime Minister

Cabinet Office

Minister of State for S&T Policy

Council for S&T Policy (CSTP)

Relevant ministries in S&T policy

- **MIC** Ministry of Internal Affairs and Communications
- **MEXT** Ministry of Education, Culture, Sports, S&T
  - *JSPS*
  - *JST*
- **MHLW** Ministry of Health, Labor and Welfare
- **MAFF** Ministry of Agriculture, Forestry and Fisheries
- **METI** Ministry of Economy, Trade and Industry
  - *NEDO*
- **MLIT** Ministry of Land, Infrastructure and Transport
- **MOE** Ministry of the Environment

Building an S&T Basic Plan towards the Future of Japan

1st Basic Plan (FY 1996-2000)

●Increasing R&D budget

17 trillion yen (actual expenditure 17.6 trillion).

●Structuring a new R&D system

Support plan for post-doctoral fellows, etc.

2nd Basic Plan (FY 2001-2005)

●Key policies

－Prioritization of R&D on national/social subjects

－Doubling of competitive research funds

●Total budget : **24 trillion yen (actual expenditure 21.1 trillion)**

3rd Basic Plan (FY 2006-2010)

●Key policies

- ✓ **How to nurture creative S&T human resources?**
- ✓ **Further reform of S&T systems, leading to higher performance,**
- ✓ **Strategic prioritization of R&D themes.**

***Total budget target: 25 trillion Yen (€210/$270 billion) roughly 1% of GDP**

Courtesy: CSTP

Strategic priority setting in S&T

As for policy-mission oriented R&D
4 priority promotion areas + 4 promotion areas were set up in the 2nd and 3rd S&T Basic Plans

4 priority promotion areas :

- **Life science**
- **IT**
- **Environment science**
- **Nanotechnology and Materials (FY2001~)**

The Second S&T Basic Plan (FY2001-2005)
The Third S&T Basic Plan (FY2006-2010)

Public Funding for Nanotechnology/Materials in Japan

2nd S&T Basic Plan (FY2001 - FY2005)

¥460B ／5yrs

3rd S&T Basic Plan (FY2006 - FY2010)

¥76.2B ／FY2006

¥78.6B ／FY2007

¥86.5B ／FY2008

NT&M shares 4~5% of total funding for 8 promotion areas (LS, IT, Env., NT&M, Energy, Mnf, Infra, Frtr)

Funding gradually increases since 2001, and will keep the level at least up to 2010

Progress in Nanoscience & Nanotechnology
(Japan – up to 2008)

Materials

Strongly-correlated electrons system / Transparent Amorphous Oxide Semiconductor / TiO2 photocatalysis – Commercialization / CNT – Super growth / Fe pnictide - Superconductor

Nano-biotechnology

Cell sheet Engineering – Tissue Eng. without scaffolds / Drug Delivery System (DDS)

Nano-electronics

Si technology / More Moore, More than Moore, Beyond CMOS
Spintronics – Tunneling Magneto Resistance / MRAM
Organic Electronics – EL, transistor, Solar cells
Molecular Electronics?

Further progress ← Integration & Evolution of Nanoscience & Nanotechnology

Japan National R&D Program on Nanotechnology / Materials (1)

Observations mainly from activities up to 2005FY (2nd S&T BP)

- **One of the top three countries highly contributing to Nanoscience & Nanotechnology publications and patents / Strongest in S&T of Nanomaterials**
- **Technology Strategy Road Map (METI)**
  Nanotechnology Business Road Map (NBCI)
- **Internaitonal Nanotechnology Exhibition & Conference**

  The biggest scale in the world !
- **But frustrated by slow technology-transfer of research output to new and existing industry *"Excellent scientific outcome, but some frustration in tech-transfer to innovation" – International Advisory Committee for the evaluation of JST Basic Research Program (Jan 2006)***

Policy makers complained of slow return of their investment although
It takes time before any emerging technology drives real innovation

Japan National R&D Program on Nanotechnology / Materials (2)

The 3rd Science and Technology Basic Plan (2006-10FY)

Nanotechnology / Materials － 10 Strategic S&T Priorities

①Materials for reducing costs of clean Energy, ②Materials for replacing rare or deficit materials, ③Nanotech and Materials supporting security and safety, ④Materials for innovation, ⑤Electronics for Break-through Devices, ⑥Nano-biotechnology and Nano-medical Technology for very early diagnosis, ⑦R & D for the Social Acceptance of Nanotechnology, ⑧ Advanced R & D at Innovation COE's for commercialization of Nanotechnology, ⑨Nano-measurement and Nano-Processing technology, ⑩X-ray Free Electron Lasers

Inter-ministry Projects (CSTP)

Nano-DDS, Medical use nano devices (2005 FY ~/ 2nd Basic Plan)
Responsible R&D of Nanotechnology (2007FY~/ 3rd Basic Plan)

Inter-ministry Collaborations

Materials Strategy for replacing Rare, Deficit or Toxic materials (METI / MEXT 2006FY~)
Nanoelectronics (METI / MEXT 2007FY~)

Inter-ministry coordination – being improved

Japan National R&D Program on Nanotechnology / Materials (3)

Social Acceptance (Responsible R & D)

Project " Standardization of Nanoparticle Risk Evaluation Method "
2005-2007FY/ METI, AIST

Project "Facilitation of Public Acceptance of Nanotechnology "

2005FY / MEXT, METI, MHLW, MOE

NEDO Project "Risk Assessment & Management of Manufactured

Nanomaterials" 2006-2010FY / AIST , Univs , Industry / US$ 20M

Late start, but running under strong inter-ministry collaboration
Coordinated by CSTP

