I
Nanotechnology Research Funding and Commercialization Prospects

The Nano–Micro Interface: Bridging the Micro and Nano Worlds
Edited by Hans-Jörg Fecht and Matthias Werner

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U.S. National Nanotechnology Initiative: Planning for the Next Five Years

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1 Introduction

Nanoscience and nanotechnology are opening up a new era of integrated fundamental research at the nanoscale, a more coherent science and engineering education, economic nanoscale manufacturing of products, and an enabling foundation for improving human capabilities and societal outcomes in the long term. The U.S. National Nanotechnology Initiative (NNI) is a visionary program that coordinates 17 departments and independent agencies [1–5] with a total budget of U.S.$ 961 million in the fiscal year 2004. An overview of the main research and development (R&D) themes, outcomes in the first two years of the initiative, and plans for the future are presented. At least 35 countries have initiated national activities in this field, partially stimulated by the NNI vision and plans.

Priority in funding in 2004 is oriented to:
- research to enable the nanoscale as the most efficient manufacturing domain;
- innovative nanotechnology solutions to biological, chemical, radiological, and explosives detection and protection;
- development of instrumentation and standards;
- nanobiosystems;
- the education and training of a new generation of workers for the future industries;
- societal implications; and
- partnerships to enhance industrial participation in the nanotechnology revolution.

Priority nanoscale science and technology goals in the next five years are in currently exploratory areas of research (including nanomedicine, energy conversion, food and agriculture, realistic simulations at the nanoscale, molecular nanosystems), in areas transiting to technological innovation (nanostructured materials, nanoelectronics, catalysts, and pharmaceuticals, development of tools for measurement and simulation), and in areas to advance broad societal goals (such as better understanding of nature and life, increasing productivity in manufacturing, interdisciplinary education, improving human performance, and sustainable develop-

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ment). Societal and educational implications, including environmental research, will increase in importance in NNI as nanotechnology products and services reach the market.

Several generations of nanotechnology products are expected to evolve from relatively simple nanostructures for products such as coatings and hard metals, to active components such as nanoscale transistors, and then nanosystems with new architectures. This chapter shows how miniaturization, self-assembling from molecules up, and multiscale architectures lead to the integration of nano- and micro-components into system applications.

2
Government R&D Investments

The worldwide nanotechnology R&D investments reported by government organizations has increased more than six-fold from U.S.$ 430 million to about U.S.$ 3 billion between 1997 and 2003 (Tab. 1 and Fig. 1). At least 35 countries have initiated national activities in this field, partially stimulated by the U.S. NNI.

Scientists have opened a broad net that does not leave any major research area untouched in the physical, biological, materials, and engineering sciences. Industry has gained confidence that nanotechnology will bring competitive advantages to both traditional and emerging fields, and significant growth is noted in small businesses, large companies, and venture capital firms. The annual global impact of products where nanotechnology will play a key role was estimated in 2000 to exceed U.S.$ 1 trillion by 2015, which would require about 2 million nanotechnol-

Tab. 1 Estimated government nanotechnology R&D expenditures during 1997–2003 (in U.S.$ millions/year).

Region	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*
West Europe	126	151	179	200	~225	~400	~600
Japan	120	135	157	245	~465	~700	~810
USA [a]	116	190	255	270	422 (465) [b]	600 (697) [b]	774 (862) [b]
Others	70	83	96	110	~380	~550	~800
Total	432	559	687	825	1492	2347	2984
(% of 1997)	100	129	159	191	346	502	690

Explanatory notes: West Europe includes countries in EU and Switzerland; the rate of exchange U.S.$1=1.1 Euro until 2002; U.S.$1=1 Euro in 2003; Japan rate of exchange U.S.$1=120 yen in 2002; others include Australia, Canada, China, Eastern Europe, FSU, Israel, Korea, Singapore, Taiwan and other countries with nanotechnology R&D.

a) A financial year begins in the United States on 1 October of the previous calendaristic year, six months before most other countries.

b) Denotes the actual budget recorded at the end of the respective fiscal year. Estimations use the nanotechnology definition as defined in NNI [1]; this definition does not include MEMS, and includes the publicly reported government spending.

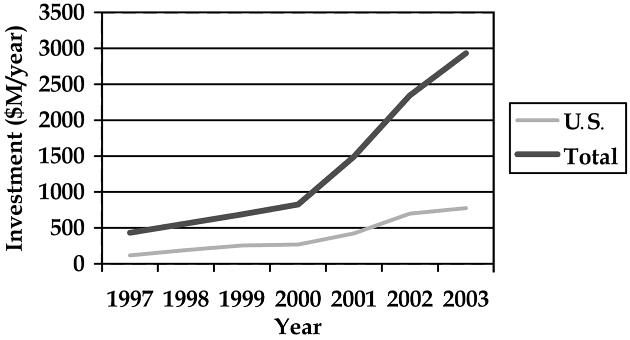

Fig. 1 Government investments in nanotechnology during 1997–2003. Upper curve = total worldwide including USA; lower curve = USA.

