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International Perspective on Government Nanotechnology Funding in 2005

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Abstract
The worldwide investment in nanotechnology research and development (R&D) reported by national government organizations and EC has increased approximately nine-fold in the last eight years - from $432 million in 1997 to about $4,100 million in 2005. The proportion of national government investments for: academic R&D and education are between 20% (Korea, Taiwan) and 65% (U.S.), industrial R&D - between 5% (U.S.) and 60% (Korea, Taiwan), and core facilities and government laboratories - about 20-25% in all major contributing economies. This evaluation uses the NNI definition of nanotechnology (that excludes MEMS or microelectronics), and is based on direct information and analysis with managers of nanotechnology R&D programs in the respective countries.

Keywords: Research and development programs, nanoscience, nanoengineering, international survey

Nanotechnology outlook in the interval 2000-2020

The emerging fields of nanoscale science, engineering, and technology – the ability to work at the atomic, molecular and supramolecular levels, to create large structures with fundamentally new properties and functions - are leading to unprecedented understanding and control over the basic building blocks of all natural and man-made things. We estimate the rapid advancement of nanotechnology in both foundational knowledge and creating the infrastructure for application areas between 2000 and 2020. This is similar to the transition from exploratory concepts to broad applications in information technology between 1960 and 2000, and in biotechnology between 1980 and about 2010. We have identified four generations for nanotechnology products (Figure 1) (Roco, 2004): passive nanostructures, active nanostructures, systems of nanosystems, and molecular nanosystems. The worldwide focus in the first five years since the announcement of the U.S. National Nanotechnology Initiative (2001-2005) was on basic discoveries and production of passive nanostructures, such as relatively simple components of nanosized particles, nanotubes and nanolayers. The main transition in 2005 is toward active nanostructures and nanosystems. An active nanostructure changes its state (morphology, shape, mechanical, electronic, magnetic, photonic, biological, etc.) during its operation. To illustrate, a mechanical actuator can change its dimensions, and nanoparticles for drug delivery can change their morphology and chemical composition. The new state may be the subject of other successive changes. Such changes are more complex as the structures and systems are larger and involve multiple phenomena. Examples of active nanostructures are: nanoelectromechanical systems (NEMS), nanobiodevices, transistors, amplifiers, targeted drugs and chemicals, actuators, molecular machines, light-driven molecular motors, plasmonics, nanoscale fluidics, laser-emitting devices, adaptive nanostructures, energy storage devices, and sensors changing their state during the measurement.

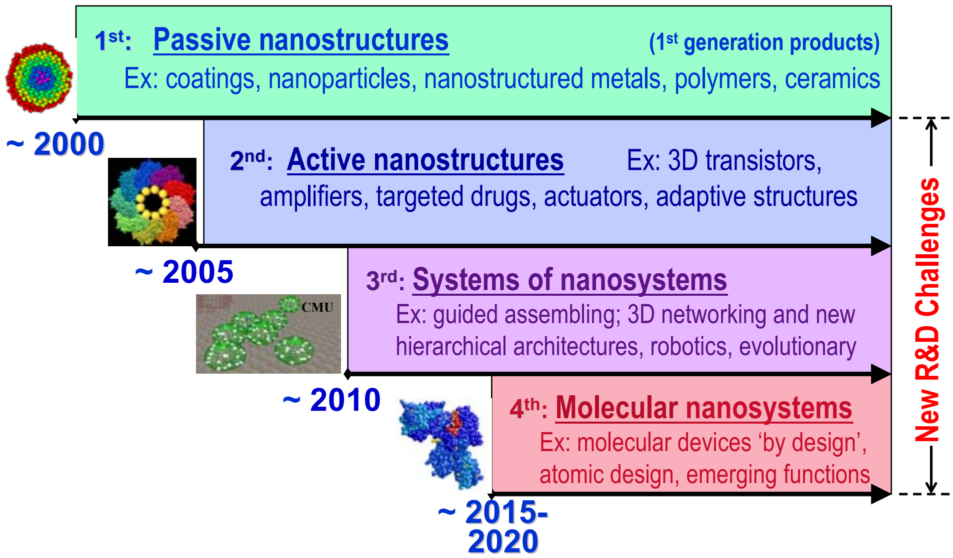

Figure 1. Four generations of products: timeline for beginning of industrial prototyping and nanotechnology commercialization

