Monitoring and analysis of policies
and public financing instruments
conducive to higher levels of R&D investments
The “POLICY MIX” Project

Case Study

R&D Policy in the United States: The Promotion of Nanotechnology R&D

by

Philip Shapira and Jue Wang

Program in Science, Technology and Innovation Policy
Georgia Institute of Technology
Atlanta, GA 30332-0345, USA

November 2007

Executive Summary

This case study reviews the evolution of nanotechnology policies and programmes in the United States. Federal R&D policy in nanotechnology has moved through several stages, including initial exploration before the 1980s, the promotion of scientific and technological breakthroughs in the 1980s, policy development in the 1990s and multi-agency national initiatives in the 2000s. Since 2001, the major federal R&D policy mechanism in nanotechnology in the US has been the National Nanotechnology Initiative (NNI). NNI promotes policy deliberation and, most importantly, coordinates federal R&D investment in nanotechnology (totalling $8.3 billion between 2001 and 2008. The leading federal agencies engaged in nanotechnology include NSF, DOD, DOE, NIH and NIST. Federal investments have been directed mainly to sponsorship of nanotechnology centres and R&D projects but also to develop infrastructure for nanotechnology research and education networks and support the consideration of environmental, health and safety issues associated with nanotechnology. A complementary policy development has been the enhancement of basic research in physical science, engineering and other disciplines which contribute to nanotechnology research. While federal programmes are primarily focused on R&D and infrastructure development, state and regional programmes are active in facilitating nanotechnology commercialisation. State nanotechnology efforts vary greatly from broad statements about policy goals to well-structured nanotechnology R&D and commercialization programmes.

Non-R&D policies also have impacts on nanotechnology development. In the US – as in other countries – dedicated regulatory policies and standards for nanotechnology are still in the process of being worked out. However, the importance of considering the risk and social implications of nanotechnology has been explicitly addressed in the framework 21st Century Nanotechnology Research and Development Act of 2003. Organisations such as ANSI-NSP, the ASTM International and the USPTO are developing nanotechnology standards and classifications, which could improve public understanding of nanotechnology. Several recent national initiatives have emphasised science and engineering education. A few efforts are explicitly targeted to nanotechnology, but most focus more broadly on science education and workforce development. Increased debate is also underway about the best ways to maintain the traditional attractiveness of the US to foreign scientists. It is anticipated that nanotechnology will have economic impact in various industries and even lead to the "next industrial revolution". Currently, applications incorporating nanotechnologies mostly represent incremental improvements to existing products, for example in paint, cosmetics, cleaning fluids, or clothing. Several studies have suggested the market for nano-enabled products, including for more advanced applications, will grow significantly in future years. As yet, there is little widespread public debate about the implication of this in the US, although as part of the policy mix a variety of nanotechnology in society and other educational initiatives have been sponsored by federal agencies. In other non R&D areas, ranging from intellectual property to the availability of venture capital, there are specific debates and recommendations for improvement, but overall, the non-R&D policy framework appears to be broadly supportive for the further research, development and commercialization of nanotechnology in the US.

1. Introduction

The policy mix project

This report is one of 34 case studies produced as internal working papers for the research project "Monitoring and analysis of policies and public financing instruments conducive to higher levels of R&D investments" (Contract DG-RTD-2005-M-01-02, signed on 23 December 2005). This project is a research project conducted for DG Research, to serve as support for policy developments in Europe.

The case study builds upon previous papers produced in this project, notably a country review on R&D funding in the United States[1] as well as several conceptual papers discussing the potential positive and negative interaction effects of different policy activities with respect to the level of R&D investment. The aim of this case study is to further explore policy mix issues stressed in the country review and conceptual papers, particularly by focusing on specific themes of great relevance to the ultimate goals of the project, namely the development of a better understanding of how policy mixes can influence R&D investment levels and the construction of a web-based tool of use to policymakers in this sphere.

The case study provides an expert's view on the policy mix in the respective area. This report is not approved by the Commission or national authorities, and is produced under the responsibility of its author.

According to the case study methodology of the policy mix project, case studies should cover policy mix issues on a country level, on a regional level or on a sector level and focus on one or more of the following policy mix issues:

- Governance, i.e. the attempts to formulate, design and implement comprehensive policy mixes at different levels.
- Routes, i.e. policy measures to stimulate R&D investment by different types of target groups.
- R&D/R&D Policy Interactions, i.e. the interaction of different R&D policy measures and approaches.
- R&D/Non-R&D Policy Interactions, i.e. the interaction of specific non-R&D policies with R&D policies.
- Industrial Restructuring, i.e. the role of different policies restructure and economy towards high-tech and R&D intensive sectors.
- Mini-mixes, i.e. attempts to combine smaller ranges of R&D policy instruments into 'policy packages', often under the flag of a single programme.

This case study on nanotechnologies in the United States is a sector case study with a particular focus on two thematic areas: governance, interactions among R&D policies, and interaction between R&D policy and non-R&D policies.

---

1 See C. Rammer, M.O. Sellenthin, S. Thorwarth, P. Shapira, "Monitoring and analysis of policies and public financing instruments conducive to higher levels of R&D investments: Country Review United States", Brussels, February 2007.

Case Study: Nanotechnologies in the United States

In the United States, there is a predominant view among policymakers in the science and technology community that nanotechnology is a leading-edge frontier of science that promises revolutionary technology opportunities. These are expected to generate significant and cross-cutting economic development, medical, social, environmental and other benefits. It is also recognized that the development of nanotechnology is likely to raise health and safety concerns and societal impacts that must be considered as nanotechnology R&D progresses and as nanotechnology applications emerge.

Against this background, US policy has actively supported the growth and spread of nanotechnology for a long time. Early Federal initiatives programmes date back to the early 1990s. The establishment of the National Nanotechnology Initiative (NNI) in 2001 further expanded the scale and scope of these programmes and marked the full emergence of a dedicated and coordinated nanotechnology R&D policy mix in the US.

This case study addresses three policy mix issues:

(a) the role of dedicated national nanotechnology initiatives for the development of this sector vis-à-vis other (more generic) R&D policy measures and compared to regional nanotechnology initiatives;

(b) the interactions between R&D funding for nanotechnology and other (non-R&D) policy areas relevant for leveraging economic and social results out of this research;

(c) the impacts of nanotechnology on the US economy, including its contribution to business and industrial development

Organisation of the case study report

The following sections provide details on important policy initiatives and programmes that offer support to research in nanotechnology and facilitate the diffusion of nanotechnology across industries. In particular, we discuss the development of US nanotechnology policy assessment, nanotechnology coordination organisations and R&D programme initiatives.

2. The National Policy Mix Context

The US Presidential Council of Advisors on Science and Technology has defined nanotechnology as the "science, engineering, and technology related to the understanding and control of matter at the length scale of approximately 1 to 100 nanometers."[2] The essence of nanotechnology is that it allows one to work at the nanometer level to generate larger structures with novel and significantly improved properties and functions. A wide range of disciplines such as physics, chemistry, biology, materials science, mathematics, and engineering have contributed to developments in nanotechnology.[3] Particular attention is focused on the understanding and manipulation of nanostructures – intermediate-size complex systems such as carbon nanotubes, magnetic nanolayers, nanowires, or biological nanostructures – to create new products, processes and applications or enhance the performance of existing technologies.

US researchers, along with other international colleagues, have been deeply involved in pioneering the nanotechnology field. The concept of nanotechnology was envisioned early in 1959 by Nobel laureate physicist and Caltech Professor Richard Feynman in his lecture "There is Plenty of Room at the Bottom".[3] He predicted that materials and devices at the atomic or molecular scale would bring about new discoveries and opportunities, and new sets of miniaturized instruments would be needed to operate on these nano structures. The term "nanotechnology" was first coined in 1974 by Japanese researcher Nobuhiko Taniguchi to describe the precision manufacture of materials on a nanometer scale and then extended by MIT's Eric Drexler (1992) as the fabrication of materials and products with the precise positioning of molecules in accordance with an explicit engineering design.[4]

An important stage in the development of major federal R&D programmes for emerging technologies in the US is that of assessment, study, and policy debate prior to the enlargement of research budget allocations. The decentralized, multi-organisational nature of US federal decision-making and budgeting processes apply to science and technology (S&T), as for other spheres. Among the branches and organisations typically involved in discourse about major R&D programme developments include executive agencies such as the President's Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB), the US Congress and committees of the House of Representatives and the Senate, federal agencies with major research responsibilities (among which are the National Science Foundation, the Department of Defence, and the National Institutes of Health), quasi-governmental and non-profit organisations including the National

---

2 PCAST (2005). The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel. Washington DC, the President's Council of Advisors on Science and Technology.

3 NSTC (1999). Nanostructure Science and Technology: A Worldwide Study. R.W. Siegel and M.C. Roco. Washington DC, National Science and Technology Council.