User Facilities Network

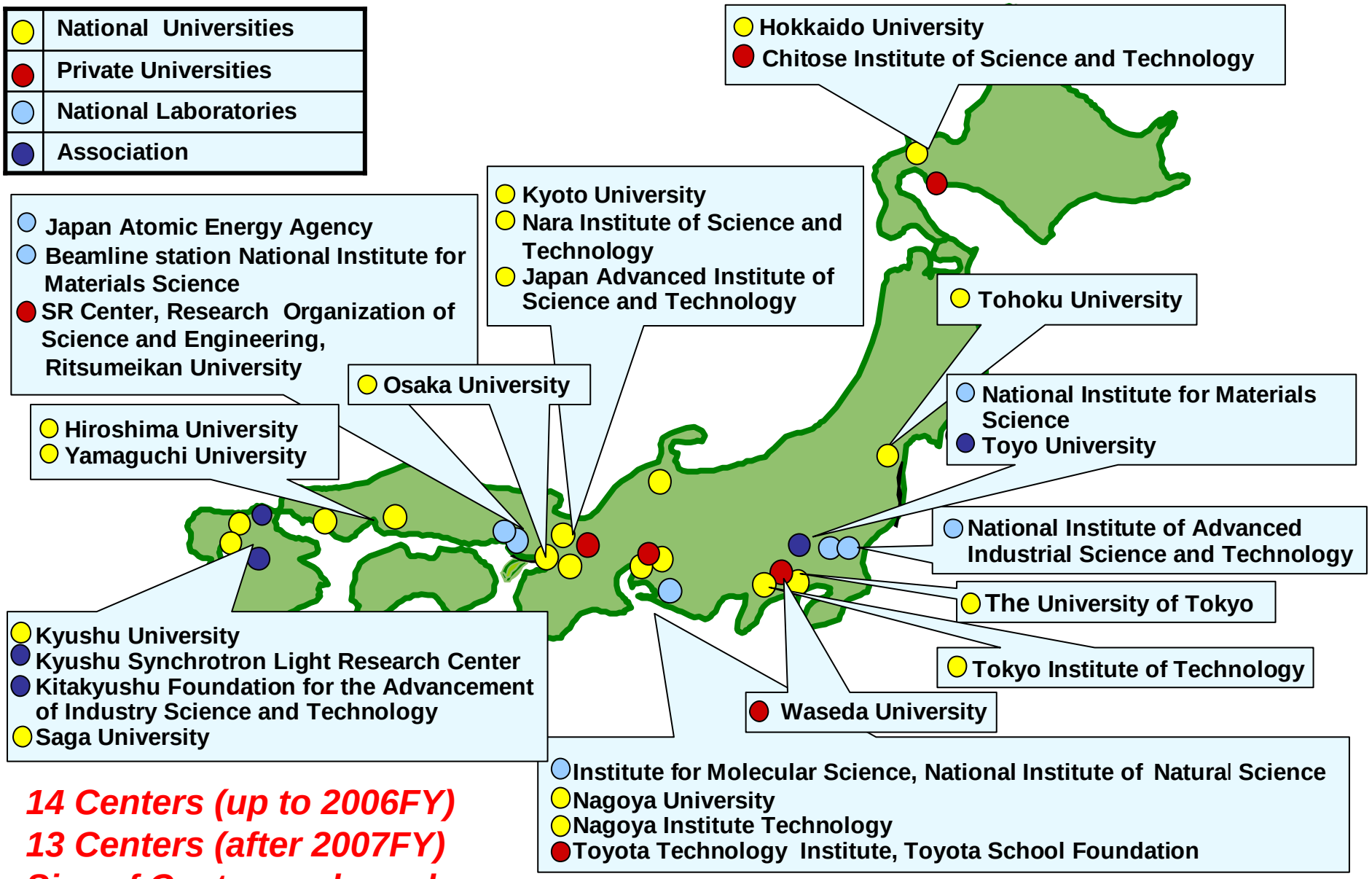
Nanotechnology Support Project (MEXT／2002-2006FY)
14 Centers／open facilities／no charge system／US$2M/Y
Encouraging new SME's to participate in Nanotechnology
Not enough for accelerating interdisciplinary collaboration
Charge system started in the second phase (2007~)

Social Acceptance, User Facilities – most important components, but funding is not enough