$1 billion products incorporating nanotechnology by 2015

In 2000, we estimated $1 trillion worth of products worldwide will incorporate nanotechnology in key functional components by the year 2015 (NSF estimation in 2000; Roco and Bainbridge, 2001). The corresponding industries would require about 2 million workers in nanotechnology, and about three times as many jobs in supporting activities. These estimates were based on a broad industry survey in Americas, Europe, Asia and Australia, and continue to hold in 2005. The current forecasts made by Mitsubishi Research Institute (Japan), Deutche Bank (Germany), Lux Research (U.S.) and other organizations support the estimated $1 trillion by 2015. The Lux Research data do not include current nanoscale applications in electronics and catalysts. The R&D areas of focus are shifting progressively as suggested in Figure 2. After five years of NNI, the R&D challenges have been extended from single components and passive nanostructures toward devices and complex nanosystems.

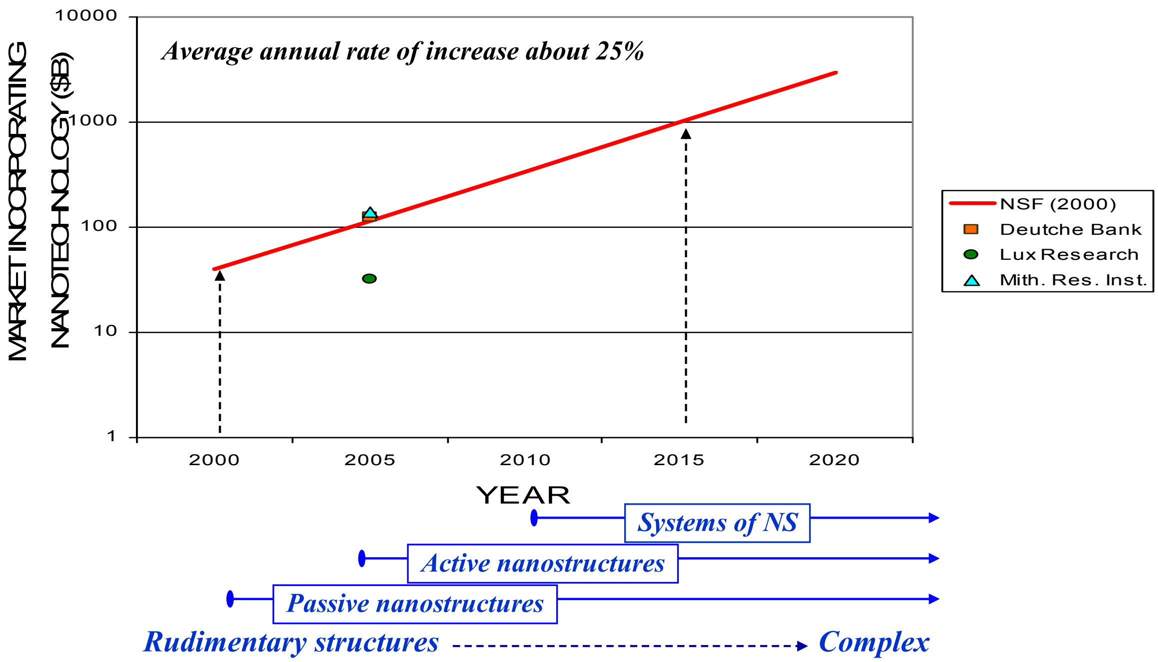

Figure 2. Worldwide market affected by nanotechnology (estimation made in 2000)

Worldwide R&D investments

The worldwide investment in nanotechnology research and development (R&D) reported by government organizations has increased approximately nine-fold in the last eight years (Table 1 and Figure 3), from $432 million in 1997 (Siegel, Hu and Roco, 1999) to about $4.1 billion in 2005. At least 60 countries have initiated activities in this field. Scientists have opened a broad net of discoveries that does not leave any major research area untouched in the physical, biological, and engineering sciences. Industry has gained confidence that nanotechnology will bring competitive advantages.

