# REPORT TO THE PRESIDENT AND CONGRESS ON THE FOURTH ASSESSMENT OF THE NATIONAL NANOTECHNOLOGY INITIATIVE

Executive Office of the President

President's Council of Advisors on Science and Technology

APRIL 2012

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EXECUTIVE OFFICE OF THE PRESIDENT
**PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY**
WASHINGTON, D.C. 20502

President Barack Obama
The White House
Washington, DC 20502

Dear Mr. President,

We are pleased to send you this "Report to the President and Congress on the Fourth Assessment of the National Nanotechnology Initiative," prepared by the President's Council of Advisors on Science and Technology (PCAST). This report fulfills PCAST's responsibilities under the 21st Century Nanotechnology Research and Development Act (Public Law 108-153) and Executive Order 13349 to provide periodic updates to Congress.

The report finds that the NNI—which has provided $16 billion in investments by 26 Federal agencies over the life of the initiative—has had a "catalytic and substantial impact" on the growth of the U.S. nanotechnology industry and should be continued. Further, the report finds that in large part as a result of the NNI the United States is today, by a wide range of measures, the global leader in this exciting and economically promising field of research and technological development.

PCAST applauds the increased efforts of the National Nanotechnology Coordinating Office in the area of commercialization and coordination with industry and in the release of a focused research strategy for addressing environmental, health, and safety (EHS) implications of nanotechnology. In addition, the NNI maintains a strong portfolio of research on the societal implications of nanotechnology.

However, the report also notes that additional efforts are needed in four areas: strategic planning, program management, metrics for assessing impact, and increasing support for research on environmental, health, and safety issues associated with nanotechnology. Continued lack of attention to these concerns will make it harder for the U.S. to maintain its leadership role in the commercialization of nanotechnology.

The full PCAST discussed and approved this report at its most recent public meeting on March 9, 2012. We appreciate your interest in this important field of work and sincerely hope that you find this report useful.

John P. Holdren
Co-Chair

Eric Lander
Co-Chair

# Executive Summary

The National Nanotechnology Initiative (NNI) is a crosscutting Federal program designed to coordinate U.S. investment in research and development (R&D) activities in nanoscale science, engineering, technology, and related efforts across 26 agencies and programs. This is the fourth review of the NNI by the President's Council of Advisors on Science and Technology (PCAST) since the council was designated in 2004 as the National Nanotechnology Advisory Panel tasked with reviewing the initiative.

The Federal Government has proposed $1.8 billion of funding in fiscal year (FY) 2013 for 15 agencies with budgets dedicated to nanotechnology research and development. The FY 2013 request represents total funding of $18 billion over the life of the Initiative. Nearly 75 percent of this funding goes to three Program Component Areas: Fundamental Nanoscale Phenomena and Processes, Nanomaterials, and Nanoscale Devices and Systems. The NNI continues to support a strong and growing portfolio of research on the societal implications of nanotechnology, nanotechnology education, and public outreach. The President's 2013 budget includes a total of $306 million—a 24-percent increase compared to 2011 actual spending—for three Nanotechnology Signature Initiatives: Nanotechnology for Solar Energy Collection and Conversion; Sustainable Nanomanufacturing: Creating the Industries of the Future; and Nanoelectronics for 2020 and Beyond. These initiatives foster meaningful interagency collaboration and serve as springboards for the rapid advancement of nanoscience and technology toward commercialization.

## Progress on 2010 Recommendations

PCAST's 2010 review of the NNI included recommendations in the categories of program management; nanotechnology outcomes; and environment, health, and safety (EHS). In this review, PCAST found that Federal agencies and offices involved in the NNI have made substantial progress in many areas, but little progress on some of the key recommendations PCAST made in 2010. On the positive side, the NNI has made progress in these areas:

- The National Nanotechnology Coordination Office (NNCO) expanded efforts in the area of commercialization and released a focused research strategy for addressing the EHS implications of nanotechnology.
- The NNCO has developed the Industry and State Liaison position to serve as a point of contact for the private sector.
- The National Science and Technology Council (NSTC) Nanoscale Science, Engineering, and Technology (NSET) Subcommittee's Nanomanufacturing, Industry Liaison, and Innovation Working Group is developing mechanisms to incorporate industrial input in NNI planning through public-private partnerships and is developing an agenda that focuses on job creation and state outreach.
- The Department of Energy initiated programs that include industrial partners to overcome technological barriers to nanotechnology commercialization.