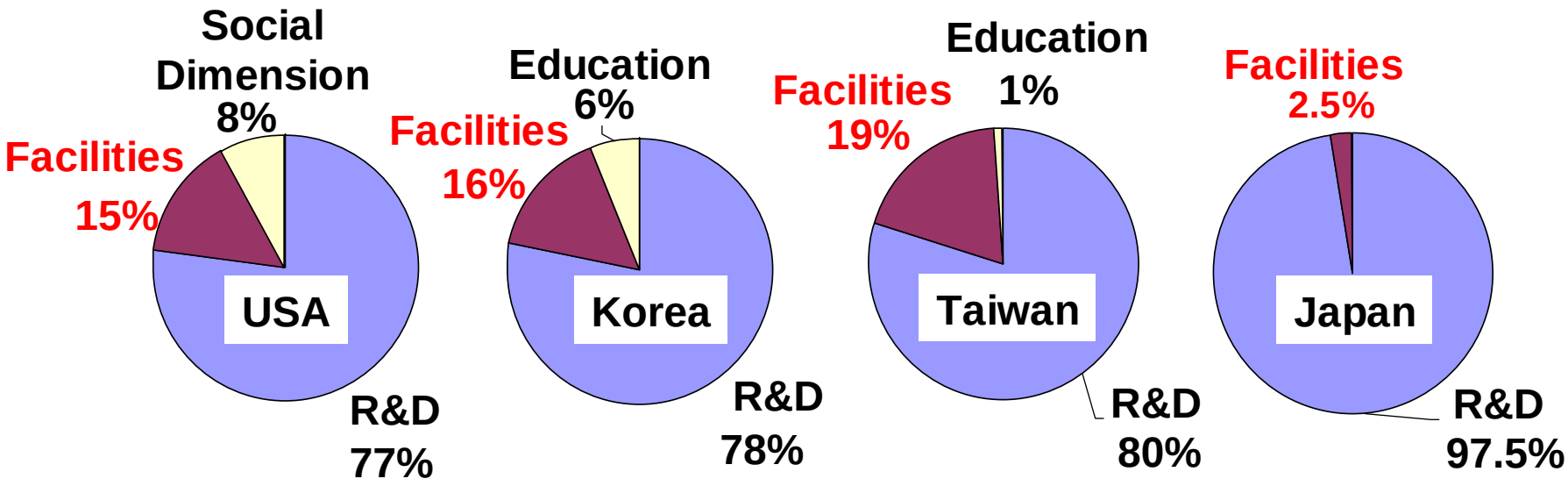
User Facilities and R&D Centers

- **Interdisciplinary fusion**
- **Academia / Industry collaboration**

Nanotechnology Users Network in Japan



14 Centers (up to 2006FY)
13 Centers (after 2007FY)
Size of Center : enlarged



（※USA, Japan: FY2001-2005, Korea: FY2001-2007, Taiwan: FY2003-2008）

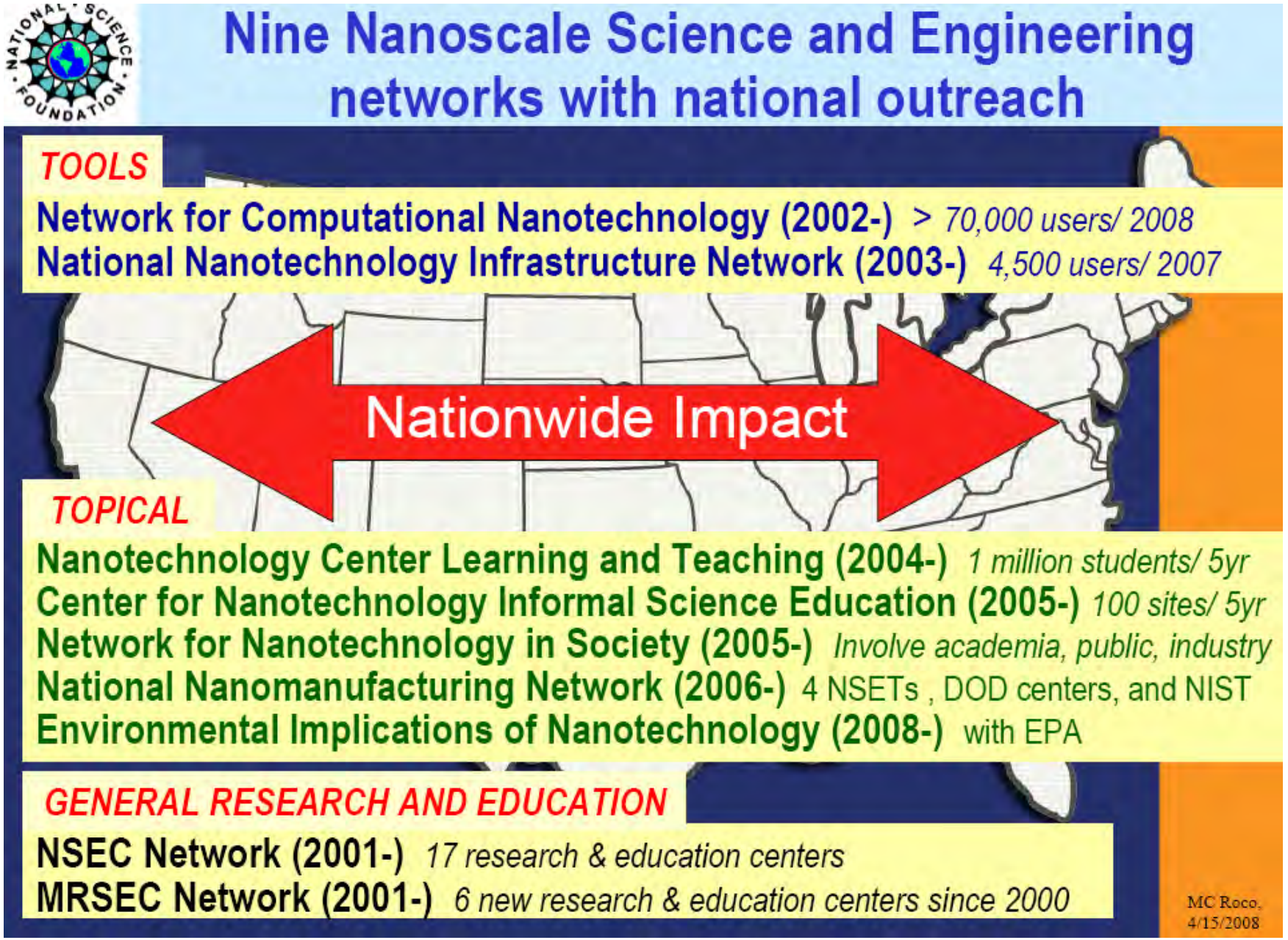
Revenue of Nanotech. User Facilities

Countries	Government (%)	Charging System (%)	Mat.Fund. From Reg. Gov. (%)	Consortium Donation (%)
USA(NNIN 13centers)	30	30	40	
Korea(KANC)	30	7	58	5
UK(MNT Network)	50	50		
Japan(14centers)	100	-	-	-

※Numbers in Table: Fraction(%) of total Revenue

Strategic Investment to Facilities / Accelerating Interdisciplinary Collaboration
Multi-Funding System needed for Sustainable Operation of User Facilities

