

CRS Report for Congress

Nanotechnology and U.S. Competitiveness: Issues and Options

May 15, 2008

John F. Sargent
Specialist in Science and Technology Policy
Resources, Science, and Industry Division



Prepared for Members and
Committees of Congress

Nanotechnology and U.S. Competitiveness: Issues and Options

Summary

The projected economic and societal benefits of nanotechnology have propelled global investments by nations and companies. The United States launched the first national nanotechnology initiative in 2000. Since then, more than 60 nations have launched similar initiatives. In 2006, global public investment in nanotechnology was estimated to be \$6.4 billion, with an additional \$6.0 billion provided by the private sector. More than 600 nanotechnology products are now in the market, generally offering incremental improvements over existing products. However, proponents maintain that nanotechnology research and development currently underway could offer revolutionary applications with significant implications for the U.S. economy, national and homeland security, and societal well-being. These investments, coupled with nanotechnology's potential implications, have raised interest and concerns about the U.S. competitive position.

The data used to assess competitiveness in mature technologies and industries, such as revenues and market share, are not available for assessing nanotechnology. In fact, the U.S. government does not currently collect such data for nanotechnology, nor is comparable international data available. Without this information, an authoritative assessment of the U.S. competitive position is not possible. Alternatively, indicators of U.S. scientific and technological strength (e.g., public and private research investments, nanotechnology papers published in scientific journals, patents) may provide insight into the current U.S. position and serve as bellwethers of future competitiveness. By these criteria, the United States appears to be the overall global leader in nanotechnology. However, other nations are investing heavily and may lead in specific areas of nanotechnology. Some believe the U.S. leadership position in nanotechnology may not be as large as it has been in previous emerging technologies.

Efforts to develop and commercialize nanotechnology face a variety of challenges — e.g., technical hurdles; availability of capital; environmental, health, and safety concerns; and immature manufacturing technology and infrastructure. Some advocate a more active federal government role in overcoming these challenges, including funding to aid in the translation of research to commercial products; general and targeted tax provisions; incentives for capital formation; increased support for development of manufacturing and testing infrastructure, standards and nomenclature development, and education and training; creation of science, technology, and innovation parks; and efforts to establish a stable and predictable regulatory environment that keeps pace with innovation.

Some support a more limited federal role. Some who hold this view maintain that the market, free from government interventions, is most efficient. They assert that federal efforts can create market distortions and result in the federal government picking “winners and losers” among technologies, companies, and industries. Others oppose federal support for industrial research and applications, labeling such efforts “corporate welfare.” Still others argue for a moratorium on nanotechnology R&D until environmental, health, and safety concerns are addressed.

Contents

Introduction	1
Current and Anticipated Applications	3
U.S. Competitiveness Indicators	5
Research and Development Investments	9
Public Investments	10
Private Sector Investments	11
Scientific Papers	12
Output of Peer-reviewed Papers	12
Citations to Peer-reviewed Papers	14
Papers in “High-impact” Journals	15
Patents	15
The Federal Role in U.S. Competitiveness: Issues and Options	17
Technology Development	18
Direct Support	21
Indirect Support	21
Infrastructure Development	22
Addressing Regulatory Concerns	22
Workforce Development	23
International Coordination and Cooperation	24
Reassessing and Realigning Resources	24
Concluding Observations	25

List of Figures

Figure 1. Nanotechnology Papers in the Science Citation Index, by Region, 2000-2005	14
Figure 2. Relative Commitment of Ten Countries to Nanotechnology, 2003 ...	15

List of Tables

Table 1. Top Ten Countries in Public Nanotechnology R&D, 2006	11
---	----

Nanotechnology and U.S. Competitiveness: Issues and Options

Introduction

Nanotechnology is believed by many to be one of the most promising areas of technological development and among the most likely to deliver substantial economic and societal benefits to the United States in the 21st century. With so much potentially at stake, a global competition has emerged among nations and companies to develop and capture the value of nanotechnology products.

Competitiveness generally refers to the comparative ability of a nation or company to bring products or services to markets. Assessments of competitive strength generally rely on indicators such as revenues, market share, and trade. However, since nanotechnology is still largely in an early stage of development the U.S. government does not collect this type of data for nanotechnology products. In addition, nanotechnology is not a discrete industry, but rather a technology applied across a wide range of products in disparate industries for which nanotechnology products generally account for a small fraction of total sales. For these reasons, an assessment of U.S. industrial competitiveness in nanotechnology — in the same manner that analysts would assess the competitiveness of mature industries — is not possible at this time. Alternatively, this report reviews national nanotechnology research and development (R&D) investments, scientific papers, and patents as indicators of current U.S. scientific and technological competitiveness and potential indicators of future industrial competitiveness in nanotechnology products.

The federal government has played a central role in catalyzing U.S. R&D efforts. In 2000, President Clinton launched the U.S. National Nanotechnology Initiative (NNI), the world's first integrated national effort focused on nanotechnology. The NNI has enjoyed strong, bipartisan support from the executive branch, the House of Representatives, and the Senate. Each year, the President has proposed increased funding for federal nanotechnology R&D, and each year Congress has provided additional funding. Since the inception of the NNI, Congress has appropriated a total of \$8.4 billion for nanotechnology R&D intended to foster continued U.S. technological leadership and to support the technology's development, with the long-term goals of: creating high-wage jobs, economic growth, and wealth creation; addressing critical national needs; renewing U.S. manufacturing leadership; and improving health, the environment, and the overall quality of life.

The United States is not alone in seeking to tap the perceived potential of nanotechnology. Following the creation of the NNI, more than 60 nations have established their own national nanotechnology initiatives, many based on the U.S.

model. Estimated global annual public investments in nanotechnology, including those of the United States, reached \$6.4 billion in 2006, with another \$6.0 billion invested by the private sector.¹ In addition, some countries have established strategic plans; nanotechnology-focused science, technology, and innovation parks; venture capital funds; and other policies and programs to accelerate the translation of nanotechnology research into products to exploit its economic potential. These investments and policies, coupled with generally optimistic expectations, have raised interest and concerns about the global competitive position of the United States in the development and commercialization of nanotechnology.

In 2003, Congress enacted the 21st Century Nanotechnology Research and Development Act (P.L. 108-153) assigning responsibilities and initiating research efforts to address key challenges. In the act, Congress explicitly established global technological leadership, commercialization, and national competitiveness as central goals of the NNI:

National Nanotechnology Initiative

The National Nanotechnology Initiative is a federal government R&D initiative, coordinated by the White House, involving 25 departments and agencies, including 13 that conduct nanotechnology R&D.

President Bill Clinton launched the NNI in 2000, and Congress provided \$464 million in R&D funding to NNI agencies in FY2001. Since then, Congress has more than tripled annual funding, providing \$1.49 billion in FY2008, bringing cumulative appropriations for NNI activities to \$8.4 billion. President Bush has requested \$1.53 billion for the NNI in FY2009.

The NNI budget is an aggregation of the nanotechnology components of the individual budgets of NNI-participating agencies. The NNI budget is not a single, centralized source of funds that is allocated to individual agencies. In fact, agency nanotechnology budgets are developed internally as part of each agency's overall budget development process. These budgets are subjected to review, revision, and approval by the White House Office of Management and Budget and become part of the President's annual budget submission to Congress. The NNI budget is then calculated by aggregating the nanotechnology components of the appropriations provided by Congress to each federal agency.

In 2003, Congress provided a statutory foundation for some of the activities of the NNI through the 21st Century Nanotechnology Research and Development Act (P.L. 108-153). The Act established a National Nanotechnology Program (NNP) and provided authorizations totaling \$3.7 billion over four years (FY2005-FY2008) for five NNI agencies: the National Science Foundation, Department of Energy, NASA, National Institute of Standards and Technology, and the Environmental Protection Agency. In total, Congress appropriated \$2.9 billion for these agencies during this period, or approximately 79% of total authorized funding. The Act did not address the participation of several agencies that fund nanotechnology R&D under the NNI, including the Department of Defense, National Institutes of Health, and the Department of Homeland Security.

¹ *Profiting From International Nanotechnology*, Lux Research, December 2006. p. 2.

The activities of the Program shall include —

...ensuring United States global leadership in the development and application of nanotechnology;

advancing the United States productivity and industrial competitiveness through stable, consistent, and coordinated investments in long-term scientific and engineering research in nanotechnology;

accelerating the deployment and application of nanotechnology research and development in the private sector, including start-up companies; ...and

encouraging research on nanotechnology advances that utilize existing processes and technologies.