ogy workers [3]. This estimate was based on the analysis of existing R&D activities in industry in the U.S., Japan, and Western Europe. One notes that U.S.$ 1 trillion represents about 10% of the U.S. GDP in 2003. If one would extrapolate the previous experience, where for each information technology worker another 2.5 jobs are created in related areas, nanotechnology has the potential to create 7 million jobs overall by 2015 in the global market. Also, if one considers the impact of information technology of increasing U.S. productivity more than 1% per year in 1990s (that is roughly half of the overall productivity growth of about 2.1% in the 1990s), a similar or possibly larger impact is expected from nanotechnology. This is because the impact is broader than a new generation of electronic hardware once nanotechnology is reaching a critical mass in knowledge and commercial markets. One may note that the initial estimates for information technology significantly under-estimated its long-term positive implications (because of successive and non-scalable qualitative changes) and over-estimated the negative effects (beginning with the risk of macroscale robots that would take over the world). By envisioning the potential synergism of many fields contributing to nanotechnology and various phases of its introduction, a similar scenario would be possible at an even more pronounced scale.

The U.S. has initiated a multidisciplinary strategy for development of science and engineering fundamentals through the NNI based on a long-term vision [1]. The estimated Federal Government budget for nanotechnology research U.S.$ 961 million in fiscal year 2004, and the request is U.S.$ 982 million for the fiscal year beginning in October 2004 [5]. Japan [6–7], the European Community (Fig. 2) [8] and more recently China [9] have initiated broad programs, and their current plans look up to five years ahead. Other countries, including Korea [10], Taiwan [11], Australia [12], Canada, Eastern Europe, Israel, India, and Singapore have encouraged their own areas of strength, several of them focusing on fields of the potential markets. Their rate of increase in government spending in the last year is higher than the sum of all other three areas (U.S., Japan, Western Europe). Differences among countries are observed in the research domains they are aiming for,

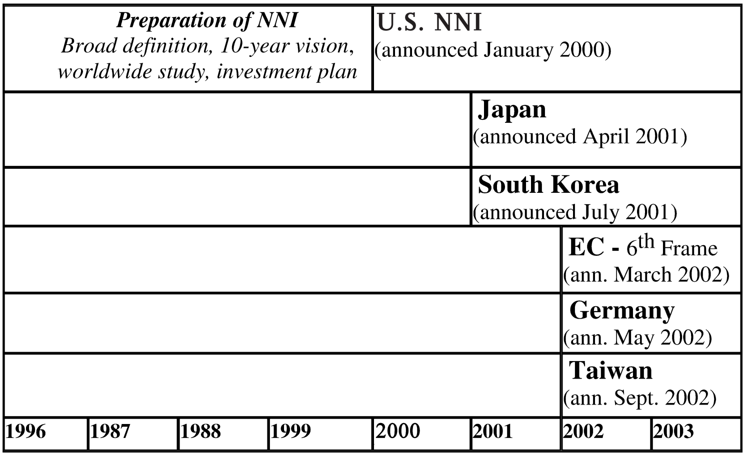

Fig. 2 Comprehensive nanotechnology research programs with funding exceeding U.S.$ 100 million/year by national governments or EC, announced after 2000.

Tab. 2 Contribution of key agencies to NNI.

Federal department or agency	*FY 2000 Actual ($M)*	*FY 2001 Actual ($M)*	*FY 2002 Actual ($M)*	*FY 2003 Actual ($M)*	*FY 2004 Current Plan ($M)*	*FY 2005 Request ($M)*
National Science Foundation (NSF)	97	150	204	221	254	305
Department of Defense (DOD)	70	125	224	322	315	276
Department of Energy (DOE)	58	88	89	134	203	211
National Institutes of Health (NIH)	32	40	59	78	80	89
National Institute of Standards and technology (NIST)	8	33	77	64	63	53
National Aeronautics and Space Administration (NASA)	5	22	35	36	37	35
Environmental Protection Agency (EPA)	–	6	6	5	5	5
Homeland Security (TSA)	–	–	2	1	1	1
Department of Agriculture (USDA)	–	1.5	0	0	1	5
Department of Justice (DOJ)	–	1.4	1	1	2	2
Total	270 (100%)	465 (172%)	697 (258%)	862 (319%)	961 (356%)	982 (364%)

the level of program integration into various industrial sectors, and in the time scale of their R&D targets.

The actual U.S. NNI budget in fiscal year (FY) 2003 was U.S.$ 862 million and current plan in FY 2004 is U.S.$ 961 million (Tab. 2). The budget decreases in FY 2004 request noted at NASA (National Aeronautics and Space Administration) and DOD (Department of Defense) in the FY 2005 may be explained by the reassignment of applied nanotechnology projects to the respective areas of relevance instead of NNI. The state and local organizations committed additional funds for infrastructure, education, and commercialization of more than half of the NNI investment in 2002.