- The National Institute of Standards and Technology plans to start the Advanced Manufacturing Technology Consortia in FY 2013 to speed up the development and commercialization of new products and services, including nanotechnology.
- The National Institutes of Health created the National Center for Advancing Translational Sciences to accelerate translation of promising technologies and clinical studies.
- The NSET Subcommittee created a standalone EHS strategy that reflects evolving research needs and the strategic research plans of three relevant agencies.

While these advances are encouraging, PCAST is concerned that little progress has been made since 2010 in four broad areas:

- *Strategic Planning.* While the NSET Subcommittee in 2011 produced a "National Nanotechnology Initiative Strategic Plan," individual agency contributions lack the cohesion of an overarching framework, and there is no clear connection between the goals and objectives of the NNI strategic plan with those of individual agencies.
- *Program Management.* PCAST is concerned that the agency representatives appointed to the NSET Subcommittee do not have a level of authority within their agencies to influence budget allocations needed to meet NNI objectives. In addition, mechanisms to solicit and act upon advice from outside of the Federal Government are still inadequate, as is the level of funding and capacity of the NNCO leadership to support the agencies in implementing programs that align with the NNI strategic plan.
- *Metrics.* The lack of clear metrics for assessing the impacts of Federal investments in nanotechnology remains a concern. Little appears to have been done to spur the development of metrics needed to determine the economic outcomes of the initiative.
- *Environmental Health and Safety.* PCAST is concerned that there is still a lack of integration between nanotechnology-related EHS research funded through the NNI and the kind of information policymakers need to effectively manage potential risks from nanomaterials.

In August 2011, the first cohort of National Science Foundation (NSF) Nanoscale Science and Engineering Centers was sunsetted. These centers have served as highly visible evidence of robust and coordinated U.S. support for nanotechnology in critical subject areas. Each of the old centers has been encouraged to seek additional funding to sustain its efforts beyond the lifetime of its NSF grant. Whether new or old Centers are funded, all future Centers should continue to exemplify an equal level of leadership, infrastructure, programs for training, and educational and public outreach and play a key role in the overarching strategic plan for nanotechnology.

## Recommendations

PCAST's recommendations in the four broad areas still of concern are summarized here:

**Strategic Planning:**

- The NNCO in partnership with the Office of Science and Technology Policy (OSTP) should work with the agencies to develop agency implementation plans for achieving the goals and objectives outlined in the 2011 NNI strategic plan.
- Participating agencies should ensure that senior agency officials capable of influencing funding decisions are participating fully and personally in strategic planning activities of the NSET. Officials at this level, in contrast with representatives active at the program or office level, could more effectively drive agency planning and budget allocations to meet NNI strategic directions.
- The Nanotechnology Signature Initiatives should be fully supported in NNI budgets. To this end, PCAST recommends that the Office of Management and Budget increase funding to these Initiatives.
- The NSET Subcommittee should create Nanotechnology Signature Initiatives in other priority areas such as homeland security, national defense, and human health.

**Program Management:**

OSTP should facilitate the following:

- Appoint the NNCO director as co-chair of the NSET Subcommittee of the NSTC.
- Change the requirement that the NNCO director must come from within the Federal Government to allow external, non-Federal experts the opportunity to direct the NNCO.
- Create a standing PCAST Nanotechnology Steering Committee of experts from industry, academia, and civil society to provide more frequent and in-depth guidance to the overall initiative and to the signature initiatives.
- Dedicate 0.3 percent of NNI funding to the NNCO to ensure the appropriate staffing and budget to effectively develop, monitor, and assess NNI programs.
- Work with the NNCO director to develop a plan for increasing the NNCO budget in line with its new responsibilities.

**Metrics:**

- Agencies should develop a mission-appropriate definition of nanotechnology that enables tracking specific nanotechnology investments supported at the program level. The definition and funding details should be published in agency implementation plans to promote clarity.
- The NNCO should track the development of metrics for quantifying the Federal nanotechnology portfolio and implement them to assess NNI outputs

**Environmental, Health, and Safety (EHS):**

The NSET should:

- Establish high-level, cross-agency authoritative and accountable governance of Federal nanotechnology-related EHS research so that the knowledge created as a result of Federal investments can better inform policy makers.
- Increase investment in cross-cutting areas of EHS that promote knowledge transfer such as informatics, partnerships, and instrumentation development.