4 Smith, R. H. I. (1998). A Policy Framework for Developing a National nanotechnology Programme. Science and Technology Studies. Blacksburg, Virginia, Virginia Polytechnic Institute and State University.

Academies of Science and Engineering, and numerous professional, private sector, academic, public-interest, and other groups.

In the nanotechnology domain, there were no explicit or dedicated nanotechnology R&D programmes before the 1990s (to the best of our knowledge). Importantly, nascent nanotechnology research *was* funded during this early phase using generally available R&D programmes, such as those sponsored by divisions of the National Science Foundation (NSF), which supported "bottoms-up" research proposals where the initiative came from individual investigators, research teams, and organisations exploring early. R&D funding was principally on an individual project basis. Beginning in the early 1990s, the first of a wave of assessment and policy studies appeared. Substantial national initiatives emerged after the first large-scale inter-agency study of nanotechnology organized by the NSF in 1997. The establishment of the National Nanotechnology Initiative (NNI) in 2001 further expanded the scale and scope of national nanotechnology programmes. This marked the full emergence of dedicated nanotechnology R&D programmes in the US.

Other federal R&D funding is available – and in recent years has been expanded – to support basic research in areas such as physics, chemistry and biotechnology that are core disciplines of nanotechnology. While direct investment in nanotechnology R&D through the NNI is $1.4 billion in 2007, total federal R&D spending amounts to some $139.9 billion, of which federal investment in basic and applied research comprises $56.8 billion[5]. Hence, researchers working at the nanoscale are also able to apply for R&D funding from other federal sources in addition to NNI or are supported at federal laboratories. Other federal R&D sources include the National Institutes of Health, the US Department of Energy, and the Defense Department. This is important in considering the R&D policy mix in that through bottoms-up researcher initiative, multiple sources for nanoscale research are available in addition to the (significant) resources made available through NNI.

Additionally, although the federal government plays the major role in formulating nanotechnology R&D policies and funding, many US state governments are also active in establishing their own policies and programmes. According to the Lux Report[6], US states spent over $400 million on nanotechnology R&D and related activities in 2004. Recognizing potential opportunities and economic gains brought by this new technology, states or regions are competing for leadership in this new field and seek to become hubs of nanotechnology research and industry. This provides both a further pathway for diversity in the US nanoscale policy mix and a complementary asset to federal policy since states are able (and willing) to fund construction projects for new nanotechnology centres (usually state university-based) that subsequently can compete for federal R&D funding.

[5] Source: AAAS R&D Budget Summary <http://www.aaas.org/spp/rd/upd107.htm>
[6] Lux Research (2005). Benchmarking U.S. States for Economic Development from Nanotechnology. New York, NY: Lux Research Inc.

3. The Sectoral Policy Mix Context

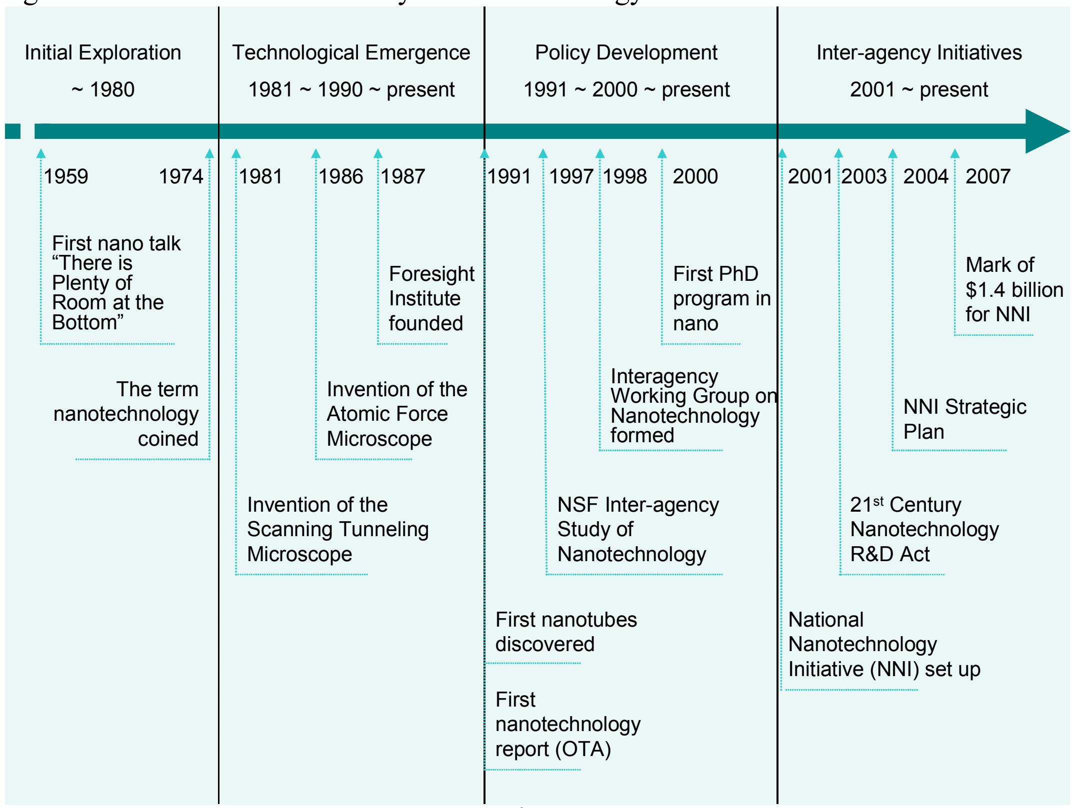
The development of nanotechnology in the US has proceeded through several stages over the last five decades, including initial exploration, technological emergence aided by a variety of available R&D programmes, and then a more explicit government pull with the development of dedicated nanotechnology R&D initiatives and policies. Figure 1 presents a brief review of the milestones in the history of nanotechnology. Two technological breakthroughs in instrumentation are highly significant: the Scanning Tunneling Microscope (by Gerd Binnig and Heinrich Rohrer at IBM Zürich in 1981) capable of displaying images of individual atoms; and the Atomic Force Microscope (by Binning and Rohrer, with Calvin Quate of Stanford University, in 1986) which displays nanoscale images of non-conducting surfaces. These inventions allowed empirical investigation to be conducted at the nanoscale, marked the birth of the nanotechnology industry, and the subsequent growth of nanotechnology research and policy activity in the US.[7]

Since the mid-1990s, nanotechnology has attracted the increasing attention of government agencies in the US: it has been listed as one of six priority areas by the National Science Foundation (NSF); R&D funding has been greatly expanded through the US National Nanotechnology Initiative (NNI); and there have been a series of federal and state R&D policy initiatives, including the framework 21st Century Nanotechnology Research and Development Act of 2003. The balance of this paper summarizes nanotechnology R&D programme initiatives, policies, and impacts in the US.

Figure 1 summarises the milestones in the history of nanotechnology development and policy support to nanotechnology in the United States.

7 NSTC (1999). Nanostructure Science and Technology: A Worldwide Study. R.W. Siegel and M.C. Roco. Washington DC, National Science and Technology Council.

Figure 1. Milestones in the history of nanotechnology



Sources: Smith (1998); Stephan, Black and Chang (2007)[8]; updated by authors.

1991 to 1994: Assessing Opportunities

In 1991, the Office of Technology Assessment (OTA) of the US Congress initiated *Miniaturisation Technologies* - one of the first studies on nanotechnology research.[9] The report covered fields such as silicon electronics miniaturisation and molecular nanotechnology and suggested the potential development of quantum effect devices and micro-mechanical systems. The report also discussed possible benefits and concerns of molecular machines and proposed to increase federal regulatory involvement to deal with the challenge and risks.[10]

This period also saw the implementation of the first major US public R&D programmes on nanotechnology by NSF – one of the key US government agencies responsible for fostering science and technology development. NSF funded the Nanoparticle Synthesis and Processing Initiative (1991-2001) with a focus on chemical processing and the National Nanofabrication User Network (1994-2003)

---

8 Stephan, Paula, Grant C. Black and Tanwin Chang (2007). "The small size of the small scale market: The early-stage labor market for highly skilled nanotechnology workers". Research Policy (36): 887-892.

9 OTA (1991). Miniaturisation Technologies. OTA-TCT-514. Congress of the United States, Office of Technology Assessment, Washington, DC.

10 Smith, R. H. I. (1998). A Policy Framework for Developing a National Nanotechnology Programme. Science and Technology Studies. Blacksburg, Virginia, Virginia Polytechnic Institute and State University.

with a focus on microelectronics miniaturisation.[11] NSF's support for the User Network began an emphasis on the development of national research infrastructures in nanotechnology in the US, where facilities and instrumentation resources were established around the country for networks of researchers to access.