The NNI centers and networks of excellence encourage long-term system-oriented projects, research networking, and shared academic users' facilities. These nanotechnology research centers play an important role in the development and utilization of specific tools, and in promoting partnerships (Tabs. 3, 4).

The research outcomes are not proportional to the investments because of research productivity, various components of the infrastructure, and culture. For example, the timeline of the patents recorded with U.S.PTO (U.S. Patent and Trade Office) is shown in Fig. 3. That office receives domestic and foreign applications as being the main target for investors because the U.S. provides the largest single market.

Tab. 3 NNI centers and networks of excellence.

Center name	***Institution***
NSF	
Nanoscale Systems in Information Technologies, NSEC (Nanoscale Science and Engineering Center)	Cornell University
Nanoscience in Biological and Environmental Engineering	Rice University
NSEC	
Integrated Nanopatterning and Detection, NSEC	Northwestern University
Electronic Transport in Molecular Nanostructures, NSEC	Columbia University
Nanoscale Systems and their Device Applications, NSEC	Harvard University
Directed Assembly of Nanostructures, NSEC	Rensselaer Polytechnic Institute
Nanobiotechnology, Science and Technology Center	Cornell University
DOD	
Institute for Soldier Nanotechnologies	MIT
Center for Nanoscience Innovation for Defense	UC Santa Barbara
Nanoscience Institute	Naval Research Laboratory
NASA	
Institute for Cell Mimetic Space Exploration	UCLA
Institute for Intelligent Bio-Nanomaterials & Structures for Aerospace Vehicles	Texas A&M
Bio-Inspection, Design and Processing of Multi-functional Nanocomposites	Princeton
Institute for Nanoelectronics and Computing	Purdue

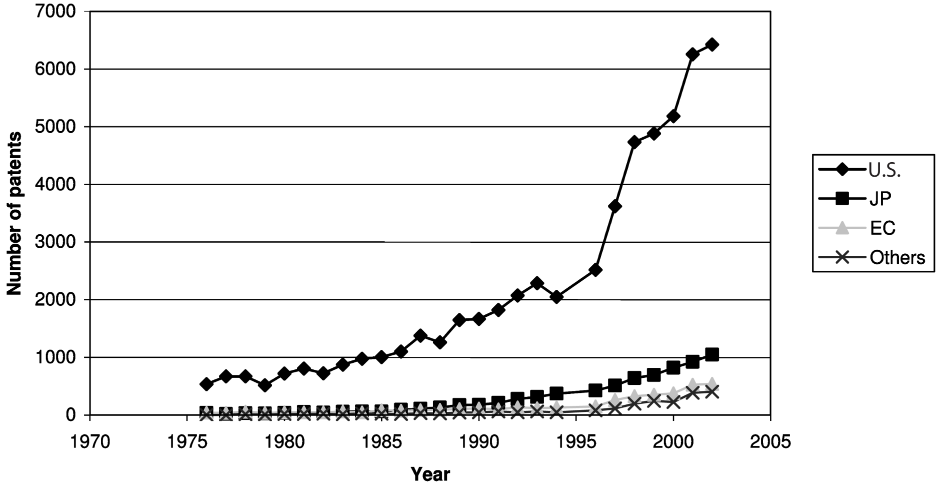

Fig. 3 Number of nanotechnology patents per four regions (1976–2002). The leading ten countries in 2002 were: U.S., 6425 patents; Japan, 1050; France, 245; UK, 100; Korea, 87; Taiwan, 86; Netherlands, 66; Australia, 61; Switzerland, 55; Italy, 44. The survey was taken using the USPTO database in April 2003 [13].

Tab. 4 NNI R&D user facilities, 2003.

Center name	***Institution***
NSF	
National Nanofabrication Users Network (NNUN; this network has been re-competed in 2004 with an expanded role and increased budget under the National Nanotechnology Infrastructure Network)	Cornell University Howard University Stanford University Pennsylvania State University UCSB
Network for Computational Nanotechnology	Purdue University University of Illinois Stanford University University of Florida University of Texas, El Paso Northwestern University Morgan State University
DOE	
Center for Functional Nanomaterials	Brookhaven National Laboratory
Center for Integrated Nanotechnologies	SNL and LANL
Center for Nanophase Materials Sciences	Oak Ridge National Laboratory
Center for Nanoscale Materials	Argonne National Laboratory
Molecular Foundry	Lawrence Berkeley National Laboratory

Nanotechnology is growing in an environment where international interactions accelerate in science, education, and industrial R&D, while industrial competitiveness difficulties are surfacing at national and industry consortia levels. Government investments in nanotechnology have jump-started the development of nanoscale science and engineering. Government activities should equally prepare society for introduction of new technologies and products, as well as future unexpected consequences of nanotechnology such as health and environmental concerns.

Acknowledgments

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