Table 1. Estimated Government Nanotechnology R&D Expenditures, 1997-2004 ($ Millions/Year). Explanatory notes: National and EU funding is included. The EU+ includes countries in EU (15)/EU(25) and Switzerland (CH): the rate of exchange $1 = 1.1 Euro until 2002, = 0.9 Euro in 2003, and = 0.8 Euro in 2004-2005; Japan rate of exchange $1 = 120 yen until 2002, = 110 yen in 2003, = 105 yen in 2004-2005; "Others" includes Australia, Canada, China, Eastern Europe, FSU, Israel, Korea, Singapore, Taiwan, and other countries with nanotechnology R&D;

* A fiscal year (FY) begins in the USA on October 1, and in most other countries six month later around April 1.

** Denotes the actual budget recorded at the end of the respective fiscal year;

Estimates use the nanotechnology definition as defined in the NNI (this definition does not include MEMS, microelectronics, or general research on materials) (see Roco, Williams and Alivisatos, 2000, Springer, former Kluwer, also on http://nano.gov), and include the publicly reported government of allocations spent in the respective financial years.

Region	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005 (est.)**
EU +	126	151	179	200	~ 225	~ 400	~ 650	~ 950	~1050
Japan	120	135	157	245	~ 465	~ 720	~ 800	~ 900	~ 950
USA*	116**	190**	255**	270**	465**	697**	862**	~ 989	1081
Others	70	83	96	110	~ 380	~ 550	~ 800	~ 900	~1000
Total (% of 1997)	**432** (100%)	**559** (129%)	**687** (159%)	**825** (191%)	**1,535** (355%)	**2,367** (547%)	**3,112** (720%)	**3,739** (866%)	**4,081** (945%)

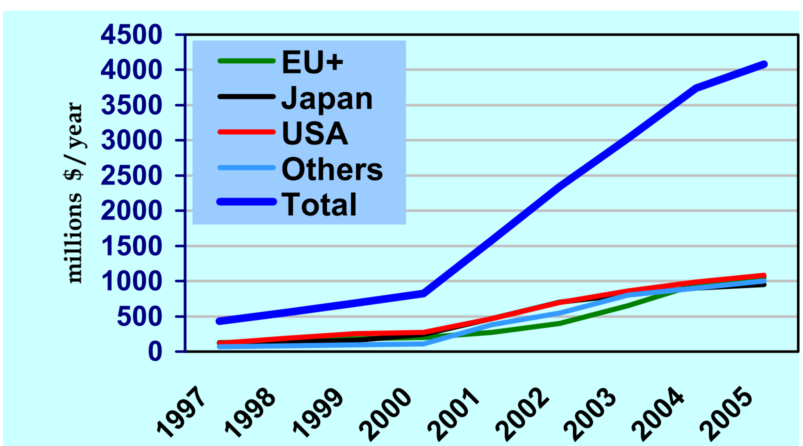

Figure 3. National government (and EU) investments in nanotechnology R&D in the past nine years (1997-2005) (see Table 1)

The Unites States, Japan, and European Union have about the same annual government investment for nanotechnology R&D - approximately $1 billion U.S. (see Table 1). Six major contributors to nanotechnology R&D are listed in Table 2. The specific nanotechnology R&D per capita in 2004 is the highest in Japan ($7.1/capita), followed by Korea ($6.1/capita), Taiwan ($4.7/capita), U.S. ($3.4/capita), EU ($2.1/capita) and China ($0.2/capita). The highest specific nanotechnology R&D per GDP is in Korea ($350/$M GDP).