1995 to 1999: Spreading Nanotechnology Support

Several nanotechnology policy studies were carried out by other organisations and agencies following the 1991 OTA report. In 1995, the RAND Corporation – a California-based "think-tank" – released a report discussing the potential impact of molecular nanotechnology on advanced manufacturing.[12] The report suggested expanding research efforts in this field and having a multidisciplinary expert group to provide technical assessment. One year later, the National Academy of Sciences issued a report, *Biomolecular Self-Assembling Materials*, addressing research on self-assembling of biomolecular materials.[13] Although the term nanotechnology was not explicitly mentioned, the report discussed the technological developments and research programmes of nanotechnology in the US and other countries. Also in 1996, the Department of Defence (DOD) organized a panel, Military Health Service System (MHSS) 2020, to study biotechnology and nanotechnology trends and published the report a year later. The study concluded that advances in biotechnology and nanotechnology would significantly change military medicine and suggested creating systematic monitoring mechanisms for their progress and implications.[14]

The first large-scale inter-agency study of nanotechnology was initiated by the NSF in 1997. The study was performed by the World Technology Evaluation Centre (WTEC) to review the status of US R&D in the field of nanotechnology. Together with NSF, eight federal agencies sponsored this study. These sponsors comprised: the Air Force Office of Scientific Research (AFOSR), the Office of Naval Research (ONR), the National Institute of Standards and Technology (NIST), the Department of Commerce (DOC), the National Institutes of Health (NIH), the National Aeronautics and Space Administration (NASA), and the Department of Energy (DOE). A workshop was held in May 1997 to report and discuss the findings of the study.[15] In addition to the seven funding agencies, four other agencies and national laboratories participated in the workshop: the Army Research Office (ARO), the Ballistic Missile Defence Organisation (BMDO), the Defence Advanced Research

---

[11] Roco, Mihail C. (2002). The Vision and Action Plan of the National Nanotechnology Initiative. Technical Proceedings of the 2002 International Conference on Modeling and Simulation of Microsystems.

[12] Nelson, Max, and Shipbaugh, Calvin (1995) The Potential of Nanotechnology for Molecular Manufacturing, RAND Corporation, Santa Monica, CA.

[13] NAS (1996), Biomolecular Self-Assembling Materials: Scientific and Technological Frontiers, National Research Council, National Academy of Sciences, Washington, DC.

[14] Smith, R. H. I. (1998). A Policy Framework for Developing a National nanotechnology Programme. Science and Technology Studies. Blacksburg, Virginia, Virginia Polytechnic Institute and State University.

[15] Siegel, Richard W., Evelyn Hu and Mihail C. Roco (1998). R&D Status and Trends in Nanoparticles, Nanostructured Materials, and Nanodevices in the United States. Proceedings of the May 8-9, 1997 Workshop, World Technology Evaluation Center, International Technology Research Institute, Baltimore, MD.

Projects Agency (DARPA), and the Naval Research Laboratory (NRL). Nanotechnology was also identified as a strategic research objective by the DOD in 1997 and the NIH in its 1999 Bioengineering Consortium (BECON) programme.[16] The collaboration among multiple R&D agencies, across several mission spheres, in sponsoring this study foreshadowed subsequent the significant interagency R&D initiatives that have emerged as a notable feature of US nanotechnology R&D promotion efforts.

Given the increasing R&D activities in nanotechnology and the involvement of more funding agencies, collaboration among various agencies became more important. Efforts have been made to coordinate nano work across agencies starting from November 1996 through an ad-hoc interagency Nanotechnology Group. The informal group was formalized as the Interagency Working Group on Nanotechnology (IWGN) in 1998 under the National Science and Technology Council (NSTC). Agencies that provided funds to nanotechnology research include NSF, DOD, DOE, NASA, DOC and NIH.

NSF continued to sponsor nanotechnology research, such as the Partnership in Nanotechnology: Synthesis, Processing and Utilisation of Functional Nanostructures (1998-2000). This programme was a collaborative initiative called by four directorates of NSF with an aim of supporting coordinated research activities in emerging nanotechnology areas, especially functional nanostructures.[17]

2000 to 2004: Bringing initiatives together: the NNI

One year after the President Clinton's speech at California Institute of Technology in 2000 on the importance of nanotechnology to the future of the US, the NNI was established and funded by the US Congress to accelerate basic and applied research in the field of nanotechnology. After that, the IWGN was replaced by the Nanoscale Science, Engineering and Technology (NSET) Subcommittee under the National Science and Technology Council's (NSTC) Committee on Technology (CT). The NSET set up the National Nanotechnology Coordination Office (NNCO) in 2001 to provide technical and administrative support for the NSET and monitor unexpected consequence of nanotechnology.

The activities of the NNI have been structured around the promotion of five major themes:

- Long-term fundamental nanoscience and engineering research
- Addressing a series of "Grand Challenges." These included developing memory storage units the size of a sugar cube that could contain the contents of the Library of Congress, doubling the efficiency of solar cells, making materials from the bottoms-up, developing materials far stronger than steel but weight much less, and detecting and targeting cancerous cells.
- Centres and Networks of Excellence
- Research Infrastructures

[16] NSTC (1999). Nanostructure Science and Technology: A Worldwide Study. R.W. Siegel and M.C. Roco. Washington DC, National Science and Technology Council.

[17] Source: NSF National Nanotechnology Initiative <http://www.nsf.gov/crssprgm/nano/>

- Ethical, Legal, Societal Implications and Workforce Education and Training

The number of agencies participating in the NNI increased from 6 in 2001 to 10 in 2002 and to 19 in 2004.[18] The US Congress called for an outside advisory body to monitor and coordinate activities in various agencies. In 2003, a fundamental framework for US nanotechnology research and development was provided by the *21st Century Nanotechnology Research and Development Act* (P.L. 108-153).[19] This Act was an omnibus measure which provided for R&D funding for nanotechnology, the development of interagency and advisory mechanisms to guide R&D, the integration of societal concerns into nanotechnology R&D, and the encouragement of citizen input. With the enactment of the Act, a National Nanotechnology Advisory Panel (NNAP) was created to review the federal nanotechnology R&D programmes. The President's Council of Advisors on Science and Technology (PCAST) was designated to act as the NNAP by President Bush in July 2003. PCAST organized a Technical Advisory Group (TAG) with 45 nanotechnology experts from both academia and industry to provide technical assistance.[20] Since then, the coordination of federal agencies in supporting nanotechnology R&D has been a focus of attention.

Since 2000, NSF initiated a series of new programmes on nanotechnology, including the Nanoscale Science and Engineering (NSE), Nanoscale Science and Engineering Education (NSEE) and the National Nanotechnology Infrastructure Network (NNIN). Through the NSE programme, NSF funded six NSE centres (or NSECs) in 2001, two in 2003 and six in 2004 to advance collaborative research in the area of nanoscale science and engineering.[21] Built on the former National Nanofabrication Users Network, NNIN was set up in 2003 to integrate resources in 13 research facilities in the country to support nanotechnology research.[22] As provided by P.L. 108-153, NSF's nanotechnology research centres were required to consider societal implications in the development of R&D.

This period also saw measures for further consideration of the societal and ethical consequences of nanotechnology R&D and application. The Nanomaterial Environment and Health Implications (NEHI) working group was established in 2003 to monitor environment, health and safety consequences.[23] In 2004, NSF sponsored the first workshop on societal implications of nanoscience and nanotechnology. Attention was also devoted to nanotechnology workforce education and training in order to have skilled workers with multidisciplinary background necessary for rapid progress in nanotechnology.

---

[18] Roco, Mihail C. (2004). International Dialogue on Responsible R&D of Nanotechnology

[19] http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=108_cong_public_laws&docid=f:publ153.108

[20] PCAST (2005). The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel. Washington DC, the President's Council of Advisors on Science and Technology

[21] Source: NSF National Nanotechnology Initiative <http://www.nsf.gov/crssprgm/nano/>

[22] Source: National Nanotechnology Infrastructure Network website < http://www.nnin.org >

[23] Roco, Mihail C. (2004). International Dialogue on Responsible R&D of Nanotechnology

2005~2007: Further Expansion

In this most recent period, US government efforts to promote nanotechnology R&D have been greatly expanded. By 2007, there were 26 agencies participating in the NNI, including 13 agencies that provided R&D funding for nanotechnology. In 2005, PCAST conducted a five-year review of NNI to assess the US position in nanotechnology and the effectiveness and achievements of the NNI.[24]

Interest in exploring the societal impact of nanotechnology and education and training programmes continued. The NSF set up two Centres for Nanotechnology in Society in 2005 through the Nanoscale Science and Engineering programme, one led by UC Santa Barbara (CNS-UCSB) and the other one by Arizona State University (CNS-ASU).[25] In addition, NSF renewed its support to two Nanotechnology in Society projects at the University of South Carolina and Harvard University respectively. These centres and projects have missions to assess the technological, social and ethical implications of nanotechnology. In the same year, NSF funded the Nanoscale Informal Science Education Network to increase general public's awareness of nanotechnology. The network is led by the Museum of Science in Boston, the Science Museum of Minnesota and the Exploratorium in San Francisco.[26]

Public efforts by NSF and other federal agencies to support nanotechnology R&D and consider its development and implications are accompanied by initiatives by multiple private and non-profit organisations in the US to promote and assess nanotechnology development. These include the non-profit Foresight Nanotech Institute (which aims at "advancing beneficial nanotechnology"), the Centre for Responsible Technology (which seeks to "raise awareness of the benefits, the dangers, and the possibilities for responsible use of advanced nanotechnology" and also to plan for the "responsible worldwide use of this transformative technology"), and the Project on Emerging Nanotechnologies at the Woodrow Wilson Institute (which seeks to minimize the risks of nanotechnology and ensure public and consumer engagement to facilitate the potential benefits of nanotechnology).