Congress has expressed interest in understanding whether the current level of appropriations and the portfolio of activities pursued by the NNI is sufficient to achieve these goals. There are a variety of perspectives on the sufficiency and balance of activities and resources devoted to nanotechnology R&D, regulation, and infrastructure. This report provides an overview of nanotechnology, current and anticipated applications, indicators of U.S. scientific and technological strength, and issues and options Congress may opt to consider for the federal role, if any, in promoting the nation's competitive position in nanotechnology.

Current and Anticipated Applications

Nanotechnology — a term encompassing nanoscale science, technology, and engineering — involves the understanding and control of matter at scales between 1 and 100 nanometers. A nanometer is one-billionth of a meter; by way of comparison, the width of a human hair is approximately 80,000 nanometers.

At this size, the physical, chemical, and biological properties of materials can differ in fundamental and potentially useful ways from the properties of individual atoms and molecules, on the one hand, or bulk matter, on the other hand. Nanotechnology research and development is directed toward understanding and creating improved materials, devices, and systems that exploit these properties as they are discovered and characterized.²

Most nanotechnology products currently on the market — such as faster computer processors, higher density memory devices, better baseball bats, lighter-weight auto parts, stain-resistant clothing, cosmetics, and clear sunscreen — are evolutionary in nature, offering valuable, but generally modest, economic and societal benefits.

² *The National Nanotechnology Initiative Strategic Plan*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, December 2007.

Over the next five to ten years, proponents see nanotechnology offering the potential for additional evolutionary improvements in existing products. Beyond the next ten years, they believe that nanotechnology could deliver revolutionary advances that could transform or replace existing products and industries, and create entirely new ones. Some hoped-for applications discussed by the technology's proponents, involving various degrees of speculation and varying time-frames, include: new prevention, detection, and treatment technologies that reduce death and suffering from cancer and other deadly diseases;³ new organs to replace damaged or diseased ones;⁴ clothing that protects against toxins and pathogens;⁵ clean, inexpensive, renewable power through energy creation, storage, and transmission technologies;⁶ universal access to safe water through portable, inexpensive water purification systems;⁷ energy efficient, low-emission "green" manufacturing systems;⁸ high-density memory systems capable of storing the entire Library of Congress collection on a device the size of a sugar cube;⁹ agricultural technologies that increase yield and improve nutrition, reducing global hunger and malnutrition;¹⁰ self-healing materials;¹¹ powerful, small, inexpensive sensors that can warn of minute levels of toxins and pathogens in air, soil, or water, and alert us to changes in the environment;¹² and environmental remediation of contaminated industrial sites.¹³ Proponents in government, academia, and industry also maintain that nanotechnology

³ National Cancer Institute website. [http://nano.cancer.gov/resource_center/tech_backgrounder.asp]

⁴ Ibid.

⁵ Risbud, Aditi. "Fruit of the Nano Loom," *Technology Review*, February 2006.

⁶ *Nanoscience Research for Energy Needs*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, December 2004.

⁷ Risbud, Aditi. "Cheap Drinking Water from the Ocean," *Technology Review*, June 2006.

⁸ Selko, Adrienne. "New Nanotechnology-Based Coatings are Energy Efficient and Environmentally Sound," *Industry Week*, August 22, 2007. "Tomorrow's Green Nanofactories," *Science Daily*, July 11, 2007.

⁹ *National Nanotechnology Initiative — Leading to the Next Industrial Revolution*, Interagency Working Group on Nanoscience, Engineering, and Technology, National Science and Technology Council, The White House. [<http://www.ostp.gov/NSTC/html/iwgn/iwgn.fy01budsuppl/nni.pdf>]

¹⁰ *21st Century Agriculture: A Critical Role for Science and Technology*, U.S. Department of Agriculture, June 2003; *Nanoscale Science and Engineering for Agriculture and Food Systems*, draft report on the National Planning Workshop, submitted to the Cooperative State Research, Education, and Extension Service of the U.S. Department of Agriculture, July 2003.

¹¹ *Nanotechnology in Space Exploration*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, August 2004.

¹² *Nanotechnology and the Environment*, Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, May 2003.

¹³ *Proceedings of the U.S. Environmental Protection Agency Workshop on Nanotechnology for Site Remediation*, U.S. Environmental Protection Agency, October 2005.

could make substantial contributions to national defense, homeland security, and space exploration and commercialization.

Many areas of public policy could affect the ability of the United States to capture the future economic and societal benefits associated with these investments. Congress established programs, assigned responsibilities, authorized funding levels, and initiated research to address key issues in the 21st Century Nanotechnology Research and Development Act. The agency budget authorizations provided for in this act extend through FY2008 (see text box, “National Nanotechnology Initiative,” for discussion of authorizations and appropriations).¹⁴ Both the House and Senate have held committee hearings related to amending and reauthorizing this act in 2008. A companion report, CRS Report RL34401, *The National Nanotechnology Initiative: Overview, Reauthorization, and Appropriations Issues*, by John F. Sargent, provides an overview of nanotechnology; the history, goals, structure, and federal funding of the National Nanotechnology Initiative; and issues related to its management and reauthorization.

As the state of nanotechnology knowledge has advanced, new policy issues have emerged. In addition to providing funding for nanotechnology R&D, Congress has directed increased attention to issues affecting the U.S. competitive position in nanotechnology and related issues, including nanomanufacturing; commercialization; environmental, health, and safety concerns; workforce development; and international collaboration. Views and options related to these issues are presented later in this report.

U.S. Competitiveness Indicators

Nanotechnology is, by and large, still in its infancy. Accordingly, measures such as revenues, market share, and global trade statistics — indicators often used to assess and track U.S. competitiveness in other technologies and industries — are not available for assessing the U.S. position in nanotechnology. To date, the federal government does not collect data on nanotechnology-related revenues, trade or employment, nor is comparable international government data available.

Nevertheless, many experts believe that the United States is the global leader in nanotechnology. For example, a survey of U.S. business leaders in the field of nanotechnology showed 63% believe that the United States is leading other countries

¹⁴ Under the act, Congress authorized \$3.7 billion over four years (FY2005-FY2008) for five NNI agencies: the National Science Foundation, Department of Energy, NASA, National Institute of Standards and Technology, and the Environmental Protection Agency. In total, Congress appropriated \$2.9 billion for these agencies during this period, or approximately 79% of authorized funding. Several NNI agencies — including two with large nanotechnology R&D budgets, the Department of Defense and National Institutes of Health — did not receive budget authorizations under the act.

in nanotechnology R&D and commercialization while only 7% identified the United States as lagging behind other countries.¹⁵

However, some believe that in contrast to many previous emerging technologies — such as semiconductors, satellites, software, and biotechnology — the U.S. lead appears narrower and the investment level, scientific and industrial infrastructure, technical capabilities, and science and engineering workforces of other nations are more substantial than in the past. Charles Vest, president of the National Academies of Engineering and a member of the President’s Council of Advisors on Science and Technology (PCAST), asserted early in 2008 that nanotechnology was the first emerging technology “where we [the United States] don’t have a huge lead.” Vest added that it was also the first emerging technology in which the federal government’s efforts included “commercialization as a specific goal” and thus was “the first real test” of the United States’ “loosely-coupled public-private partnership in the new competitive environment.”¹⁶

Evidence of commercialization of nanotechnology-based products is generally available. For example, the Woodrow Wilson International Center for Scholars’ Project on Emerging Nanotechnologies counts more than 600 company-identified nanotechnology products on the market, more than half of which are produced by companies based in the United States.¹⁷ Some private organizations have attempted to estimate current nanotechnology-derived revenues and to estimate future revenues. For example, Lux Research estimates that products incorporating nanotechnology produced \$50 billion in global revenues in 2006¹⁸ (less than 0.1% of global manufacturing output), and that by 2014 revenues will reach \$2.6 trillion or 15% of projected global manufacturing output.¹⁹

In the absence of comprehensive and authoritative economic output data (e.g., revenues, market share, trade), indicators such as inputs (e.g., public and private research investments) and non-financial outputs (e.g., scientific papers, patents) are now used to gauge a nation’s current and future competitive position in emerging technologies. These indicators offer insights into nations’ scientific and technological strength which may serve as a foundation for future product and process innovation.

¹⁵ “Survey of U.S. Nanotechnology Executives,” conducted by Small Times Magazine and the Center for Economic and Civic Opinion at the University of Massachusetts-Lowell, Fall 2006. [http://www.masseconomy.org/pdfs/nano_survey_report_gocefd2.pdf]

¹⁶ Personal notes from PCAST meeting held January 8, 2008.