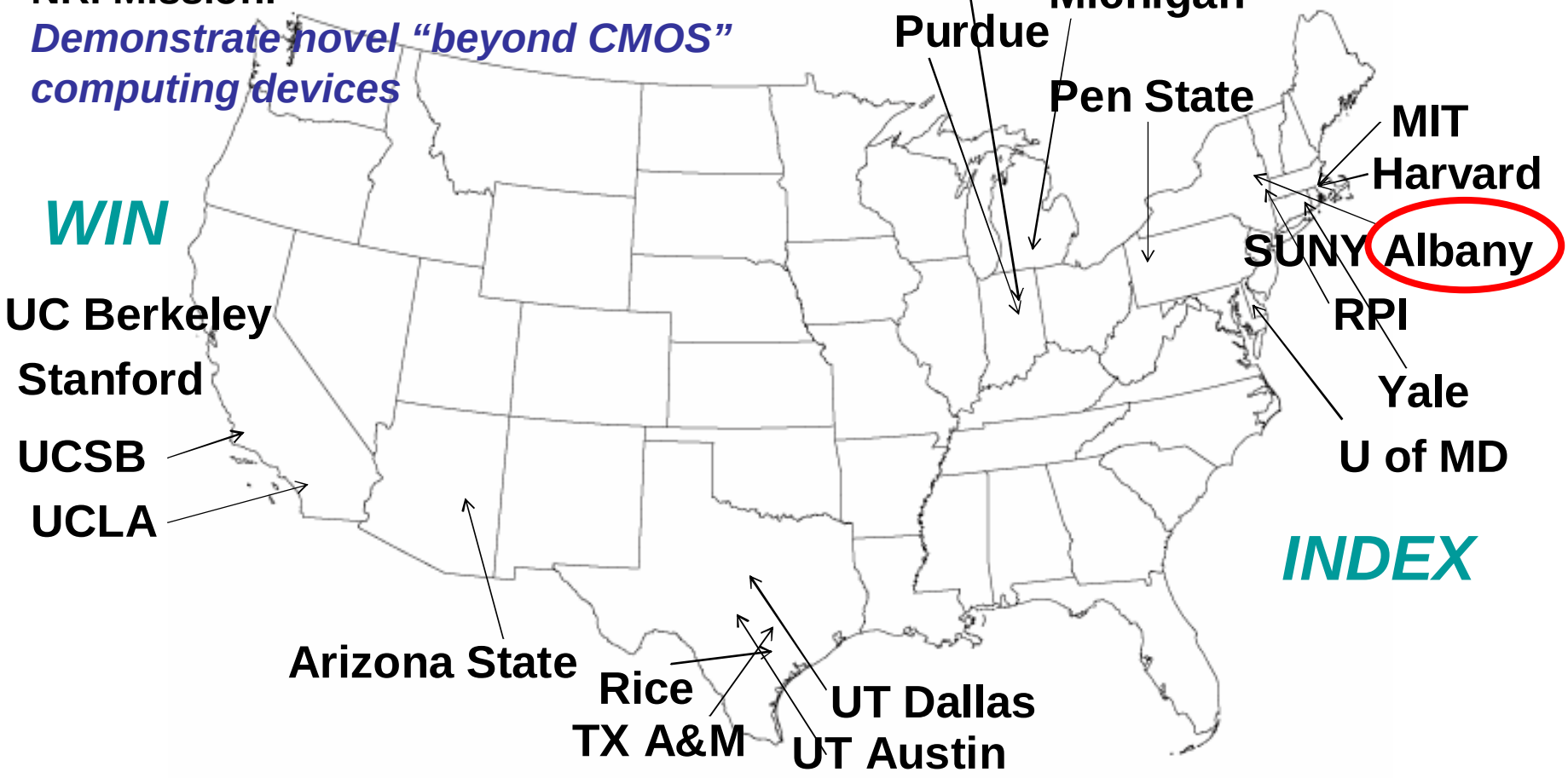
Nine Nanoscale Science and Engineering networks with national outreach



Courtesy: MC. Roco

NRI Funded Universities

NRI Mission:
Demonstrate novel "beyond CMOS" computing devices



Industry-Gov-Academia Allience (35 univs)