---

24 PCAST (2005). The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel. Washington DC, the President's Council of Advisors on Science and Technology.

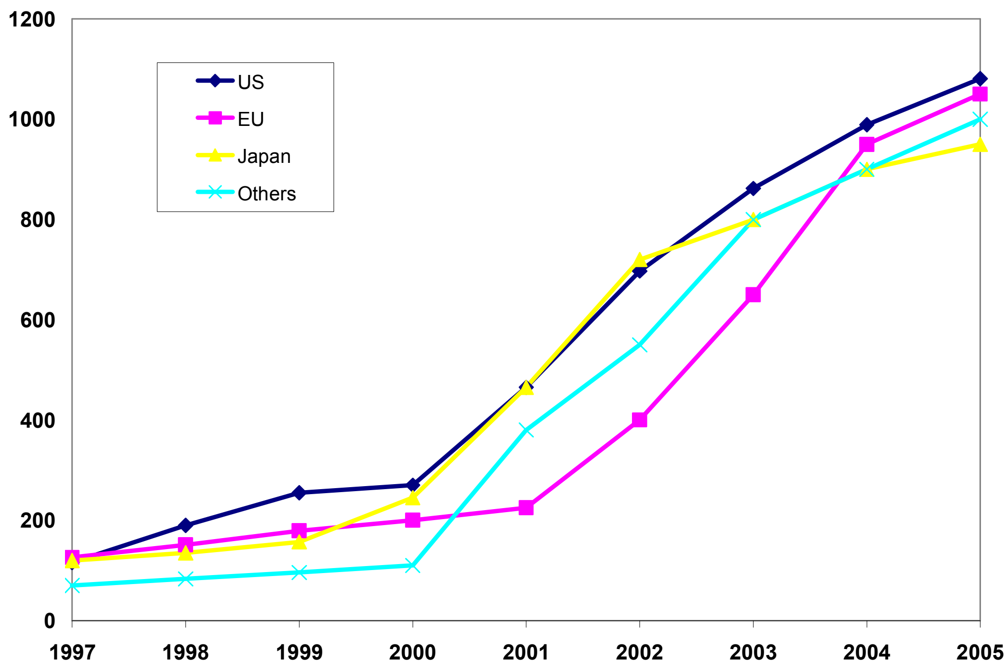
25 CNS-ASU is a partnership led by Arizona State University that also involves several other universities including Georgia Institute of Technology. The authors of this paper are associated with CNS-ASU at Georgia Tech.

26 Source: NSF Press Release < http://www.nsf.gov/news/news_summ.jsp?cntn_id=104505>

4. R&D Policies in Favour of Nanotechnology

Financing sources for nanotechnology research include government (national, state and regional), corporations, and venture capitalists. Government is contributing not only by providing funds directly but also by mobilizing resources from other sources such as requiring matching funds from industry. In 2005, government funding for nanotechnology R&D reached $4.61 billion worldwide, accounting for 48% of total nanotechnology funding.[27] According to PCAST[28], the amount of worldwide government investments in nanotechnology in 2005 was 9 times of the figure in 1997 (Figure 2). The US is the world's largest governmental R&D spender on nanotechnology – contributing 26.4% of world total in 2005, followed by the EU at 25.6% and Japan at 23.2%.

Figure 2 Government nanotechnology R&D investment (US$ million), 1997-2005



Source: PCAST (2005)

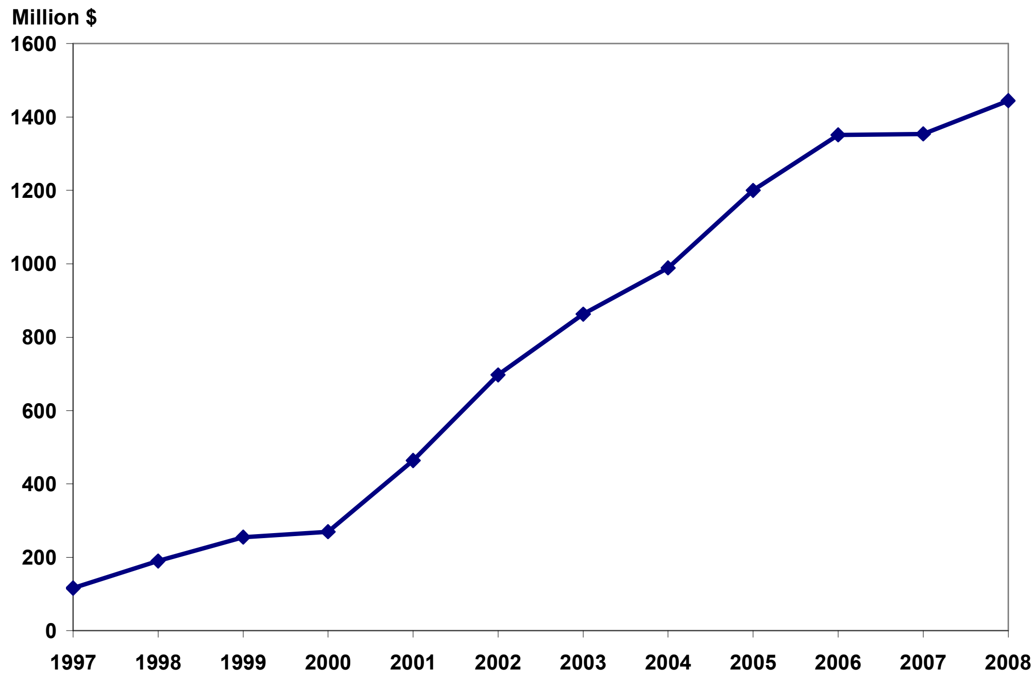
The United States government has expanded its support of nanotechnology since the formation of the NNI. The NNI has become the primary programme coordinating federal R&D investment in nanotechnology. As shown in Figure 3, federal

[27] Lux Research (2006). The Nanotechnology Report 4th Edition. New York, NY: Lux Research Inc.

[28] PCAST (2005). The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel. Washington DC, the President's Council of Advisors on Science and Technology.

investments in nanotechnology increased by 72% in 2001 and continued with 25% average annual growth rate since then. The estimated federal nanotechnology investment in 2008 is expected to reach $1.4 billion, or 12.5 times of the figure in 1997.

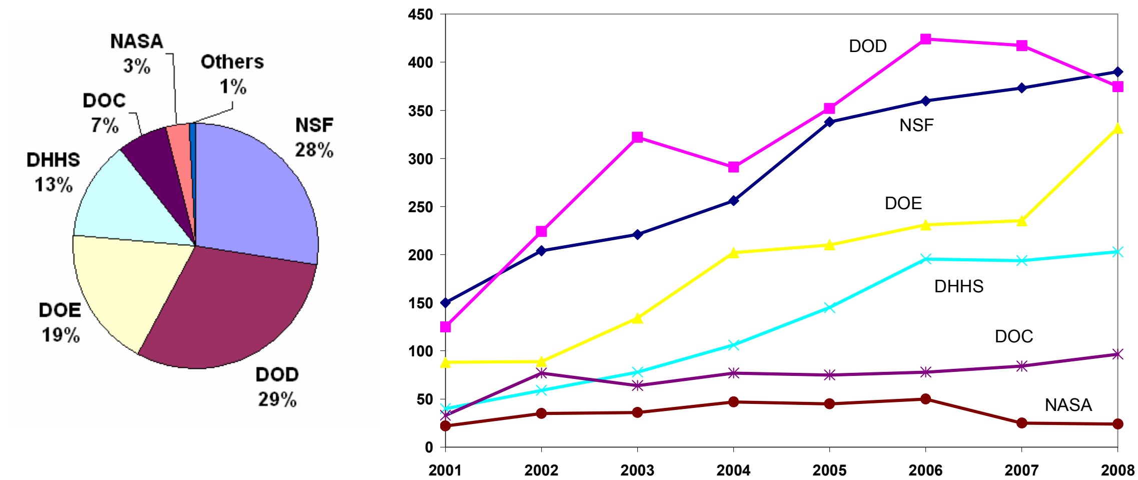
Figure 3 US Federal investments in nanotechnology (US$ million), 1997-2008