¹⁷ “Consumers Talk Nano,” press release, Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars, October 22, 2007. [http://www.wilsoncenter.org/index.cfm?topic_id=166192&fuseaction=topics.item&news_id=297072]

¹⁸ *The Nanotech Report, 5th Edition, Vol. 1*, Lux Research, November 2007. p. iii.

¹⁹ Nordan, Matthew, president, LuxResearch, Inc. Testimony before the Subcommittee on Science, Technology, and Innovation, Committee on Commerce, Science and Transportation, U.S. Senate. Hearing on “National Nanotechnology Initiative: Charting the Course for Reauthorization.” 110th Cong., 2nd Sess., April 24, 2008. [http://commerce.senate.gov/public/_files/LuxResearchSenateCommerceCommitteetestimony4242008.pdf]

However, research and development investments, scientific papers, and patents may not provide reliable indicators of the United States' current or future competitive position. Scientific and technological leadership may not necessarily result in commercial leadership and/or in national competitiveness for the following reasons:

Basic research in nanotechnology may not translate into viable commercial applications. Though no formal assessment of the composition of the NNI budget has been made, there is general consensus that the NNI investment since its inception has been focused on basic research. The National Science Foundation defines the objective of basic research as seeking “to gain more comprehensive knowledge or understanding of the subject under study without applications in mind.”²⁰ Therefore, while basic research may underpin applied research, development, and commercialization, that is not its primary focus or intent. In general, basic research can take decades²¹ to result in commercial applications, and many advances in scientific understanding may not present commercial opportunities.

Basic research is generally available to all competitors. Even when basic research presents the potential for commercial exploitation, it may not deliver national advantage. Open publication and free exchange of research results are guiding principles of federally funded fundamental research²² and research conducted by U.S. colleges and universities. This approach may allow for the rapid expansion of global scientific and technical knowledge as new work is built on the scaffolding of previous work. However, the information is available to all competitors, U.S. and foreign alike, and thus may not confer competitive advantage to the United States.

U.S.-based companies may conduct production and other work outside of the United States. In today's economy, supply chains are global and the work required to develop, design, produce, market, sell, and service products is generally conducted where it can be done most efficiently. Even if U.S.-based companies successfully develop and bring nanotechnology materials and products to market, work may be conducted, and the economic value captured, outside of the United States. Federal policies and investments may offer tools that can make the United States the most attractive place for companies to conduct a greater share of value-adding activities, contributing to U.S. economic growth and job creation.

²⁰ *Science and Engineering Indicators 2008*, National Science Foundation, January 2008.

²¹ For example, the first working fuel cell was built in 1843, but the first semi-commercial use of a fuel cell did not occur for more than a hundred years when the technology was used in NASA's Project Gemini space program. Even today, commercial production and use of fuel cells is limited and federal technology development efforts continue.

²² National Security Decision Directive 189 states that, “It is the policy of this Administration that, to the maximum extent possible, the products of fundamental research remain unrestricted.” The directive allows for restriction of some results through national security classification. Fundamental research is defined in the directive as including both basic and applied research in science and engineering, but distinct from proprietary research and industrial development, design, production, and product utilization. For further information on U.S. policy toward unrestricted access to federally-funded fundamental research, see CRS Report RL31695, *Balancing Scientific Publication and National Security Concerns: Issues for Congress*, by Dana A. Shea.

U.S.-educated foreign students may return home to conduct research and create new businesses. In the era following World War II, many of the most gifted and talented students from around the world were attracted to the science and engineering programs of U.S. colleges and universities. For many years, many of those who graduated from these programs decided to stay in the United States and contributed to U.S. global scientific, engineering, and economic leadership. Today, many foreign students educated in the United States have economic opportunities in their home countries that did not exist for previous generations. Some nations are making strong appeals and offering significant incentives for their students to return home to conduct research and create enterprises. Thus, federal support for universities, in general, and scientific and engineering research activities, in particular, may contribute to the development of leading scientists and engineers who might return to their home countries to exploit the knowledge, capabilities, and networks developed in the United States.

Small businesses may lack the resources needed to bring their nanotechnology innovations to market. Federal programs, such as the Small Business Innovation Research (SBIR) program and the Small Business Technology Transfer (STTR) program, support leading-edge nanotechnology research by small innovative firms. Federally funded university research can produce small start-up ventures. These small businesses may develop commercially valuable technology, and even successfully develop new nanotechnology materials, tools, processes, or products, but lack the capital, infrastructure, or sales and distribution channels to effectively bring such advances to market.

U.S. companies with leading-edge, nanotechnology capabilities and/or their intellectual property may be acquired by foreign competitors. Foreign companies may acquire leading-edge nanotechnology companies or their intellectual property. This can take place, for example, as the result of an intentional business strategy to be acquired (a common exit strategy for start-up companies), a hostile takeover if the enterprise is a public company, or when a business has failed or is failing. In the latter case, the company or its intellectual property might be acquired at a fraction of its development cost or potential value.

U.S. policies or other factors may impede nanotechnology commercialization, make it unaffordable, or make it less attractive than foreign alternatives. Federal, state, and local policies (e.g., taxes, environmental and health regulations, ethical restrictions) and other factors (e.g., availability, quality, and cost of labor; proximity to markets; customer requirements; manufacturing infrastructure; public attitudes) may prevent or discourage commercialization of nanotechnology innovations in the United States. Companies may be prohibited from producing a commercially viable product in the United States, may be unable to do so affordably, or may find comparatively favorable conditions (e.g. lower taxes or tax holidays; fewer regulatory restrictions; qualified, available, and less costly workforce) outside the United States.

Comparisons of aggregate national data may be misleading. For example, a small nation with limited resources may be unable to pursue leading-edge research across a broad spectrum of nanotechnology-related disciplines and applications, and instead opt to seek technological dominance in a discreet area by investing in a

limited set of disciplines and applications (or even a single one). In such a case, that country may become the strongest competitor in a given area, while analysis of aggregate numbers might obscure this strength. Alternatively, a rapidly developing nation may invest substantial capital in nanotechnology research, but lack key elements — such as a strong scientific and technological infrastructure; mature industry, service, and private capital infrastructure; experienced scientists, engineers, managers, and entrepreneurs; and/or a market-oriented business climate — needed to fully capitalize on such an investment.

In addition, the concept of a national competitive position may differ from the past as a result of increased globalization of research, technical talent, and production. For example, the world's leading-edge research in a field of nanotechnology might be conducted at an American university, by Chinese students, supported by research funds from a German-based corporation, with engineering underway in Russia, plans to manufacture in Taiwan, shipping by Greek-flagged vessels, and technical support provided online and by telephone from India. In such an example, the global distribution of knowledge workers, investors, and producers make the determination of national competitiveness more difficult.

Just as other countries might benefit from U.S. nanotechnology R&D, so too might the United States benefit from nanotechnology R&D conducted in other nations through a variety of means including studying published research results, acquiring or licensing patents, conducting joint business ventures, and by fostering a business environment that attracts production and related activities. Some economists assert that international R&D collaboration can benefit the United States as well by improving the productivity of the R&D process.²³

With these caveats, the following section reviews input and non-economic output measures as indicators of the U.S. competitive position in nanotechnology.

²³ *Economic Report of the President*, Council of Economic Advisors, The White House, 1989. p. 225.

Research and Development Investments²⁴

National research and development investment is an input measure that may provide some perspective on how successful a nation and the firms within the nation may become in producing scientific and technical knowledge that can lead to innovative products and processes. However, the long-term value of these investments may be affected by a variety of factors such as: the capability of the scientists and engineers conducting the R&D and the tools available to them; the efficiency of the system (e.g., businesses, supply chains, infrastructure, innovation climate, government policies) for translating R&D results into commercial products; the fields of nanoscience and nanotechnology pursued; the balance in fundamental research, applied research, and development efforts; and balance in R&D directed at exploiting commercial opportunities, meeting societal needs (e.g., health, environment), addressing government missions (e.g., defense, homeland security), and non-directed efforts to expand the scientific knowledge frontier.