Country/ Region	Population in Millions	GDP in $T	Growth (%)	Per Capita GDP in $10^3$$	Research % of GDP†	**Government Nano R&D 2004 ($M)**	**Specific Nano R&D 2004 ($/Capita)**	**Specific Nano R&D 2004 ($/$M GDP)**
USA	**293**	**11.0**	**3.1**	**37.5**	**2.8**	**989***	**3.4**	**90**
EU-25	**456**	**11.1**	**1**	**24.3**	**1.9**	**~ 950**	**2.1**	**86**
Japan	**127**	**3.6**	**2.7**	**28.3**	**2.9**	**~ 900**	**7.1**	**250**
China	**1,300**	**6.45**	**9.1**	**5.0**	**~ 1.0**	**~ 200**	**0.2**	**31**
Korea	**48.6**	**0.86**	**3.1**	**18.0**	**2.7**	**~ 300**	**6.1**	**350**
Taiwan	**23**	**0.53**	**3.2**	**23.0**	**2.3**	**~ 110**	**4.7**	**208**

Table 2. Global Research Investment in Nanotechnology by national governments and EU-25 (2004). Note: GDP data are Purchasing Power Parity estimates for 2003 (after ATIP, 2005);
(*) Excludes the Congressionally directed budget of $103M to DOD in FY 2004 (after NNI, 2005); Exchange Rates: $1= 105 Yen (Japan); $1= 8.2 Yuan (China); $1= 1100 Korean won; $1= NT $ 34 (Taiwan)

Differences among countries are observed not only in the level of investment, but also in the structure of the investment (Table 3), nanotechnology research domain they are aiming for, level of program integration into various industrial sectors, and the time scale of their R&D targets. Several countries (beginning with Japan, Korea and China) have adopted coordinating offices at the national level similar to the National Science and Technology Council (NSTC) in the United States. Nanotechnology is growing in an environment where international interactions accelerate in science, education and industrial R&D. International activities and agreements have increased in importance in the last years because of multidisciplinary and accelerating rate of development, as well as global knowledge generation and global markets. Examples are the agreements are between NSF (U.S.) and EC (EU), NSF (U.S.) and MEXT/METI (Japan), within Asia Pacific Economic Council (APEC), between Russia and China, and between the states of New York (U.S.) and Quebec (Canada).

	Academic R&D and education	Core facilities and gov. lab. infrastructure	Industrial R&D
U.S. NNI	65%	25%	10%
Germany	45%	25%	30%
Japan	45%	25%	30%
China, Beijing	30%	20%	50%
China, Taiwan	20%	20%	60%
Korea	20%	20%	60%

Table 3. Estimated government investment structures for nanotechnology R&D by country, 2004 (rounded within 5%)

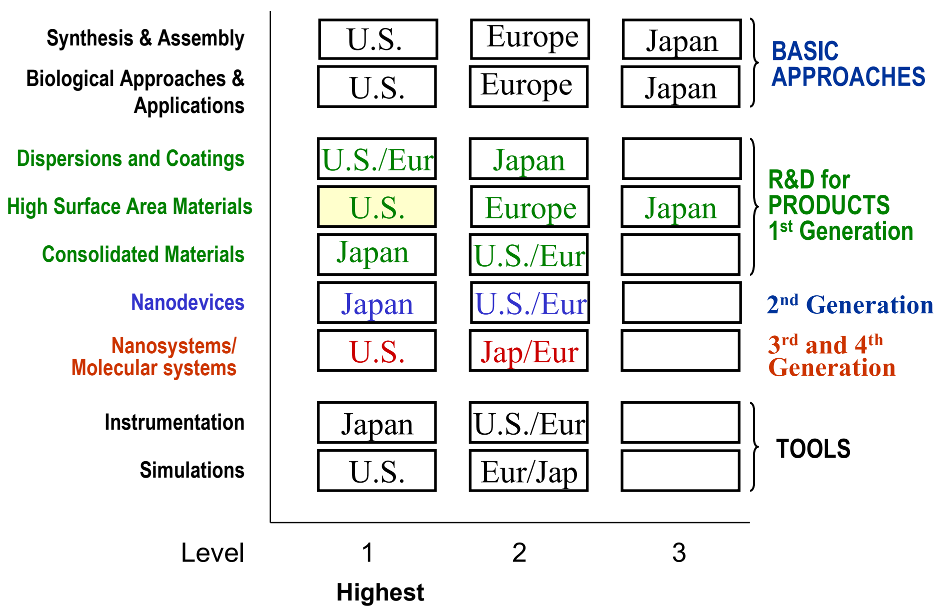

Figure 4. Technological comparison between EU, Japan and U.S. in 2005 (extension of initial WTEC evaluation in 1999)