Source: PCAST (2005) and the NNI budget (http://www.nano.gov/html/about/funding.html)

The principal federal agencies that provide research funds for nanotechnology include DOD, NSF, DOE, DHHS, DOC, NASA, EPA, USDA, DHS, DOJ and DOT. Among these agencies, the DOD is the largest contributor to nanotechnology, accounting for 30% of total federal investment in nanotechnology, but its budget has fluctuated over the years. In 2004, the budget dropped by 10%, and in 2007 and 2008, the budget is expected to drop again by 2% and 10% respectively. The budget of the NSF, the second largest contributor to nanotechnology (27%), has grown steadily at an average of 15% between 2001 and 2008. The budgets of the DOE (18%) and the DHHS (12%) have exhibited a similar trend as that of the NSF, but increasing at an even faster rate of 23% and 28% respectively. Among the remaining agencies, the DOC accounted for 7% of nanotechnology R&D investment, NASA 3%, the EPA 0.6%, the USDA 0.3%, the DOJ 0.12%, the DHS 0.11%, and the DOT 0.03%. Figure 4 presents the NNI budget for nanotechnology from main funding agencies between 2001 and 2006 and estimations for 2007 and 2008.

Figure 4. Estimated federal investments in nanotechnology (US$ million), 2001-2008



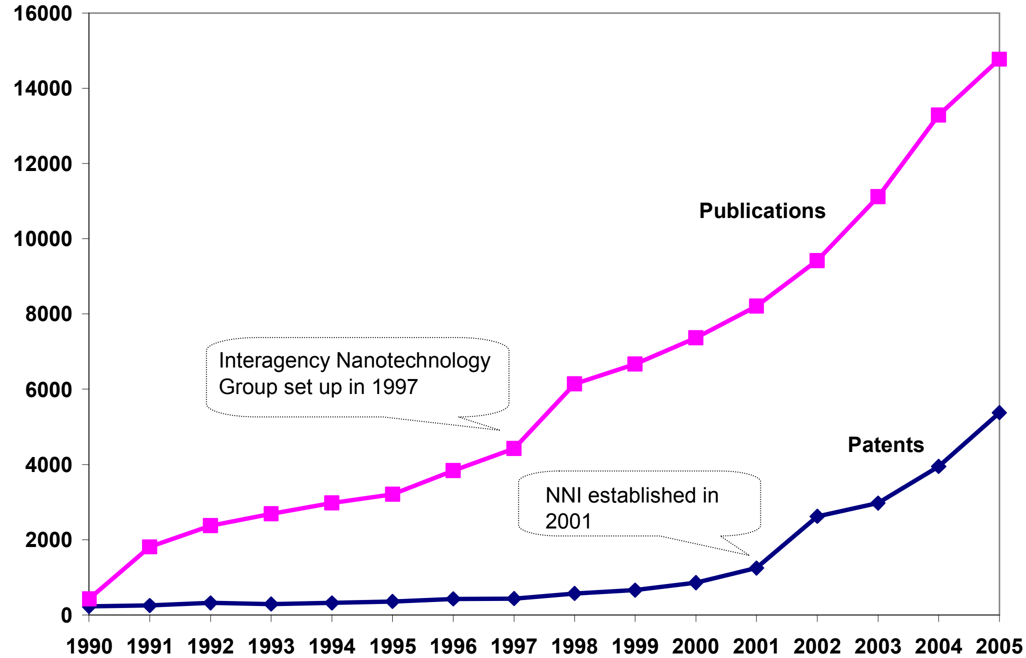
Source: The NNI budget (http://www.nano.gov/html/about/funding.html)

These government initiatives have resulted in an extensive, nationwide set of nanotechnology R&D activities in the US. Around 50 national nanotechnology centres or networks have been established with funding from federal agencies.[29] Nanotechnology R&D outputs as indicated by publications and patents also exhibit strong growth. The number of SCI nanotechnology publications in the US increased by 34 times and the USPTO nanotechnology patents increased by 23 times in 1990-2005 (Figure 5). The growth in nanotechnology publications and patents coincides with (although is not necessarily directly related to) the increased awareness and funding to nanotechnology associated with the establishment of the interagency Nanotechnology Group established in 1997 and the NNI set up in 2001 (as noted by Huang et al. in their study of USPTO nanotechnology patents[30]). Holding over 14,000 SCI publications and 5,000 USPTO patents in 2005, the US remains the world's leading national player in nanotechnology. However, it is worth noting that the global share of US publications and patents has been declining over time. Many other countries are also expanding nanotechnology R&D, with the US facing challenges not only from Japan and the EU but also from emerging countries such as China and South Korea. The consciousness of increased international R&D activity has been a factor in sustaining increases in the US nanotechnology R&D federal budget.

[29] PCAST (2005). The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel. Washington DC, the President's Council of Advisors on Science and Technology.

[30] Huang, Zan, Hsinchun Chen, Zhi-Kai Chen, and Mihail C. Roco (2004). "International Nanotechnology Development in 2003: Country, Institution, and Technology Field Analysis based on USPTO Patent Database." Journal of Nanoparticle Research (6).

Figure 5 SCI Publications and USPTO Patents in Nanotechnology in the US, 1990-2005



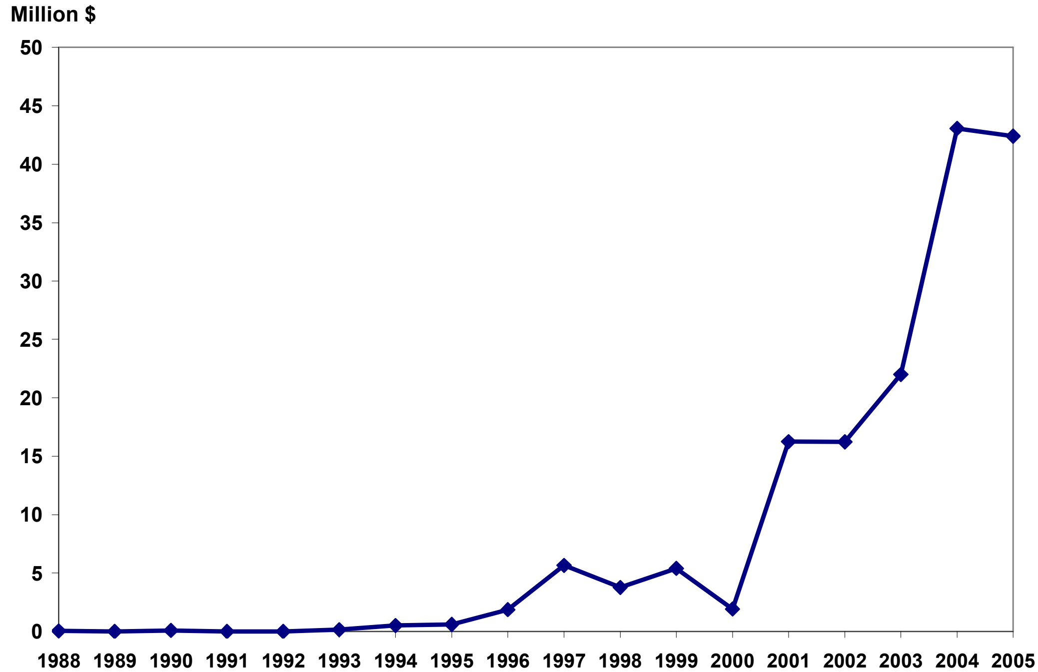
Sources: Georgia Tech (CNS-ASU) nanotechnology publication and patent datasets (see Porter et al., 2007).[31]

US federal nanotechnology programmes are largely focused on improving nanotechnology research infrastructure and advancing nanotechnology R&D. There are few *dedicated* efforts to promote nanotechnology commercialisation and industry development. There is already a well-established infrastructure of venture capital, small business support, and technology licensing and commercialisation which is available to commercialize nanotechnology R&D. For example, the Small Business Innovation Research (SBIR) programme (established in 1982) provides funds for small businesses with technologically-promising products or processes at their start-up and development stages. SBIR requires ten agencies to reserve R&D funds for small business: DOA, DOC, DOD, ED, DOE, DHHS, DOT, EPA, NASA and NSF. More than $2 billion is available for SBIR projects annually, across all technologies (not only nanotechnology).