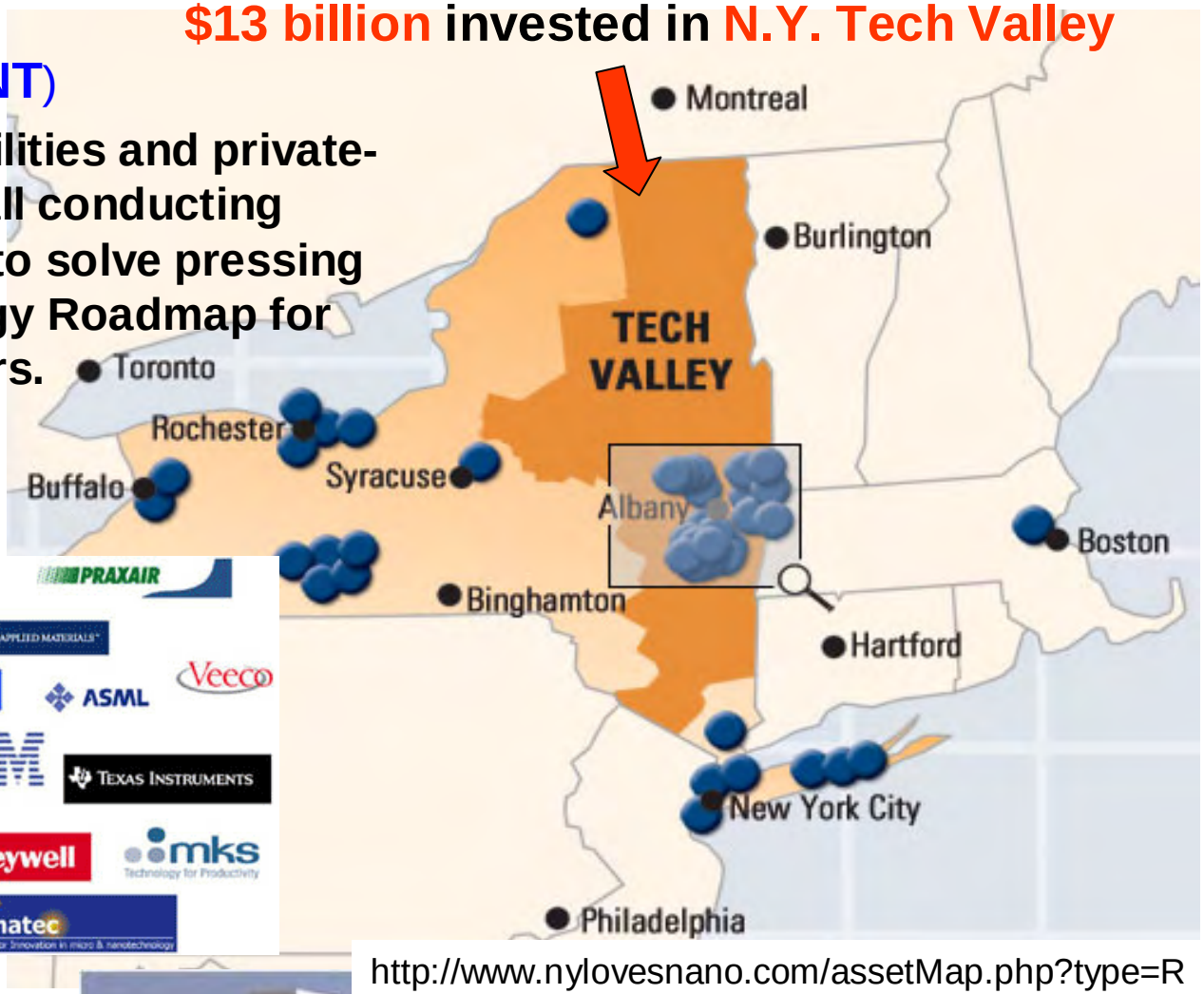
Four Institutes (21 states)

New York is the Premier Location for Nanotech

$13 billion invested in N.Y. Tech Valley

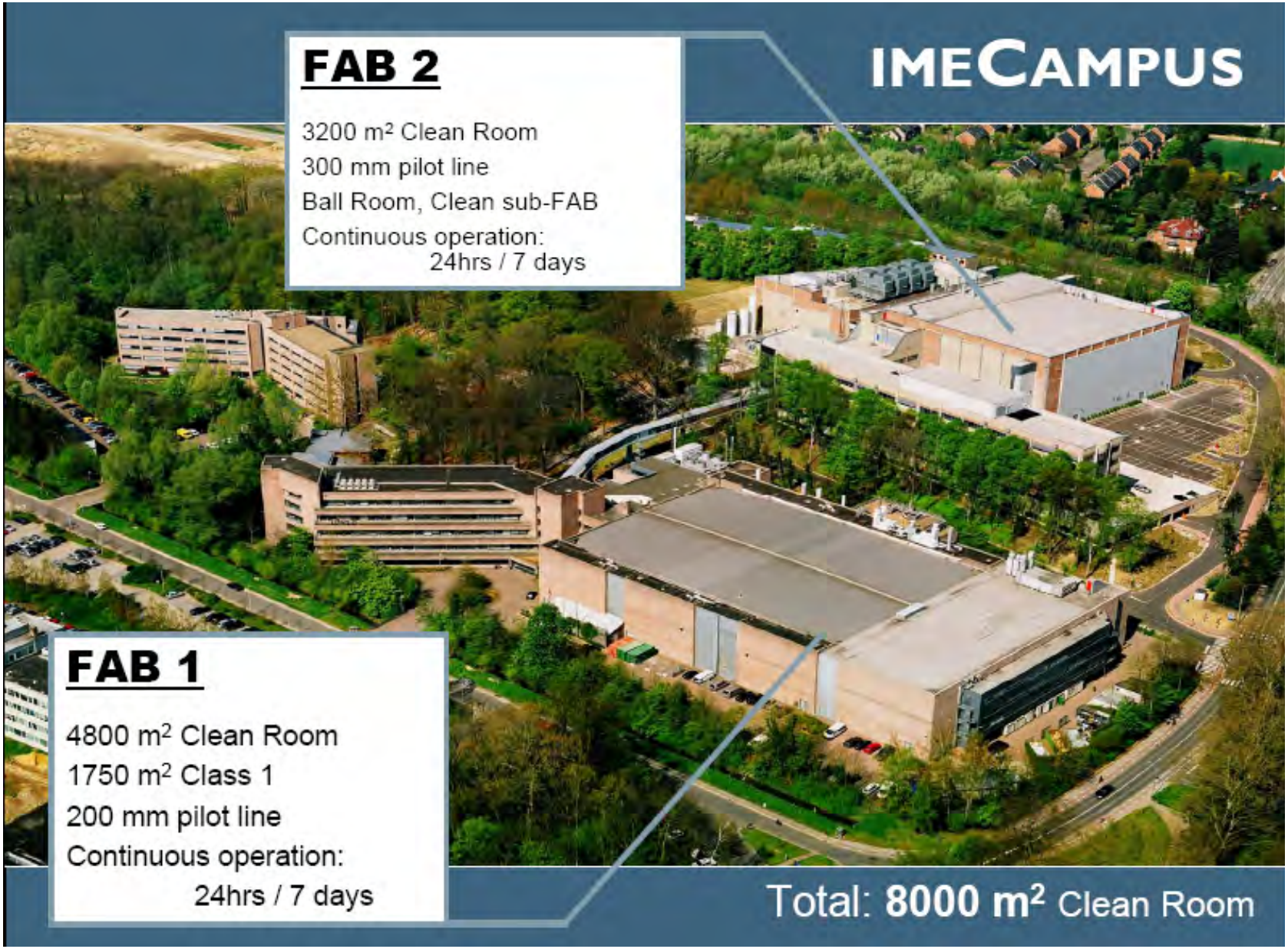
Albany NanoTech (ANT)