The international benchmarking published in 1999 (World Technology Evaluation Center Report; Siegel, Hu and Roco, 1999) led to a technological comparison of three leading regions in nanotechnology R&D: EU, Japan and U.S. We have updated that comparison for 2005 by including new categories corresponding to the four generations of nanotechnology products (Figure 1), and directly surveying the experts at professional and individual meetings. U.S. is relatively well positioned in fundamental synthesis, molecular assembly and biological approaches (Figure 4). There is a relative balance in the first generation of nanotechnology products among Europe, Japan and U.S., while Japan seems to have a better position for the second generation (active nanodevices) and U.S. for the third and fourth generations (complex nanosystems). Concerning nanotechnology tools, Japan is higher ranked by experts for instrumentation, and U.S. has a lead in modeling and simulations. U.S. has the highest number of nanotechnology patents and start-up companies followed by Japan and Germany. The largest number of nanotechnology articles originates in order from Europe, U.S. and Japan, while the nanotechnology articles with high citation index originate in order from U.S., Europe and Japan.

The United States FY 2005 funding and FY 2006 request for nanotechnology R&D in eleven federal departments and independent agencies is summarized in Table 4 (www.nano.gov; www.nsf.gov/nano). It is noted that the FY 2005 budget ($1,081 million) is four times larger than in FY 2000 ($270 million). In the interval 2001-2005, the United States has emphasized long-term, fundamental research aimed at discovering novel phenomena, processes, and tools; addressing NNI Grand Challenges; supporting new interdisciplinary centers and networks of excellence including shared user facilities; supporting research infrastructure; and addressing research and educational activities on the societal implications of advances in nanoscience and nanotechnology.

Table 4. Contribution of key federal departments and agencies to NNI investment*

Federal Department or Agency	**FY 2000 Actual ($M)**	**FY 2001 Actual ($M)**	**FY 2002 Actual ($M)**	**FY 2003 Actual ($M)**	**FY 2004 Actual ($M)**	**FY 2005 Estimate ($M)**	**FY 2006 Request ($M)**
National Science Foundation (NSF)	97	150	204	221	256	338	344
Department of Defense (DOD)	70	125	224	322	291	257	230
Department of Energy (DOE)	58	88	89	134	202	210	207
National Institutes of Health (NIH)	32	40	59	78	106	142	144
National Institute of Standards and technology (NIST)	8	33	77	64	77	75	75
National Aeronautics and Space Administration (NASA)	5	22	35	36	47	45	32
National Institute for Occupational Safety and Health (NIOSH)						3	3
Environmental Protection Agency (EPA)	-	6	6	5	5	5	5
Homeland Security (TSA)	-	-	2	1	1	1	1
Department of Agriculture (USDA)	-	1.5	0	1	2	3	11
Department of Justice (DOJ)	-	1.4	1	1	2	2	2
TOTAL (% of FY 2000 budget)	**270** (100%)	**465** (172%)	**697** (258%)	**862** (319%)	**989** (356%)	**1,081** (400%)	**1,054** (390%)

* Each Fiscal Year (FY) begins October 1 of the previous year and ends September 30 of the respective year.

Nanoscale science and engineering R&D is mostly in a precompetitive phase (the major applications and particularly the breakthrough technologies are expected to come after five-ten years and are not yet well defined), and there are good win-win partnering and effort-sharing opportunities. International collaboration in establishing the nanotechnology knowledge base, addressing long-term challenges for human health, clean water and energy conversion, educating the new generation, and studies on environment and societal implications will play an important role in the affirmation and growth of the field. Several suggestions for an "international strategy on nanotechnology R&D" were presented four years ago (Roco, 2001), and several activities on nanotechnology research programs, student exchanges, development of common nomenclature and standards, regional and bi-lateral exchanges have become reality. In 2005, the International Council on Risk Governance (IRGC, 2005) has undertaken a study on global governance of nanotechnology with a focus on long-term and global issues.

Acknowledgements

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