Figure 6 shows the level of nanotechnology funding provided by the SBIR programme by searching the key term "nano" in the SBIR awards database. While funding for nanotechnology commercialisation was available as early as 1988, the overall amount of funding was small and remained less than $1 million until boosted by the large scale federal nanotechnology activities in 1997. With the establishment of NNI in 2001, SBIR funding for nanotechnology increased by 7.4 times compared with the previous year. In 2005, the total funding reached $42.4 million, which was nevertheless still small considering the $1.2 billion total government funding for nanotechnology that year.

[31] Porter, A., Youtie, J., Shapira, P., Schoeneck, D., 2007. Refining Search Terms for Nanotechnology, Journal of Nanoparticle Research (Online First, August 3).

Figure 6. SBIR Investments in Nanotechnology ($US million), 1988-2005



Source: Tech-Net <http: //tech-net.sba.gov>

In addition, *state* nanotechnology initiatives are active in involving the business sector and promoting university-industry partnership since state governments in general are more concerned about generating job opportunities and promoting economic development. As noted below, all the state programmes have the main theme of facilitating commercialisation of nanotechnology discoveries and the integration of different communities. Table 1 presents major state nanotechnology initiatives in the US.

The efforts of state governments vary greatly in design, scope and scale. Some states have well-structured and coordinated dedicated nanotechnology programmes while other states offer only slight adjustments to existing programmes. For instance, the State of New York invested over $150 million on nanotechnology in 2004 while 20 states committed almost nothing.[32] Also, some states have made efforts in increasing nanotechnology R&D but not much more than that. For example, the State of Georgia committed $45 million in 2003 to support the Nanotechnology Research Centre at Georgia Institute of Technology following a contribution of $36 million from an anonymous donator. [33] The Centre is expected to be the most advanced nanotechnology research facility in the southeast area and enable the research community in Georgia to be able to compete with other regions. However, Georgia has not developed other coordinated state-wide initiative to mobilize resources for nanotechnology research and development.

[32] Lux Research (2005). Benchmarking U.S. States for Economic Development from Nanotechnology. New York, NY: Lux Research Inc.

[33] Source: Georgia Tech press release < http://www.gatech.edu/news-room/release.php?id=201 >

The dedicated nanotechnology initiatives of four leading states in the US – California, New York, Massachusetts and Pennsylvania – are described in the following section.

Table 1 Major State Nanotechnology Initiatives

State	Initiative
Arizona	Arizona Nanotechnology Cluster
California	California NanoSystems Institute; Northern California Nanotechnology Initiative; Nanotechnology Alliance in Southern California; Bay Area Nanotechnology Initiative
Colorado	Colorado Nanotechnology Alliance
Illinois	AtomWorks
Massachusetts	Massachusetts Nanotechnology Initiative
Michigan	Michigan Small Tech
Minnesota	Minnesota Nanotechnology Initiatives
New Jersey	New Jersey Nanotechnology Consortium
New Mexico	New Mexico Micro and Nano Technology Partnership
New York	Albany Nanotech; NanoNY
Oklahoma	Oklahoma Nanotechnology Initiative
Oregon	Oregon Nanosciences and Microtechnologies Institute
Pennsylvania	The Nanotechnology Institute; Nanofabrication Manufacturing Technology (NMT) Partnership
Texas	Texas Nanotechnology Initiative; Strategic Partnership for Research in Nanotechnology; Nano-at-the-Border Consortium
Virginia	Virginia Nanotechnology Initiative
Washington	Washington Nanotechnology Initiative
Washington DC	Greater Washington (DC) Nanotech Alliance

Source: Major State and Regional Nanotechnology Organisations
<http://www.ncnanotechnology.com/public/root/links.asp>

The State of California

The State of California is consistently ranked as the leading state in the development of nanotechnology in the annual *Small Times Review*[34] and performs well in several indicators (Table 2). California has been receiving significant R&D funding from the federal government and state government, as well as foundations such as the Kavli Nanoscience Institute and the Burnham Institute. The California Nanotechnology Initiative (CNI) is a private-public partnership programme aiming at expediting the development and commercialisation of nanotechnology in California. The California Institute of Nanotechnology was established by CNI to conduct applied research in nanotechnology and train nanotechnologists and technicians for nanotechnology

[34] ANGLE Technology Group (2004). Commonwealth of Pennsylvania Nanotechnology Strategy.

industry. At the request of the California Legislature's Joint Committee on Preparing California for the 21st Century, in 2004 the California Council on Science and Technology (CCST) produced a report, *Nanoscience and Nanotechnology: Opportunities and Challenges in California*, assessing California's position in nanotechnology and suggesting a long-term nanotechnology strategy. [35] Nanotechnology centres or laboratories are set up in universities such as UC Berkeley, Davis, Irvine, Los Angeles, UC Merced, UC Riverside, UC San Diego, UC San Francisco, UC Santa Barbara, UC Santa Cruz, and also in national labs such as Berkeley, Lawrence Livermore, and Los Alamos (Table 3).[36]

In addition to the state-wide initiative, different regions in California also develop their own programmes. The main regions are Northern California, Southern California, and the San Francisco Bay Area. Northern California is strong in technology commercialisation and early development while Southern California and the Bay Area have strong science and engineering base. The Northern California Nanotechnology Initiative (NCnano) is an economic development programme designed to build a leading nanotechnology cluster in Northern California by integrating universities, labs, governments and entrepreneurs.

Hosting UC Los Angeles (UCLA), UC Santa Barbara (UCSB), UC Riverside (UCR), Caltech, and University of South California (USC), Southern California has a solid base of nanotechnology expertise and research infrastructure. In 2000, UCLA and UCSB jointly set up the California NanoSystems Institute (CNSI) with $100 million from the State of California and an additional $250 million in federal research grants and industry funding. Its mission is to promote university-industry collaboration and expedite nanotechnology commercialisation. In 2002, UCLA, UCSB and UCR jointly formed the Centre for Nanoscience Innovation for Defence (CNID) to facilitate the transition of nanoscience research into defence applications. Larta Institute, formally known as the Los Angeles Regional Technology Alliance, expressed special interest in nanotechnology. Larta published the Nanotechnology Industry Report and Yellow Pages in June 2001 as an overview of the nanotechnology industry and has been producing the Nano Republic conferences since 2002 to promote technology transfer. In spite of strong research programmes, Southern California lacks a regional initiative such as UCNano and BANI.[37]

The Bay Area has made efforts to strengthen nanotechnology research capabilities and promote technology commercialisation. New nanotechnology research facilities are set up such as the Bio-Nanotechnology Centre and the Nanogeoscience Centre in Berkeley and the NASA Ames Centre for Nanotechnology and Stanford's Nanofabrication Facility in Silicon Valley. The San Francisco Council for Economic Development initiated the Bay Area Nanotech Initiative (BANI) in April 2003, which is a coordination programme with the aim of building partnerships with enterprises, R&D institutions and venture capitalists in the Bay Area and Silicon Valley.

---

35 CCST (2004). Nanoscience and Nanotechnology: Opportunities and Challenges in California. the California Council on Science and Technology.

36 Source: University of California website <http://www.universityofcalifornia.edu/research/nanotech.html>

37 CCST (2004). Nanoscience and Nanotechnology: Opportunities and Challenges in California. the California Council on Science and Technology.

Table 2 Nano NSF Funds, Publications and Patents by State, 2002-2004[38]

State	NSF Nano Funds	Nano Publications	Nano Patents Issued
California	$119 m.	2,077	530
New York	$100 m.	937	97
Pennsylvania	$62 m.	935	100
Massachusetts	$59 m.	984	172

The State of New York

The State of New York has been the largest investor of nanotechnology, contributing to 37.5% of nationwide state expenditure on nanotechnology in 2004. A coordinated programme, Albany Nanotech, was created by the state government in 2001 to develop the Albany metropolitan area as a global centre for nano-based semiconductor devices. Through Albany Nanotech, the state government is expected to invest over $500 million to construct semiconductor facilities at the State University of New York at Albany, which has also triggered matching commitments from industry. SUNY-Albany is the leading university in nanotechnology education. The College of Nanoscale Science and Engineering (CNSE) at SUNY-Albany is the first college dedicated to nanotechnology research and education and awarded the world's first Ph.D. degrees in nanoscience in 2004.[39] The State of New York also receives significant federal funding through NSF nanotechnology centres, such as the NSF Centre for Electronic Transport in Molecular Nanostructures at Columbia University, the NSF Centre for Nanoscale Systems in Information Technologies and the NSF-sponsored Science and Technology Centre on Bio-nanotechnology at Cornell University, the NSF Centre for Directed Assembly of Nanostructures at Rensselaer Polytechnic Institute and the National Nanofabrication Infrastructure Network.[40]

The State of Massachusetts

The State of Massachusetts has been one of leading areas of nanotechnology research. The Massachusetts Technology Collaborative (MTC) launched the Massachusetts Nanotechnology Initiative (MNI) in January 2003 to promote the industrialisation of nanotechnology in Massachusetts. In 2004, MTC and NSTI jointly published a report Nanotechnology in Massachusetts to assess the state's position in this new technology. Massachusetts is home to three of the NNI's nine Centres of Excellence: the Harvard Centre for the Science of Nanoscale Systems and Their Device Applications, the MIT Institute for Soldier Nanotechnologies (ISN) and the Northeastern University/UMass Lowell/University of University New Hampshire Nano Science and Engineering Centre, which have attracted significant funding from NSF and DOD. Nine universities in the state are participating in nanotechnology R&D, including Harvard University, the Massachusetts Institute of Technology, and the University of Massachusetts (Amherst, Dartmouth, and Lowell campuses). [41]

---

38 Geiger, Roger L. and Paul Hallacher (2005). Nanotechnology and the States: Public Policy, University Research, and Economic Development in Pennsylvania. A Report to the National Science Foundation.