Universities, public facilities and private-sector companies are all conducting leading-edge research to solve pressing International Technology Roadmap for Semiconductors barriers.



http://www.nylovesnano.com/assetMap.php?type=R

CNSE

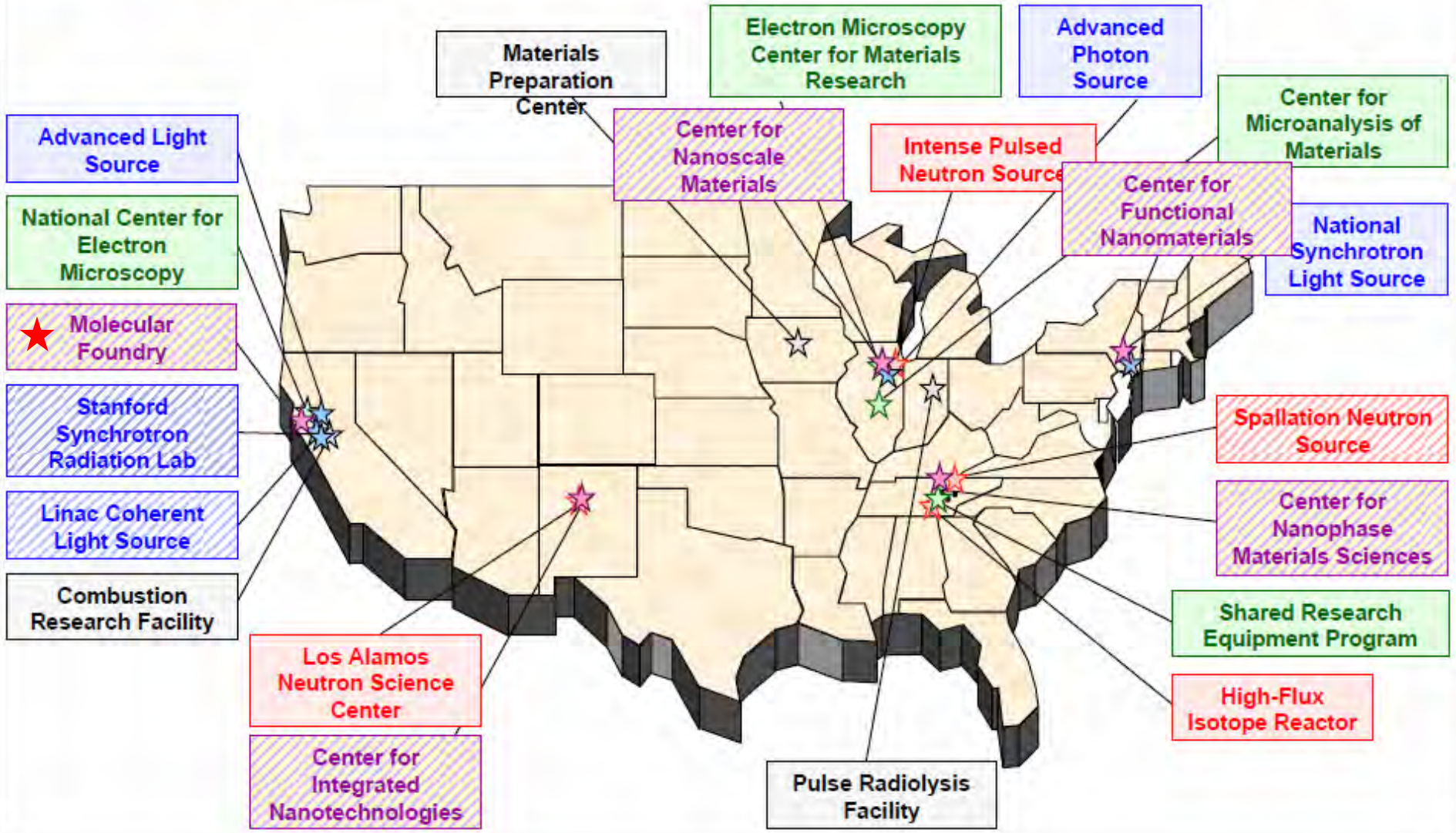


Courtesy: R. DeKeersmaecker

IMEC Partner Update 2008

Courtesy: R. DeKeersmaecker

Department of Energy Scientific User Facilities



Coutesy: MC. Roco

M.C. Roco, 11/01/2007

Molecular Foundry（NSRC／NNI／2005）

Steven Chu, Sixth Director of Lawrence Berkeley National Laboratory, DOE
Steven Chu, 57,