Public Investments. The United States has led, and continues to lead, all nations in public investments in nanotechnology R&D. However the estimated U.S. share of global public R&D investments in nanotechnology has fallen as other nations have established similar programs and increased funding. In the early part of this decade, many nations followed the U.S. lead and established formal national nanotechnology programs in recognition of the potential contributions nanotechnology may offer for economic growth, job creation, energy production and energy efficiency, environmental protection, public health and safety, and national security. According to Mike Roco, past chair of the National Science and Technology Council's (NSTC) Nanoscale Science, Engineering, and Technology (NSET) subcommittee, at least 60 countries have adopted national nanotechnology projects or programs.²⁵ Japan, Germany, and South Korea are making substantial sustained investments across a broad range of nanoscale science, engineering, and technology and are strong competitors for global leadership. More recently, China and Russia have increased investments in nanotechnology. In addition, others — such as Israel, Singapore, and Taiwan — have focused their resources on either a

²⁴ Comparisons and aggregations of investments in R&D across organizational and national boundaries are fraught with imprecision and inaccuracy. One challenge with quantifying public or private investment in nanotechnology R&D relates to the definition of nanotechnology used by different governments and institutions. There is significant debate in and among federal agencies with respect to what should be considered (and thus counted) as nanotechnology R&D, notwithstanding the NNI definition, as well as within and between companies, industries, and governments. In addition to substantive definitional disagreements about nanotechnology, some seek to take advantage of the cachet of the term “nano” or “nanotechnology.” Strong interest in nanotechnology on the part of policymakers, investors, and consumers may induce some to characterize non-nanotechnology activities or products as nanotechnology, or to characterize an entire effort as nanotechnology R&D when in fact only a portion of it is devoted to nanotechnology. Conversely, some firms may not characterize nanotechnology research efforts as “nanotechnology” out of concern for potential negative reactions from customers or unwanted regulatory attention.

²⁵ Roco, M.C. “International Perspective on Government Nanotechnology Funding in 2005,” *Journal of Nanoparticle Research*, 2005, Vol. 7(6).

specific nanotechnology niche or on technology development (in contrast to fundamental research).²⁶

Lux Research estimates that total 2006 public global R&D investments increased 10% over the 2005 level, reaching \$6.4 billion. International investment levels can be compared using differing methods, producing substantially different perspectives on leadership. For example, using a currency exchange rate comparison, the United States ranks ahead of all others, with federal and state investments of \$1.78 billion in 2006 (27.8% of global public R&D investments), followed by Japan (\$975 million, 15.2%) and Germany (\$563 million, 8.8%). When national investments are adjusted using purchasing power parity (PPP) exchange rates (which seek to equalize the purchasing power of currencies in different countries for a given basket of goods and/or services),²⁷ China ranks second in public nanotechnology spending in 2006 at \$906 million, behind only the United States; Japan drops to third as its PPP-adjusted investment falls to \$889 million.²⁸ Comparative international public funding for nanotechnology R&D is provided in **Table 1**.

Table 1. Top Ten Countries in Public Nanotechnology R&D, 2006

in millions of U.S. dollars using currency exchange rates		in millions of U.S. dollars using PPP exchange rates	
United States	1,775	United States	1,775
Japan	975	China	906
Germany	563	Japan	889
France	473	South Korea	563
South Korea	464	Germany	508
United Kingdom	280	France	403
China	220	Taiwan	249
Taiwan	132	United Kingdom	227
Russia	106	India	186
Canada	61	Russia	184

Source: *Profiting from International Nanotechnology*, Lux Research, December 2006.

²⁶ *Ranking the Nations: Nanotech's Shifting Global Leaders*, Lux Research, November 2005. p. 2.

²⁷ The use of PPP-adjusted numbers may distort the comparative value of national R&D investments since the "basket of goods" used to adjust prices generally (which may include food and other consumer items) may bear little resemblance to the goods and services purchased for nanotechnology research and development. In addition, while salaries of researchers in countries such as China may be lower than in other countries (i.e., more research can be bought with a dollar in China than in the United States), the cost of nanotechnology research equipment is likely to be essentially the same in all countries.

²⁸ *Profiting from International Nanotechnology*, Lux Research, December 2006. pp. 8-9.

Private Sector Investments. Private investments in nanotechnology R&D come from two primary sources, corporations and venture capital investors. Globally, corporations invested an estimated \$5.3 billion in nanotechnology research and development in 2006. This figure represents a 19% increase over the 2005 estimate, a growth rate nearly twice that of global public R&D investments.²⁹ Faster growth in corporate R&D may be an indicator that nanotechnology research is moving closer to commercial production.

As with public R&D investments, on a PPP comparison basis, the United States led the world in 2006 in private sector R&D investments in nanotechnology with an estimated \$1.9 billion investment, led by companies such as Hewlett-Packard, Intel, DuPont, General Electric, and IBM. Japan's \$1.7 billion in private investments in nanotechnology R&D — led by companies such as Mitsubishi, NEC, and Hitachi — ranks a close second behind the United States. The private investments of companies headquartered in these two nations account for nearly three-fourths of corporate investment in nanotechnology R&D in 2006. In contrast to its high PPP ranking in public R&D investment, China ranks fifth in corporate investment, accounting for only about 3% of global private R&D investments in nanotechnology.³⁰

Strength in an existing industry base may be a driver for private investment in nanotechnology innovations. For example, multi-walled carbon nanotubes (MCWNTs) offer significant improvements in lithium-ion (Li-ion) battery life. Japan's strength in Li-ion batteries is seen as a driving force in Japan's leading position in the manufacture of MWCNTs and Japanese companies' investments in ton-scale production capabilities.³¹

Venture capital investment — early-stage equity investment, generally characterized by high risk and high returns — provides another possible indicator of international competitiveness. In 2007, venture capital for nanotechnology reached an estimated \$702 million worldwide of which U.S.-based companies received \$632 million (approximately 90%).³²

Scientific Papers

The quantity of peer-reviewed scientific papers published by scientists and engineers of each nation is one indicator of the scientific leadership of that nation. The scientific journals used to generate such counts tend to be considered among the most reliable and prestigious in the fields. Nevertheless, as a tool for assessing national competitiveness, this indicator has shortcomings. For example, paper counts do not assess the level or significance of contributions made by each of the authors. While an article may list a principal investigator, such as a university professor, as the lead author, the other authors, possibly graduate students or post-grads from a

²⁹ *Profiting from International Nanotechnology*, Lux Research, December 2006. pp. 25-26.

³⁰ *Profiting from International Nanotechnology*, Lux Research, December 2006. pp. 9-10.

³¹ *International Assessment of R&D in Carbon Nanotube Manufacturing and Applications*, World Technology Evaluation Center, Inc., June 2007.

³² Private communication between CRS and Lux Research, Inc., April 28, 2008.

country other than that of the lead author, may have made the most important contributions to the work. Publication of a scientific paper may also represent a recognition of its unique scientific insights, yet offer little or no potential for useful applications or commercial relevance.

Output of Peer-Reviewed Papers. The United States leads all other nations in peer-reviewed nanotechnology papers published in scientific journals. A National Bureau of Economic Research (NBER) analysis reported that the United States' 24% share of global publication output was more than double that of the next most prolific nation, China.³³ However, this share represents a decline from the early 1990s when the United States accounted for approximately 40% of nanotechnology papers. The NBER working paper concludes, "Taken as a whole these data confirm that the strength and depth of the American science base points to the United States being the dominant player in nanotechnology for some time to come, while the United States also faces significant and increasing international competition."³⁴

A quantitative analysis of published scientific papers comparing the United States to the Europe Union (EU) nations as a whole was prepared by United Kingdom-based Evaluametrics, Ltd. following an inquiry from the Congressional Research Service in December 2007.³⁵ Evaluametrics' analysis shows that the number of nanotechnology papers more than doubled between 2000 and 2005. Using a fractional count of papers,³⁶ the United States maintained about a 22% share of papers from 2000 to 2005. The EU27's³⁷ share of papers fell from 32% to 25% during this period, while China's share rose from 11% to 20%. Viewed from this perspective, the EU27 led the United States in output of nanotechnology-related scientific papers, but the EU27 share has been in decline. China's share is approaching that of both the United States and the EU27 (see **Figure 1**).³⁸

Using an integer count, with each paper assigned to the nation of the lead author's address, yields similar results. By this method, the EU27 led the world in 2006 with approximately 29% of all papers, followed by the United States with 25%,

³³ Zucker, L.G. and M.R. Darby. "Socio-Economic Impact of Nanoscale Science: Initial Results and Nanobank," *National Bureau of Economic Research*, March 2005. [<http://www.nber.org/papers/w11181>]

³⁴ Ibid.