39 Source: CNSE website < http://cnse.albany.edu/ >

40 ANGLE Technology Group (2004). Commonwealth of Pennsylvania Nanotechnology Strategy.

41 Massachusetts Nanotechnology Initiative < http://www.mtpc.org/mni/ >

The State of Pennsylvania

Pennsylvania is one of the few states with explicit policies to support nanoscience and engineering (NSE). Not being a top destination of federal nanotechnology R&D, Pennsylvania develops nanotechnology largely based on state initiatives. Pennsylvania started to invest in NSE in 1998 and created the Pennsylvania Nanofabrication Manufacturing Technology (NMT) Partnership, which was the earliest state investment in nanotechnology in the U.S. Ben Franklin Technology Partners of Southeastern Pennsylvania (BFTP/SEP), a non-profit economic development organisation, together with the University of Pennsylvania and Drexel University established the Nanotechnology Institute (NTI) in 2000. With funding from state and federal sources, NTI has the mission to promote university-industry collaboration and advance business development in nanotechnology in southeastern Pennsylvania.[42] In 2002, Pennsylvania State University started the nanotechnology research and commercialisation programme with the state funding. Pennsylvania is also part of the Mid-Atlantic Nanotechnology Alliance (MANA). MANA was created in fall 2004 and was the first multi-state partnership for nanotechnology is the U.S. MANA is funded by DOC with the aim of promoting R&D, application and commercialisation of nanotechnology in the Mid-Atlantic region – Pennsylvania, New Jersey and Delaware.

In January 2004, the state Department of Community and Economic Development (DCED) commissioned the ANGLE Technology Group to develop a state-wide initiative for nanotechnology. Based on the ANGLE report, DECD issued a Whitepaper entitled Pennsylvania Initiative for Nanotechnology in early 2005. Following that, a new Pennsylvania Initiative for Nanotechnology (PIN) was launched in mid 2005 with foci on maintaining research excellence and promoting nanotechnology commercialisation.[43] Penn State University, University of Pennsylvania, Carnegie Mellon University, University of Pittsburgh, Drexel University and Lehigh University are the main nanotechnology R&D performers in the state.[44]

---

42 The Nanotechnology Institute < http://www.nanotechinstitute.org/nti/index.jsp >

43 Geiger, Roger L. and Paul Hallacher (2005). Nanotechnology and the States: Public Policy, University Research, and Economic Development in Pennsylvania. A Report to the National Science Foundation.

44 ANGLE Technology Group (2004). Commonwealth of Pennsylvania Nanotechnology Strategy.

Table 3 Nanotechnology Research Facilities in Selected States in the U.S.[45]

New York	Pennsylvania	California	Massachusetts
– NSF Center for Nanoscale Systems (Cornell) – NSF Nanoscale Facility (Cornell) – Albany Nanotech (SUNY) – Center for Electronic Transport in Molecular Nanostructures (Columbia) – Dept. of Microelectronic Engineering (RIT) – Center for Functional Nanomaterials (Brookhaven) – Kavli Institute for Nanoscale Science (Cornell) – NSF Nanobiotechnology Center (Cornell) – Center for Directed Assembly of Nanostructures (RPI) – National Nanotechnology Infrastructure Network (Cornell) – NSF Center for Materials Research (Cornell)	– NSF Nanofabrication Center (PSU) – MEMS/Nanofabrication Center (CMU) – Data Storage Systems Center (CMU) – Center for Nanoscale Science (PSU) – Materials Characterisation Lab (PSU) – Center for Advanced Materials and Nanotechnology (Lehigh) – AJ Drexel Nanotechnology Institute (Drexel) – Keck Smart Materials Integration Lab (PSU) – Materials Science Research and Engineering Center (Penn)	– NASA Ames (Space Based applications) – NanoSystems Institute (UCLA/UCSB) – Center for Embedded Network Sensing (UCLA) – NSF Nanofabrication Center (UCSB) – Center for Scalable and Integrated Nanofabrication (UC) – DOE Molecular Foundry (LLNL) – MEMS Lab (UCLA) – Materials and Process Simulation Center (Caltech) – Kavli Nanoscience Institute (CalTech) – NASA Ames Research Lab (Computational Nanotechnology) – Institute for Collaborative Biotechnologies (UCSB/Caltech/MIT) – Dept. of Biomolecular Engineering (UCSC) – National Nanotechnology Infrastructure Network (Stanford) – Burnham Institute (San Diego) – Center for Nanoscale Science and Engineering (UCR) – Center for Nanoscience Innovation for Defense (UCR/UCLA/UCSB)	– Army Institute for Soldier Nanotechnologies (MIT) – MassNanoTech Research Center (Umass) – Space Nanotechnology Laboratory (MIT) – Institute for Collaborative Biotechnologies (UCSB/Caltech/MIT) – National Nanotechnology Infrastructure Network (Harvard) – Nano Science and Technology Institute (Cambridge)

[45] ANGLE Technology Group (2004). Commonwealth of Pennsylvania Nanotechnology Strategy.

5. Impacts of Non-R&D Policies on US Nanotechnology

The *21st Century Nanotechnology Research and Development Act* explicitly notes the importance of understanding the risk and social implications of nanotechnology. However, there is no specific framework for nanotechnology regulation beyond existing ones, such as regulations on food and drug monitored by the Food and Drug Administration (FDA). Possible governance approaches have been discussed in several reports including *Securing the Promise of Nanotechnology* by the Environmental Law Institute (ELI), *Managing the Effects of Nanotechnology* by the Woodrow Wilson Centre, and *End-of-life Regulations of Nanotechnology* also by the Woodrow Wilson Centre. These reports suggested that several federal statutes could be applied to regulate nanotechnologies, such as the Toxic Substances Control Act (TSCA), the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or the Superfund Law).

While the consensus on the definition of nanotechnology has not been reached, several organisations have made efforts to develop nanotechnology related standards and classifications. For example, the American National Standards Institute established the Nanotechnology Standards Panel (ANSI-NSP) in 2004 to coordinate the development of standards in nanotechnology. The ASTM International Committee on Nanotechnology approved the first standard terminology for nanotechnology in 2006. The United States Patent and Trademark Office (USPTO) has an ongoing project of developing a comprehensive nanotechnology classification (Class 977). These efforts have contributed to the R&D policy mix by establishing categories and standards which facilitate information collection, communication among different sectors, and monitoring.

A broader contribution to the policy mix is the renewed interest in science and engineering education in the US. Initiatives such as the *Innovate America* initiated by the Council on Competitiveness in 2004, the *Rising Above the Gathering Storm* report produced by the National Academy of Sciences in 2006, and the *America Competes Act* introduced in the US Senate and House of Representatives in 2007 proposed a new education strategy and encouraged more graduates in science, technology, engineering and mathematics occupations. These federal investments in science education and workforce development complement NNI investments in education and workforce issues associated with the advancement of nanotechnology.[46]

However, the attractiveness of the US to foreign scientists has been increasingly challenged by European countries. The visa and immigration situation in the US becomes more stringent after 911, which largely reduces the willingness of foreign scholars and students to do research in the US. The newly announced European Blue Card plan is competing with the American Green Card in attracting foreign scientific human capital. Hence, the US is gradually losing talents to other countries, which might affect its leadership in science and technology, including nanotechnology.

[46] NSTC (2007). The National Nanotechnology Initiatives: Supplement to the President's 2008 Budget.