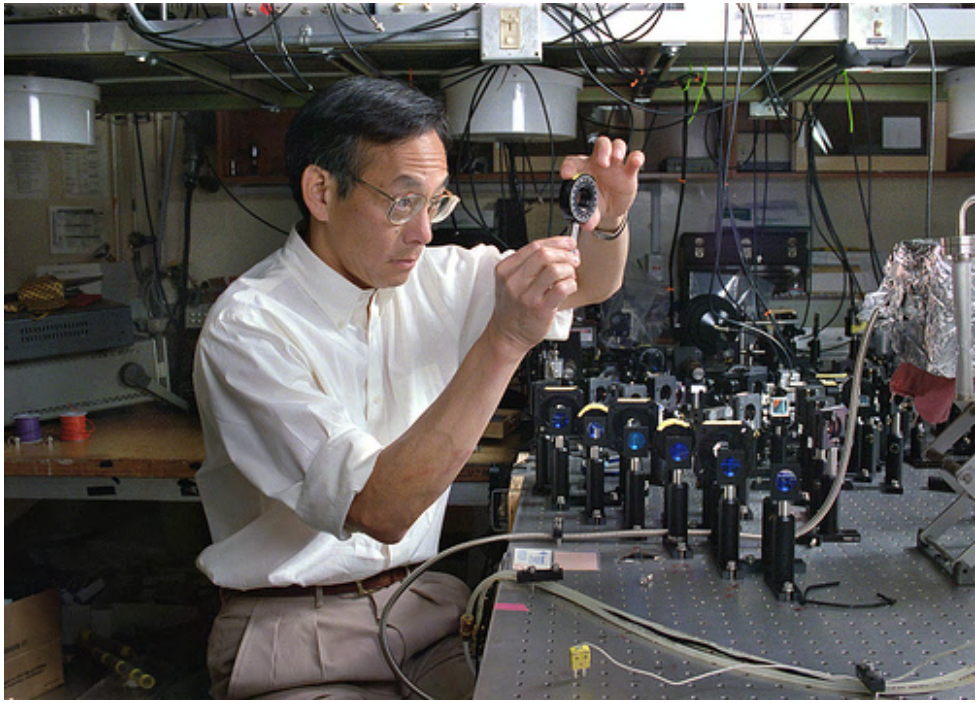
http://foundry.lbl.gov/

User facility for nano-scale science open to every sector
Molecular Foundry／Synthesis, characterization and theory for nano-scale materials／Integration into larger functional complex
Interdisciplinary R&D of soft and hard materials, lithography

Under one roof ***Mutual understanding***

Obama's Remarkable Choice for Energy Secretary

This is a signal Obama's administration will "value science".
"We will make decisions based on the facts, and we understand that facts demand bold action," Obama said.

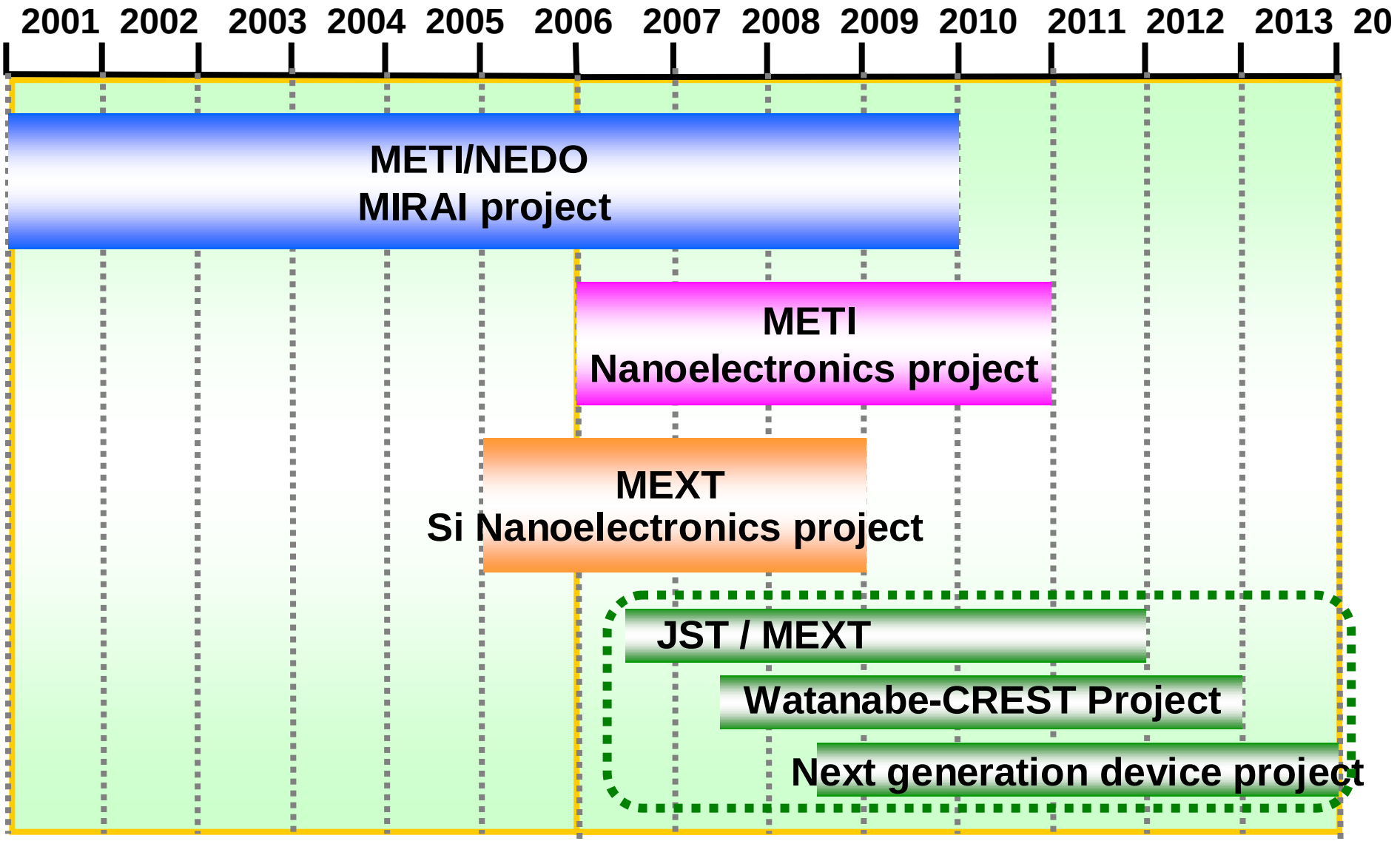


Steven Chu

http://wonkroom.thinkprogress.org/2008/12/10/steven-chu-new-energy/

Berkeley Lab Director Steven Chu shared the 1997 Nobel Prize in Physics for "development of methods to cool and trap atoms with laser light."