³⁵ *Nanotechnology Research Outputs 2000-2007: Interpretation of Results*, prepared for CRS by Evaluametrics, Ltd. in December 2007. This analysis was performed using information from Thompson Scientific's Science Citation Index, selecting papers based on two filters, a list of specialist journals and a list of key nano-related words in the title of the paper.

³⁶ Using a fractional count approach, if a paper has multiple authors of different nations, a fraction of the paper is assigned to each country in proportion to the nations listed in the authors' addresses. Thus, a paper with three authors, two of which list U.S. addresses and one of which has an address in the United Kingdom, would be allocated as 0.67 (two-thirds) of a paper to the United States and 0.33 (one-third) of a paper to the United Kingdom.

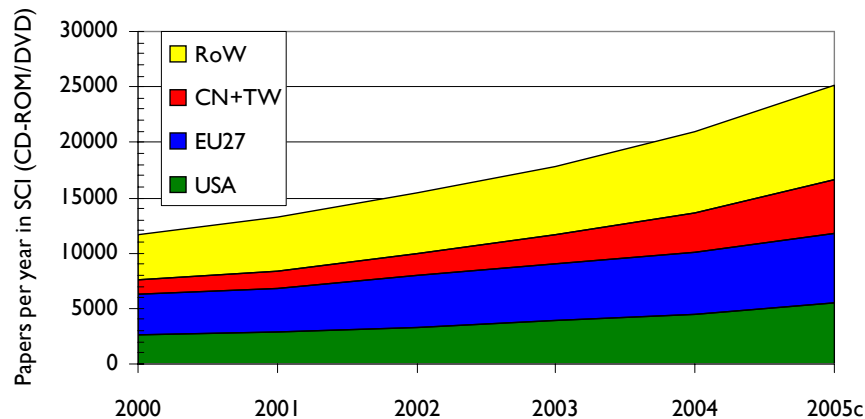
³⁷ The EU27 represents the combined output for the 27 nations of the European Union.

³⁸ For purposes of this analysis, Evaluametrics attributes Taiwan's data to China.

and China with approximately 23%. Evaluametrics' analysis of preliminary data shows that China may have surpassed the United States in share of papers in 2007.³⁹

Evaluametrics' analysis of the papers by scientific disciplines reveals regional differences. The United States' articles were more heavily weighted toward the biological and medical fields, China's toward chemistry and engineering, and the EU27's toward the biological and medical fields, similar to the United States, but with a greater emphasis on physics and less on chemistry.

Figure 1. Nanotechnology Papers in the Science Citation Index, by Region, 2000-2005



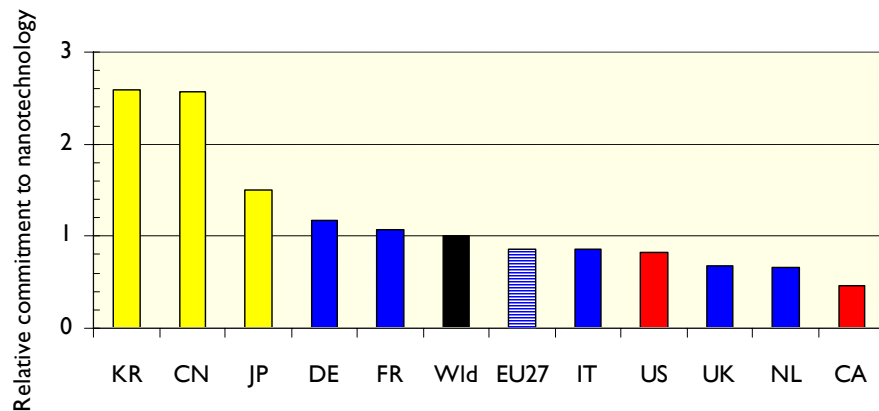
Source: Evaluametrics, Ltd., December 2007.

Note: RoW = Rest of World, CN+TW = China, including Taiwan, EU27 = nations of the European Union.

Evaluametrics also calculated for each country/region the share that nanotechnology papers represented as a percentage of all scientific papers. Dividing this percentage by the average for all nations yields a ratio the author calls a nation's "relative commitment" to nanotechnology. Of the 10 countries examined, South Korea, China, and Japan showed the highest relative commitment, while the United States and EU27 fell somewhat short of the world average (see **Figure 2**).

³⁹ *Nanotechnology Research Outputs 2000-2007: Interpretation of Results*, Evaluametrics, Ltd., December 2007.

Figure 2. Relative Commitment of Ten Countries to Nanotechnology, 2003



Source: Evaluametrics, Ltd., December 2007.

Note: KR = South Korea, CN = China (including Taiwan), JP = Japan, DE = Germany, FR = France, Wld = World, EU27 = nations of the European Union, IT = Italy, UK = United Kingdom, NL = The Netherlands, CA = Canada.

Citations to Peer-Reviewed Papers. Another measure of global leadership in nanotechnology is the quality and value of peer-reviewed papers. One measure of the quality and value of a paper is the frequency with which it is cited in other peer-reviewed papers. Evaluametrics' analysis shows that papers attributed to the United States are much more frequently cited than those attributed to China, the EU27, and the rest of the world as a whole. This held true overall and separately in each of the four disciplines examined (biology, chemistry, engineering, and physics).⁴⁰ The U.S. lead was particularly pronounced in biology. China fell below the world average number of citations in each of the four disciplines, as well as overall. The EU27 performed near the world average in engineering and physics, and somewhat higher in chemistry. Using a slightly different citation metric,⁴¹ 56% of U.S. papers have 10 or more citations, in contrast to only 38% for the EU27 and approximately 30% for China. The Netherlands and Germany lead the EU27 in papers with 10 or more citations with approximately 45% each.

Papers in "High-Impact" Journals. A second measure of the quality of a nation's papers is the share of its papers in influential journals. A review of *Science*, *Nature*, and *Physical Review Letters* (which PCAST refers to as "high impact journals") shows the United States accounted for more than 50% of nanotechnology-related papers in these journals in 2004. However, while the absolute number of papers in these journals attributed to the United States has grown

⁴⁰ Using the Potential Citation Index metric based on the mean five-year citation counts to papers in the given journals.

⁴¹ Using the Actual Citation Index metric for papers published in 2003 and cited between 2003 and 2007.

continuously since 1991, the U.S. share of papers has fallen as other countries collectively increased their production at an even faster rate.⁴²

Patents

Patent counts — assessments of how many patents are issued to individuals or institutions of a particular country — are another indicator used to assess a nation's competitive position. According to the U.S. Patent and Trade Office (USPTO), a patent grants ownership rights to a person who “invents or discovers any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof.” By this definition, patents may be an indicator of future value and national strength in a technology, product, or industry.

By this measure the United States position appears to be very strong. United States assignees dominate all other countries in patents issued by the USPTO. According to an analysis by the USPTO of patents in the United States and in other nations, U.S. origin inventors and assignees/owners have:

- the most nanotechnology-related U.S. patents by a wide margin;
- the most nanotechnology-related patent publications globally, but by a narrower margin (followed closely by Japan); and
- the most nanotechnology-related inventions that have patent publications in three or more countries, 31.7% — an indication of a more aggressive pursuit of international intellectual property protection and, by inference, of its perceived potential value. By this measurement, the United States is followed by Japan (26.9%), Germany (11.3%), Korea (6.6%), and France (3.6%).⁴³

There has been rapid growth in nanotechnology patents in the USPTO and European Patent Office (EPO) patent databases. A 2007 study reports that the number of U.S. nanotechnology patents in the USPTO and EPO databases grew at a near exponential pace between 1980 and 2004. The study showed that each year since 1990, U.S. assignees have accounted for approximate two-thirds of all patents in the USPTO database. In 2004, U.S. assignees accounted for 66.9% of USPTO nanotechnology patents.⁴⁴

⁴² *The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel*, President's Council of Advisors on Science and Technology, May 2005. [http://www.nano.gov/FINAL_PCAST_NANO_REPORT.pdf]

⁴³ Eloshway, Charles. “Nanotechnology Related Issues at the U.S. Patent and Trademark Office,” Workshop on IPR in Nanotechnology: Lessons from Experiences Worldwide, Brussels, Belgium, April 2007. [ftp://ftp.cordis.europa.eu/pub/nanotechnology/docs/iprworkshop_eloshway_en.pdf]

⁴⁴ Li, Xin; Lin, Yiling; Chen, Hsinchun; Roco, Mihail C. “Worldwide Nanotechnology Development: A Comparative Study of USPTO, EPO, and JPO Patents (1976-2004),” *Journal of Nanoparticle Research*, Vol. 9, December 2007.