6. Economic Impacts of Nanotechnology

It is anticipated that nanotechnology will have many economically valuable applications in a diverse range of industries, including materials and manufacturing, nanoelectronics and computer technology, medicine and health, aeronautics and space exploration, environment and energy, national security, global trade and competitiveness.[47] The benefits that nanotechnology are expected to bring include greatly improved coatings, higher strength and hardness for materials, greater ductility and toughness, enhanced efficiency in optics, improved catalysis and novel magnetic properties.[48] Some proponents argue that nanotechnology will lead to the "next industrial revolution." The NSF predicts that "the entire semiconductor industry and half of the pharmaceutical industry will rely on nanotechnology in 10 years and that, by 2015, the global market will be 1 trillion US dollars".[49]

To date, numerous applications of nanotechnology have emerged in the market. Typically, many of these applications incorporate nanotechnologies into products already being used by consumers are the paints and cosmetics (e.g., shampoos, skin creams, and sunscreens) industries. [50] Other commercial applications of nanotechnology already in use include hard-disks for computers and improvements to telecommunications. According to the Lux Report 2006, the electronics and IT sector will be the main beneficiary of nanotechnology, with half of manufactured output being nano-enabled in 2014. The revenue from nanotechnology related products was $13 billion in 2004, two-thirds of which was contributed by cars and airplanes incorporating nanocomposites and nanocoatings. The Lux Report predicts that the revenue from products incorporating nanotechnologies will reach $2.6 trillion in 2014, 15% of manufacturing output that year. The number of jobs in making nano-enabled products will reach over 10 million in 2014, 11% of total manufacturing jobs.[51]

The impact of nanotechnology on industry has been explored in several empirical studies by researchers in the US and elsewhere. Darby and Zucker managed to link scientific breakthroughs in nanotechnology with industry development by studying entrepreneurial activities and bibliometric indicators.[52] Bibliometric methods are also applied to explore growth trends in nanotechnology research and patterns of research

---

47 NSTC (1999). Nanostructure Science and Technology: A Worldwide Study. R.W. Siegel and M.C. Roco. Washington DC, National Science and Technology Council.

48 Smith, R. H. I. (1998). A Policy Framework for Developing a National nanotechnology Programme. Science and Technology Studies. Blacksburg, Virginia, Virginia Polytechnic Institute and State University.

49 ETC-Group (2002). "No Small Matter! Nanotech Particles Penetrate Living Cells and Accumulate in Animal Organs." ETC Group Communique **76**(May/June).

50 Wood , S., R. Jones, et al. (2003). The Social and Economic Challenges of Nanotechnology. Swindon, UK, Economic and Social Research Council.

51 Lux Research (2006). The Nanotechnology Report 4th Edition. New York, NY: Lux Research Inc.

52 Darby, MR and L Zucker (2003). "Growing by leaps and inches: Creative destruction, real cost reduction, and inching up". Economic Inquiry 41 (1): 1-19.

collaboration in nanoscience and technology.[53] The impact of nanotechnology on the general public has been the subject of several public opinion studies. It has been found that public perception and understanding of nanotechnology is influenced not only by existing knowledge of nanotechnology, but also by statements of nanotechnology and media framework and culture.[54]

Arising alongside the anticipated economic benefits have been concerns about social equity, environmental, and ethical consequence of nanotechnology. News narratives about nanotechnology in major U.S. and non-U.S. newspapers 1988-2004 were dominated by concerns regarding the ethical, legal, and societal implications of nanotechnology.[55] It is cautioned that nanotechnology has the potential to be used for harmful purposes, leading to destructive rather than constructive results if the knowledge is abused.[56] New classes of nanosubstances could adversely affect the stability of cell walls or disturb the immune system when inhaled or digested.[57] Noting the potential effects nanotechnology having on environment, human health and cultural values, studies have been done to survey social and ethical issues in nanotechnology[58], assess long-term impact of nanotechnology on environment and sustainability[59], and propose risk governance models[60] and risk assessment framework to support the decision about safety[61]. In particular, Altman examined the specific dangers to arms control and stability arising from nanotechnology applications in military and suggested to limit military development for the near term.[62] Nonetheless, as yet, public debate about nanotechnology development in the US has not been

---

53 Braun, T., A. Schubert and S. Zsindely (1997). “Nanoscience and nanotechnology on the balance”. Scientometrics 38 (2): 321-325.Huang, Z. HC Chen, A. Yip, G. Ng, F. Guo, Z.K. Chen and M.C. Roco (2003). “Longitudinal patent analysis for nanoscale science and engineering: Country, institution and technology field”. Journal of Nanoparticle Research 5 (3-4): 333-363; Schummer, J (2004). “Multidisciplinarity, interdisciplinarity, and patterns of research collaboration in nanoscience and nanotechnology”. Scientometrics 59 (3): 425-465.

54 Lee, CJ. D.A. Scheufele and B.V. Lewenstein (2005). “Public attitudes toward emerging technologies - Examining the interactive effects of cognitions and affect on public attitudes toward nanotechnology”. Science Communication 27 (2): 240-267; Bainbridge, W.S. (2002). “Public attitudes toward nanotechnology”. Journal of Nanoparticle Research 4 (6): 561-570; Cobb, MD (2005). “Framing effects on public opinion about nanotechnology”; Macoubrie, J (2006). “Nanotechnology: public concerns, reasoning and trust in government”. Public Understanding of Science 15 (2): 221-241; Gaskell, G. T. Ten Eyck, J. Jackson and G. Veltri (2005). “Imagining nanotechnology: cultural support for technological innovation in Europe and the United States”. Public Understanding of Science 14 (1): 81-90.

55 Stephens, LF (2005). “News narratives about nano S&T in major US and non-US newspapers”. Science Communication 27 (2): 175-199.

56 Wood , S., R. Jones, et al. (2003). The Social and Economic Challenges of Nanotechnology. Swindon, UK, Economic and Social Research Council.

57 Freitas, R. A. J. (2003). "Nanomedicine, Volume IIA: Biocompatibility." Retrieved April 25, 2005, from http://www.nanomedicine.com/NMIIA.htm.

58 Lewenstein, BV (2005). “What counts as a 'social and ethical issue' in nanotechnology?”. HYLE 11 (1-2): 5-18 2005.

59 Dewick, P., K. Green and M. Miozzo (2004). “Technological change, industry structure and the environment”. Futures 36 (3): 267-293.

60 Renn, O. and M.C. Roco (2006). “Nanotechnology and the need for risk governance”. Journal of Nanoparticle Research 8 (2): 153-191.

61 Morgan, K. (2005). “Development of a preliminary framework for informing the risk analysis and risk management of nanoparticles”. Risk Analysis 25 (6): 1621-1635.

62 Altmann, J. (2004). “Military uses of nanotechnology: Perspectives and concerns”. Security Dialogue 35 (1): 61-79.

intense, and there is little evidence that public perception (whether expressed as apprehension or confidence) has significantly influenced the policy mix.

7. Concluding Observations

The US has been one of the first countries to recognize the potential of nanotechnology and to establish R&D funding for nanotechnology. Initial support for nanotechnology R&D dates back to the 1980s. With the establishment of the multi-agency NNI in 2001, federal investment in nanotechnology has been coordinated. R&D funding for nanotechnology has increased greatly since then.

However, what is significant about the US is not just the scale of nanotechnology support but the policy mix. The policy landscape comprises a variety of approaches including dedicated nanotechnology funding, general R&D programs which are also open to nanoscale research, a specific legislative framework (21st Century Nanotechnology R&D Act), other facilitative legislative and regulatory measures (such as the Bahy-Dole Act, which governs patenting derived from federally-sponsored R&D in universities), specific nanotechnology human capital initiatives, and general human capital policies, and a multiplicity of policy stakeholders, organizational sponsors and research performers at federal and state levels.

The policy landscape prioritizes nanotechnology research, but nanotechnology research projects are not predefined: R&D funding is provided primarily based on bottom-up research proposals. Scientists enjoy a large extent of freedom and flexibility in defining their research priorities and setting research agenda. At the same time, a certain portion of nanotechnology R&D has been invested on infrastructure of research networks and user facilities. The NNI has also made substantial efforts to address the societal and ethical implications of nanotechnology by bring research and regulatory agencies together, organizing workshops and creating centres and education programmes. State nanotechnology initiatives have a different yet complementary focus when compared with federal initiatives. Since state governments are concerned with regional economic development and job creation, state and regional nanotechnology programmes play an active role in promoting university-industry partnership and facilitating nanotechnology commercialisation.

Finally, non-R&D policies are also relevant to the development of nanotechnology. In the US – as in other countries – regulatory policies and standards for nanotechnology are still under development, notwithstanding concerns and interests expressed about the risks and ethical issues associated with nanotechnology. Concerns about workforce development in science and engineering have resulted in increased investment in science and engineering and renewed debate about immigration policies for foreign technical talent. In other areas, ranging from intellectual property to the availability of venture capital, there are specific debates and recommendations for improvement, but overall, the non-R&D policy framework appears to be broadly supportive for the further research, development and commercialization of nanotechnology in the US.