Government funding projects



Courtesy: H. Watanabe

<Draft Concept>

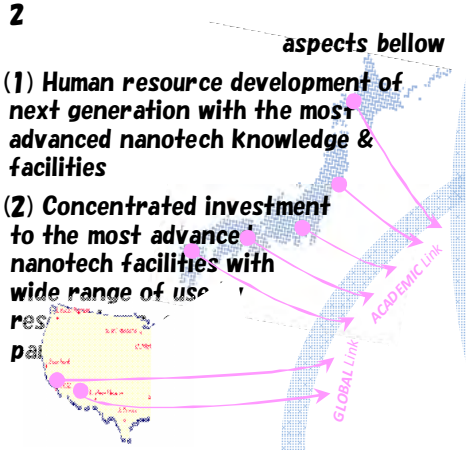
Nanotech Research Competence in Tsukuba & New Framework of Public-Private Collaboration for Nanotech Driven Innovation

✔ MEXT & METI's joint initiative, working together with relevant u[illegible] si[illegible] & industries and the Cabinet office, CSTP

✔ Mutually beneficial Tie-Up with [illegible]versities to be developed, [illegible]operated with MEXT, especially taking account of the 2 aspects bellow

(1) Human resource development of next generation with the most advanced nanotech knowledge & facilities

(2) Concentrated investment to the most advanced nanotech facilities with wide range of use[illegible] res[illegible] pa[illegible]



✔ International research cooperation promoted, s[illegible] for innovative front edge

NIMS

National Institute for Materials Science

物質 molecular → 材料 material → 部材 device/component → 製品 product

*

National Institute of Advanced Industrial Science &Technology

AIST

- Japan's sole National Institute specializing in materials science, principally funded by MEXT (Ministry of Education, Culture, Sports, Science & Technology).
- All 450 researchers involved in various fields of materials science, based on the concept of "Nanotechnology-Driven Materials Science for Sustainability".
- World's top level research facilities such as Ultra-High Voltage Electron Microscopes, High Magnetic Field (37.3 Tesla) and Solid-State NMR (930MHz).
- Top research organization in Japan as for the number of published papers on materials science per one researcher.
- Press on with globalization and fostering researchers as a world-leading research center.
- One of the Centers of Advanced Nanotechnology Network (NIMS Center for Nanotechnology Network)

- Japan's largest National Institute with 2400 researchers conducting research from the base to the application on various fields of industrial technology, principally funded by METI (Ministry of Economy, Trade & Industry).
- About 800 researchers involved in Nanotechnology driven field (Nano-electronics , Nano-photonics, Nano-materials etc.), based on the concept of "Integration for Innovation".
- More than 10 clean rooms, such as the super clean room (SCR:4500m^2) under Millennium Research for Advanced Information Technology (MIRAI) project, collaborated with the private consortium "Selete" and various clean rooms essential for a wide range of Nanotech-driven-research (Silicon, Inorganic and Organic Devices, MEMS etc.)
- One of the Centers of Advanced Nanotechnology Network (Nano-Processing Partnership Platform)

930 MHz NMR

UHV TEM

Selete

4500m^2(class 3) CR

Nano-Processing Facility

Gross area : 600m^2

Power Electronics Research Center

Two 300m^2 CRs and 100m^2 CR

International Center for Materials Nanoarchitectonics

NIMS Nanotechnology Support Network

NPP NanoProcessing Partnership Platform

✔ Essential Nonotech-facilities, such as SCR, to be renovated to highly energy efficient & all-around test device foundry, funded by METI (2009 budget request)

✔ International joint research on advanced Nano-electronics of 1M$ to be globally offered by AIST (2009 budget request)

✔ Next stage R&D programs, especially Nano-electronics, to be launched in 2010 by the new public-private framework based on study w[illegible] COCN Council on Competitiveness-Nippon industries, such as COCN

✔ Research Association Law to be amended in 2009 to promote open-innovation type of R&D consortium NANOTECHNOLOGY BUSINESS CREATION INITIATIVE

✔ Nano-material safety reseach program to be proposed in 2010 internationally by AIST, jointly worked with NBCI

✔ Nano-tube joint R&D program to be proposed by AIST in 2010 as its core competence

Cluster of Research Labs of Naonotech Leading Companies In TSUKUBA

NEC Corporation Tsukuba Research Laboratories

Texas Instruments Japan Tsukuba Technology Center (TRDC)

Intel K.K. Tsukuba

ULVAC JAPAN, Ltd. Tsukuba Institute for Super Materials

JSR Corporation Tsukuba Research Laboratories

Hitachi Chemical Co.,Ltd.Tsukuba Research Lab

Mitsubishi Chemical Group Science & Technology Research Center, Inc. Tsukuba Area

KURARAY CO., LTD. Tsukuba Research Laboratories

Astellas Pharmaceutical Inc., Tsukuba (Miyukigaoka, Toukoudai)

Sumitomo Chemical Co., Ltd. Tsukuba Research Laboratory

Courtesy: R. Doi (METI)

Summary

Nanotechnogy

World-wide Investment (public and private) keeps increasing from $9.5B (2005) up to $14.9B (2008)
Nanotech-based goods – rapid increase after 2006

Now in the second generation (Fusion Nano)
Towards the third generation (Integration Nano)

User Facilities and R&D Open Centers are crucially Important for promoting and accelerating inter-disciplinary fusion and integration of various types of nanoworlds developed independently.

Nano-electronics

IMEC, Albany, NRI, ・・・, New R&D center in Japan?

YES, WE CAN