An earlier study of USPTO data, covering patents from 1976 to 2002, also indicated U.S. nanotechnology patent leadership, with the United States accounting for more than 67% of patents (based on a full text search of patents for nanotechnology-related key words), followed by Japan, Germany, France, and Canada. In 2003, the United States, Japan, Germany, Canada, and France continued to rank in the top five, with the Republic of Korea and the Netherlands jumping several spots each to sixth and seventh places, respectively; Ireland and China made their first appearance in the top 20 nations. With respect to patent citations by subsequent patents — a possible indicator of the usefulness of a patent — the study showed U.S. nanotechnology patents dominated citations and reflected strong interactions with Japanese and German patents.⁴⁵

Patent counts, however, have shortcomings in assessing future competitiveness. Experience shows that not all patents have equal value. Some patents are “blockbusters” that largely define products and industries, and result in substantial wealth creation and competitive advantage for its owners. Other patents are useful, but offer only moderate value. And some patents are never realized in materials, products or processes. Patent counts do not attempt to assess the relative value of each patent, instead assigning equal value to each. Thus, a nation with a high patent count in nanotechnology may not benefit as much as a nation with fewer, but more valuable, patents.

In addition, companies may choose not to patent a particular idea — even one with significant value — for a variety of reasons. For example, public exposure of the idea as required by the patent application process may enable other companies to engineer around their patent, finding a way to do what the original patent accomplished, but in a way that is sufficiently different that it qualifies for a new patent. Alternatively, a company may be able to block the original patent holder from further improvements by filing patent applications that essentially block out potential improvements. Or, unscrupulous producers may ignore the patent and use the intellectual property without compensating the patent holder. Instead of filing for a patent, a company may choose instead to hold a valuable intellectual property as a trade secret. In contrast to patents which provide protection for defined periods, trade secrets can extend indefinitely. The Coca-Cola Company has held its formula(s) for Coke as a trade secret for over 100 years.⁴⁶

The Federal Role in U.S. Competitiveness: Issues and Options

Congress has provided \$8.4 billion in funding for nanotechnology R&D under the National Nanotechnology Initiative, and more than tripled annual funding since

⁴⁵ Huang, Zan, Hsinchun Chen, and Zhi-kai Chen. “International Nanotechnology Development in 2003: Country, Institution, and Technology Field Analysis Based on USPTO Patent Database,” *Journal of Nanoparticle Research*, Vol. 6, August 2004.

⁴⁶ The Coca-Cola Company website. [<http://www.thecoca-colacompany.com/heritage/worldcocacola.html>]

its inception. At the same time, other nations have established and bolstered their nanotechnology investments, programs, and policies, stirring debate about how the federal government can best ensure U.S. competitiveness in this field.

While there is broad consensus that U.S. competitiveness in nanotechnology is important, there are a wide variety of views about the role the federal government could or should play in supporting this objective. These perspectives are reflective of long-running policy debates over the appropriate role of government in promoting research, development, innovation, and industrial competitiveness. Some argue that the federal role should be limited to funding basic research, R&D needed to meet agency mission requirements, and development of the U.S. scientific and technical workforce.⁴⁷ Some believe the federal government should also fund development efforts that move nanotechnology closer to commercial products, especially in light of its potential economic and societal benefits.⁴⁸ Others assert that the federal government's role in competitiveness should be limited to establishing a healthy business environment and allowing market forces and the private sector to shape U.S. competitiveness.⁴⁹ Among those concerned about nanotechnology's potential adverse implications for health, safety, and the environment are those who support a more active federal role in funding environmental, health, and safety (EHS) research to better understand, characterize, and regulate nanotechnology,⁵⁰ and those who prefer the federal government act to slow the development and commercialization of nanotechnology pending further EHS research.⁵¹

⁴⁷ Vannevar Bush's 1945 seminal report to President Truman, *Science: The Endless Frontier*, advocated this approach to support both government mission needs and industrial requirements.

⁴⁸ This perspective is exemplified by President Clinton's first technology policy statement, *Technology for America's Economic Growth, A New Direction to Build Economic Strength*, February 22, 1993. The Brookings Institution also advocates this position.

⁴⁹ Organizations such as the Cato Institute and the Heritage Foundation generally support such an approach.

⁵⁰ This position is held by many organizations, including the Woodrow Wilson International Center for Scholar's Project on Emerging Nanotechnologies, Environmental Defense, and DuPont.

⁵¹ The ETC Group and Natural Resources Defense Council are advocates for this approach.

Survey of Industry Views on the Federal Role

A survey of U.S. nanotechnology business leaders indicated this community was divided on the desired level of government involvement in the development of nanomanufacturing technologies with 45% wanting “government to take the lead in R&D and commercialization incentives” and 43% wanting “limited participation.” Another 11% of respondents said they wanted government to “stay out of it.”

Among the most significant barriers to growth identified by U.S. nanotechnology business leaders in a survey conducted by Small Times magazine and the University of Massachusetts-Lowell were: intellectual property issues (46%), lack of financing (45%), lack of available prototype facilities (43%), and lack of nanotechnology safety standards (36%). Ninety-two percent of respondents identified access to unique equipment and facilities as very important, and 91% identified access to processes and tools to reduce time-to-market from R&D as very important.

Nearly three of five respondents indicated that they use or planned to use shared-use facilities at local universities, with science and engineering labs (25%), electronic labs (24%), and biotech labs (17%) topping the list, followed by specific diagnostic equipment (14%) and microfabrication labs (12%). More than three-fourths of the nanotechnology executives surveyed identified internal R&D as the primary source of expertise for the development of products and processes. Another 9% of executives identified industry associations or consortiums as their primary source of expertise, while only 7% identified collaboration with universities.

Source: “Survey of U.S. Nanotechnology Executives,” conducted by Small Times Magazine and the Center for Economic and Civic Opinion at the University of Massachusetts-Lowell, Fall 2006.

Technology Development

Much of the public dialogue on how the government can advance U.S. strength in nanotechnology has focused on federal technology funding. Advocates for increased federal support put forth a variety of arguments.

Some believe that the federal government should provide increased funding for “downstream research,” i.e., applied research and development closer to commercial products, including production prototypes.⁵² Those who advocate this position generally assert that many promising research breakthroughs and early technology developments fail to make it to market. This failure, they argue, results from inadequate funding mechanisms to bring the technology to a state of maturity in which private corporations and other sources of capital are willing to invest in the technology — or in the company that holds the technology — to bring it to market. For example, they assert that investor demand for short-term returns can result in companies being unable to invest in higher-risk, longer-term technology development projects needed to sustain their viability in the future. Similarly, according to these advocates, venture capitalists and other investors often have exit strategies and/or seek returns in a timeframe (generally three to five years) inconsistent with the

⁵² This position is held by many small technology businesses and start-ups.

longer-term development horizons of emerging and enabling technologies. With federal investments, say supporters, technical risk could be reduced to a level that enables promising research and early-stage technologies to overcome “the valley of death”⁵³ and reach the marketplace where the nation would be able to capture their economic and societal benefits.

One rationale offered by some economists for federal funding of R&D is that the private sector underinvests in R&D because many of the benefits (economic and societal) are captured by others, particularly where the results cannot be easily appropriated for production and profit.⁵⁴ However, as research moves closer to commercialization, private sector incentives to invest increase and the rationale for federal R&D funding is diminished.

Another argument for government R&D funding put forth by economists and others is that the development of emerging and enabling technologies may be beyond the ability of any single company or industry to develop due to high cost, high risk, lack of requisite expertise, and an inability to capture adequate returns. While a single company or industry may not be able to achieve adequate returns across its limited line of products and services, the economic benefits that accrue across all industries may be sufficient, even sweeping. Another justification for federal funding, say advocates, is that institutional, legal, cultural and other barriers may inhibit or prevent all parties from working together to share the costs and risks of R&D. The National Cooperative Research Act of 1984 (P.L. 98-462) and the National Cooperative Production Amendments of 1993 (P.L. 103-42) sought to spur collaborative research and manufacturing efforts by lowering legal barriers.

Opposition to expanded federal R&D efforts stem from a variety of perspectives, including those who believe that such efforts may be ineffective or counterproductive, a view held by many economists.

The best way to deal with the many changes in demand that occur in a dynamic economy is to allow investors and workers to respond to such changes....

Government allocation of investment that ignores market signals usually stunts growth by diverting labor and capital from more productive uses....

An industrial policy that increases government planning, government subsidies, and international protectionism would only be a burden on our economic life and a threat to our long-term economic prosperity.⁵⁵

⁵³ The “valley of death” is a term applied to the period in the innovation process generally between development of a laboratory prototype and its wide-scale commercial adoption. The term is an analogy intended to highlight the difficulties in overcoming barriers to innovation by evoking a comparison to the crossing of a barren desert strewn, as one writer says, with the “carcasses of great innovations.”

⁵⁴ *Economic Report of the President*, Council of Economic Advisors, The White House, 1989. p. 223.

⁵⁵ *Economic Report of the President*, Council of Economic Advisors, The White House, (continued...)

Some economists assert that public R&D funding displaces private R&D investment. In his book, *The Economic Laws of Scientific Research*, Cambridge University scientist Terence Kealey argues that public R&D funding actually decreases overall R&D funding as companies reduce their R&D investments and rely on public investments.⁵⁶ Other research suggests that evidence of displacement is ambiguous.⁵⁷

Opponents also argue that industry, not government, is best suited to make commercial technology decisions, citing the failure of some high-profile commercially-directed government efforts, such as the Concorde supersonic transport aircraft, a failed effort of the governments of the United Kingdom and France. Opponents further contend that governments — responding to political interests, not market signals — have often continued to invest in technologies — such as those supported by the U.S. synfuels program — that have been proven by markets and technological developments to be economically unsound.⁵⁸

Libertarian opposition to increased federal R&D, such as that put forth by the Cato Institute, is grounded in a philosophy of limited government and reliance on the free market. Libertarians generally assert that markets, free from government interventions, are the most effective mechanism for allocating resources to the most promising opportunities. In their view, government interventions represent an industrial policy in which the preferences of politicians and bureaucrats are substituted for market forces and/or objective criteria. When the federal government provides direct and/or indirect financial support to a particular technology,⁵⁹ assert these advocates, it may not only provide a direct benefit to the technology — especially with respect to existing technology or alternatives — but it may also signal technology developers and investors that the technology may receive future preferential treatment by government as well. This may, as a result, skew corporate development activities and private investments toward less-promising directions producing more costly and/or less beneficial results.

Many libertarians also see government financial support for technology development as an inappropriate involuntary transfer of wealth from taxpayers to private interests — including large, highly profitable companies. The Cato Institute has labeled such efforts “corporate welfare” and has expressed concerns that such

⁵⁵ (...continued)
1984. p. 88.

⁵⁶ Kealey, Terrence. *The Economic Laws of Scientific Research*. New York: St. Martin's Press, 1996. pp. 246-247

⁵⁷ David, Paul A., Brownyn H. Hall, and Andrew A. Toole. *Is Public R&D a Complement or Substitute for Private R&D? A Review of the Econometric Evidence*. August 1999. [<http://129.3.20.41/eps/dev/papers/9912/9912002.pdf>]

⁵⁸ *Economic Report of the President*, Council of Economic Advisors, The White House, 1990. p. 117.

⁵⁹ “Technology” is used in this instance, but these arguments apply to companies and industries as well.

efforts may “create an unhealthy relationship between government and industry that might corrupt both.”⁶⁰

Options for federal efforts to support technology development include both direct support and indirect support:

Direct Support. There are a variety of mechanisms that the federal government might use to support downstream research. Some favor a direct approach with the federal government providing grants or loans to companies, universities, and or consortia to support research and development activities that move their work closer to commercial production. Examples of this approach include the National Institute of Standards and Technology’s (NIST) Technology Innovation Program (TIP); its defunct predecessor, the Advanced Technology Program (ATP), also administered by NIST; and the multi-agency Small Business Innovation Research (SBIR) program. According to NIST, the mission of TIP is to “accelerate innovation in the United States through high-risk, high-reward research in areas of critical national need.”⁶¹ As originally conceived, ATP was intended to support the development of emerging and enabling technologies that offered the potential for significant economic and/or societal returns to the nation. The SBIR program, operating at each of the major R&D funding agencies, provides funding to help advance technology development with a goal of commercialization. (For additional information, see CRS Report 96-402, *Small Business Innovation Research Program*, and CRS Report RS22815, *The Technology Innovation Program*, both by Wendy H. Schacht.)

Indirect Support. In addition to direct funding mechanisms, a variety of indirect approaches might be used by the federal government if it chose to support additional nanotechnology research and development. The tax code could be used to increase private investment in nanotechnology companies, or to create incentives for companies to expand and accelerate their research, development, and production activities. Tax options might include general provisions to induce greater corporate investment, such as the current research and experimentation (R&E) tax credit;⁶² targeted tax provisions that support a particular technology, application, industry, or sector; consumer tax deductions or credits designed to induce the purchase of targeted technologies and products, such as tax credits currently provided for the purchase of hybrid and flex-fuel vehicles; or incentives for the formation of capital pools to support R&D, such as favored tax treatment for research and development limited partnerships (RDLPs). (For additional information, see CRS Report RL31181, *Research and Experimentation Tax Credit: Current Status and Selected Issues for Congress*, by Gary Guenther.)

⁶⁰ *Cato Handbook on Policy, 6th Edition*, The Cato Institute, 2005.

⁶¹ NIST website. [http://www.nist.gov/public_affairs/tip.htm]

⁶² The “R&E tax credit” is often referred to as the “R&D tax credit,” though its provisions do not extend to development activities.

Infrastructure Development

Another option for federal support, proposed by some in industry, is increased investments in infrastructure and supporting technologies to reduce the cost of, and to accelerate, applied research and development. Candidate activities for such support include modeling, prototyping, testing, and materials characterization facilities; measurement tools and sensors; standards; reference materials; and nomenclature development.

In addition, state and local governments in the United States, as well as foreign governments, have established science, technology, and innovation parks, both specialized and general, to foster innovation. Some nanotechnology advocates believe the federal government should provide funding for the planning and development of nanotechnology-focused parks that offer land, facilities, equipment, and services to new, emerging, and established companies, and that bring together a variety of stakeholders with unique capabilities and interests.

Some in the private sector have also sought increased federal efforts to protect the intellectual property rights of inventors and companies, including increasing the speed and quality of the patent process and protecting the rights of U.S. patent holders against infringement and abuse by actors in other nations. The USPTO, an NNI-participating agency, has undertaken efforts to educate its patent examiners on nanotechnology, established a separate class for nanotechnology (Class 977), and created over 250 cross-reference sub-classes to improve the ability to search and examine nanotechnology-related patent documents.⁶³

Addressing Regulatory Concerns

Environmental, health, and safety (EHS) concerns also present potential barriers to nanotechnology commercialization and U.S. competitiveness in nanotechnology. The properties of nanoscale materials — e.g., small size; high surface area-to-volume ratio; unique chemical, electric, optical, and biological characteristics — that have given rise to great hopes for beneficial applications have also given rise to concerns about their potential implications for health, safety, and the environment. EHS issues have become a specific concern of the National Nanotechnology Initiative. In FY2008, the NNI will spend \$58.6 million on EHS research, accounting for about 3.9% of NNI funding. President Bush has requested \$76.4 million for NNI EHS research in FY2009, or 5.0% of NNI funding. Some believe that these funding levels are too low and should amount to 10% or more of NNI funding.

The potential for adverse effects on health, safety, and the environment may discourage investment in, and development of, nanotechnology resulting from the possibility of regulations that bar products from the market or impose excessive regulatory compliance costs, and the potential for costly product liability claims and clean-up costs. If U.S. regulations are restrictive and expensive, companies may move nanotechnology research, development, and production to nations that do not impose or enforce regulations, or take a less stringent approach to regulation. Many

⁶³ USPTO website. [<http://www1.uspto.gov/web/patents/biochempharm/crossref.htm>]

advocates in industry, academia, and environmental non-governmental organizations believe the federal government should increase its EHS R&D investments to reduce uncertainty, inform the development of regulations, and protect the public. Regulation of nanotechnology products may fall under the authorities of several federal agencies, including the Environmental Protection Agency, Food and Drug Administration, Occupational Safety and Health Administration, and Consumer Product Safety Commission. (For additional information, see CRS Report RL34332, *Engineered Nanoscale Materials and Derivative Products: Regulatory Challenges*, and CRS Report RL34118, *The Toxic Substances Control Act (TSCA): Implementation and New Challenges*, both by Linda-Jo Schierow.)

Beyond support for research and development, the federal role in a variety of other policy and programmatic activities might be strengthened. For example, some argue for the use of specialized extension centers, both university-based and independent centers, to provide technical and EHS best practices information to small and medium-size manufacturers that lack the in-house expertise and resources of larger enterprises. USDA's Agricultural Extension Service and NIST's Manufacturing Extension Partnership (MEP) may serve as possible models for such efforts.

In addition, some experts advocate efforts to create regulatory processes that can keep pace with rapid technological change and help create a more predictable environment for those investing in nanotechnology development and commercialization. Another potential regulatory barrier to nanotechnology development and commercialization is over-regulation of the export of nanotechnology and nanotechnology-related products due to their potential military applications. Such restrictions, or even the anticipation of them, might impede investment in, and development of, nanotechnology since global revenues may account for a significant share of expected return on investment. In this regard, the Department of Commerce asked the President's Export Council (PEC), a presidential advisory committee, to undertake efforts to ensure that nanotechnology products were not unnecessarily restricted from sale to other nations under export control regulations. In December 2005, the PEC sent a letter to President Bush recommending principles for the federal government's approach to export controls to maximize U.S. companies' access to global markets consistent with the protection of national and homeland security.⁶⁴ In February 2008, the Commerce Department's Bureau of Industry and Security announced its intent to establish an Emerging Technologies and Research Advisory Committee (ETRAC) comprised of representatives of research universities, government laboratories, and industry to make recommendations regarding emerging technologies, including nanotechnology.⁶⁵

⁶⁴ Transcript of President's Export Council meeting, Dirksen Senate Office Building, Washington, DC, December 6, 2005. [<http://www.ita.doc.gov/td/pec/12605transcript.html>].

⁶⁵ Private communication between CRS and the Bureau of Industry and Security, U.S. Department of Commerce, May 9, 2008.

Workforce Development

Ensuring the United States has a cadre of world-class scientists, engineers, and technicians — an asset deemed critical to U.S. innovation and competitiveness — has been an enduring concern of Congress, generally,⁶⁶ and now specifically with respect to nanotechnology. Advocates for this position assert the need for federal support for curricula development, as well as scholarships and expanded efforts to encourage students to pursue associate, bachelor's and advanced degrees in nanotechnology-related disciplines.

International Coordination and Cooperation

Some nanotechnology advocates want the federal government to work with other nations to ensure a “level playing field” for nanotechnology development and commercialization (i.e., to ensure they are not put at a disadvantage by government subsidization of their foreign competitors, less stringent regulatory standards, fewer worker protections, and/or imposition of tariffs and non-tariff trade barriers), to develop common international standards and nomenclature, to harmonize regulations, and to open markets for nanotechnology products.

Reassessing and Realigning Resources

As discussed above, the federal government is engaged in fostering the advancement of nanotechnology across a broad range of activities, including: conducting and supporting nanotechnology R&D; seeking to address environmental, health, and safety issues; preparing students and workers for nanotechnology job opportunities through investments in education and training; fostering public understanding and engagement; coordinating and cooperating with other nations; and promoting the development of standards, nomenclature, and reference materials. These activities involve substantial investments of capital, personnel, facilities, equipment, and other resources.

Many NNI activities have developed over time to address new challenges and opportunities as the NNI advanced. Resource allocation decisions have been made piecemeal, generally without consideration for alternative uses of the resources. Over time, such an approach may produce a portfolio of activities that is out of balance with current needs. More than seven years into the NNI, some observers believe that reassessing and realigning resources with opportunities and challenges would improve the efficiency and effectiveness of federal investments and activities.

However, there are substantial barriers to such an effort. First, the NNI is not funded centrally, but rather is an aggregation of the resources provided to agencies to meet their mission requirements. Moving funds from one program or agency to another might meet with resistance within agencies, between agencies, or from the Congressional appropriations subcommittees with jurisdiction for these programs and agencies. Second, agencies participate in the NNI on a voluntary basis. If it appears

⁶⁶ For additional information, see CRS Report RL34328, *America COMPETES Act: Programs, Funding, and Selected Issues*, by Deborah D. Stine.

that participation in the NNI might reduce funding, an agency may choose to no longer participate or may not classify its activities as nanotechnology. Third, the NNI seeks to meet multiple goals, including scientific leadership, meeting agency mission requirements and national needs, and fostering U.S. commercial leadership. No relative values have been explicitly set for these and other goals making comparative resource allocation choices subjective.

The National Research Council (NRC)⁶⁷ and the National Nanotechnology Advisory Panel (NNAP)⁶⁸ have each conducted assessments of the NNI at the direction of Congress as specified in the 21st Century Nanotechnology Research and Development Act. The act requires assessments to be performed triennially by the NRC and biennially by the NNAP. Past assessments have addressed U.S. competitiveness in nanotechnology as part of wider reviews. To clarify the U.S. competitive position, Congress could opt to direct the NRC, NNAP, or the U.S. Government Accountability Office to conduct a focused assessment of: the effectiveness of the NNI in achieving the global technological leadership, commercialization, and national competitiveness goals established under the act; whether the current portfolio of NNI resources and activities are appropriately balanced; and whether additional resources activities may be required to achieve these objectives.

Concluding Observations

Nanotechnology is expected by many to deliver significant economic and societal benefits. The United States launched the first national nanotechnology initiative in 2000, but has since been joined by more than 60 other nations. Tens of billions of dollars have been invested in nanotechnology research and development over the past eight years by governments, companies, and investors.

While it has been estimated that there are more than 600 nanotechnology products on the market today, most involve incremental improvements to existing products. Much of the investment has been focused on fundamental research to gain scientific understanding of nanoscale phenomena and processes, and to learn how to manipulate matter at the nanoscale. These investments are expected by many to deliver revolutionary changes in products and industries with implications for global technological, economic, and military leadership. The potential implications of nanotechnology, coupled with the substantial sustained investments, have raised concerns and interest in the U.S. competitive position in nanotechnology.

The data typically used to assess technological competitiveness in mature industries — e.g., revenues, market share, trade — is not available to assess the U.S.

⁶⁷ The National Research Council functions under the auspices of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

⁶⁸ In July 2004, President Bush designated the President's Council of Advisors on Science and Technology to serve as the NNAP by issuing Executive Order 13349, *Amending Executive Order 13226 To Designate the President's Council of Advisors on Science and Technology To Serve as the National Nanotechnology Advisory Panel*.

position in nanotechnology because it is a new technology, commercial products are just beginning to enter the market in a significant manner, and it is incorporated in wide array of products across many industries. Accordingly, the federal government currently does not collect this data on nanotechnology, nor do other nations. The number of nanotechnology products in the marketplace is increasing quickly though. Congress may elect to ask federal agencies to assess what data (e.g. economic, labor force, students) would be useful in formulating federal policies and making resource allocation decisions and direct federal statistical agencies to collect, analyze, and make public such data. The federal government may also seek to foster data collection efforts in other nations.

In the absence of such data, assessments of nanotechnology depend largely on alternative indicators, such as inputs (e.g., public and private investments) and non-economic outputs (e.g., scientific papers, patents). By these measures, the United States appears to lead all other nations in nanotechnology, though the U.S. lead in this field may not be as large as it has been in previous emerging technology areas. This is due to increased investments and capabilities of many nations based on recognition that technological leadership and commercialization are primary paths to increased economic growth, improved standards of living, and job creation.

Nevertheless, these alternative indicators may not present an accurate view of technological leadership and economic competitiveness for many reasons. Nor does national technological leadership alone guarantee that the economic value produced by nanotechnology innovations will be captured within a nation's borders. In today's global economy, companies have the option of locating work — e.g. research, development, design, engineering, manufacturing, product support — where it can be done most effectively.

A variety of federal policy issues may affect the development and commercialization of nanotechnology in the United States, including the magnitude and focus of research and development efforts, the regulatory environment, and science and engineering workforce development. Some support an active federal approach; others believe that a more limited federal involvement is likely to be more successful and equitable. In addition to these factors, U.S. competitiveness in nanotechnology will depend not just on the efforts of the United States, but also on the speed and efficacy of foreign nanotechnology development efforts.

Congress established a legislative foundation for some of the activities of the National Nanotechnology Initiative and to address key issues associated with nanotechnology thorough enactment of the 21st Century Nanotechnology Research and Development Act, 2003. The act provided funding authorizations for five NNI agencies through FY2008. Action is being considered in both the House and Senate on possible amendments to and reauthorization of the program. Congress may opt to address some or many of the issues identified in this paper in the course of deliberation on the reauthorization of this act or, alternatively, in separate legislation.