# Table of Contents

# The President's Council of Advisors on Science and Technology

## *Report to the President and Congress On the Fourth Assessment of the National Nanotechnology Initiative*

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# Introduction

In 2001 the Federal Government launched the National Nanotechnology Initiative (NNI) with an initial budget of $500 million. The NNI is a crosscutting Federal program designed to coordinate U.S. investment in research and development (R&D) activities in nanoscale science, engineering, technology, and related efforts across 26 agencies and programs, 15 of which have budgets dedicated to nanotechnology research and development. The NNI has four broad objectives: (1) to advance world-class nanotechnology research and development; (2) to foster the transfer of new technologies into products for commercial and public benefit; (3) to develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology; and (4) to support the responsible development of nanotechnology.[1] Many of these goals may take decades to develop. As President Clinton explained in his January 21, 2000, speech at the California Institute of Technology, "Some of our research goals will take twenty or more years to achieve. But that is why, precisely why…there is such a critical role for the Federal Government."[2]

The NNI is managed within the framework of the Cabinet-level National Science and Technology Council (NSTC) through the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee. The NSET is composed of representatives from participating agencies and coordinates the planning, budgeting, program implementation, and review of the initiative and has four working groups dedicated to key NNI activities. The National Nanotechnology Coordination Office (NNCO) provides technical and administrative support to the NSET Subcommittee, including the preparation of multiagency planning, budget, and assessment documents. The NNCO also serves as the primary point of contact for agencies participating in the NNI as well as for public engagement and outreach. (An NNI organizational chart is found in Appendix B.)

**What Is Nanotechnology?**

Nanotechnology is the control and restructuring of matter at the nanoscale, in the size range of approximately 1–100 nanometers, in order to create materials, devices, and systems with fundamentally new properties and functions due to their small structure. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale. A nanometer is one-billionth of a meter. One sheet of paper is about 100,000 nanometers thick; a single gold atom is about a third of a nanometer in diameter.

The 21st Century Nanotechnology Research and Development Act of 2003 (Public Law 108-153) calls for a National Nanotechnology Advisory Panel (NNAP) to periodically review the NNI. The President's Council of Advisors on Science and Technology (PCAST) was designated as the NNAP in 2001 and

1. "NNI Vision, Goals, and Objectives," National Nanotechnology Initiative website, http://www.nano.gov/about-nni/what/vision-goals.
2. Bill Clinton, "President Clinton's address to the California Institute of Technology," speech, California Institute of Technology, Pasadena, CA, January 21, 2000, http://today.caltech.edu/theater/list?subset=culture&story_count=end.

subsequently re-instated in 2004 by Executive Order and reviewed the NNI in 2005, 2008, and 2010. This report represents PCAST's fourth review of the NNI as the NNAP.

Since 2001, the Federal Government has committed over $16 billion to the NNI, and has proposed $1.8 billion of funding in fiscal year (FY) 2013 for the 15 participating agencies with budgets dedicated to nanotechnology research and development. This request represents a $146 million decrease from 2010 funding levels.* At least in part, this investment has been made to ensure that the United States continues to maintain a global leadership position in nanotechnology research, development, and commercialization. There are three ways to consider how NNI funds are distributed: by agency, by Program Component Area (PCA), or by Nanotechnology Signature Initiative (NSI). Table 1 provides recent NNI funding for the seven agencies with the highest funding. Four of the seven agencies (DOE, NSF, NASA and EPA) show an increase in funding between the 2010 actual and 2013 proposed budgets.*

**Table 1. National nanotechnology initiative funding for select agencies 2009–2013 (dollars in millions)**

| Agency | 2009 | 2009 Recovery | 2010 | 2011 | 2012 Estimate** | 2013 Proposed |
|---|---|---|---|---|---|---|
| Department of Energy (DOE) | 333 | 293 | 374 | 346 | 315 | 443 |
| National Science Foundation (NSF) | 409 | 101 | 429 | 485 | 426 | 435 |
| Department of Health and Human Services (HHS)/National Institutes of Health (NIH) | 343 | 73 | 457 | 409 | 410 | 409 |
| Department of Defense (DOD) | 459 | — | 440* | 425 | 361 | 289 |
| Department of Commerce (DOC)/ National Institute of Standards and Technology (NIST) | 93 | 43 | 115 | 96 | 95 | 102 |
| National Aeronautics and Space Administration (NASA) | 14 | — | 20 | 17 | 23 | 22 |
| Environmental Protection Agency (EPA) | 12 | — | 18 | 17 | 18 | 19 |

* Includes $75 million in congressionally directed funding that is outside the NNI plans.
** Based on FY 2012 appropriated levels.

* In the initial public release of this report on April 27, 2012 this sentence contained several typos which were corrected and the updated version of the report was released on May 4, 2012.

NNI investments are distributed across eight PCAs, as determined collaboratively among the White House Office of Science and Technology Policy (OSTP), the Office of Management and Budget (OMB) and the participating agencies. The PCAs are thematic areas that represent the organizational framework under which NNI research and major activities are grouped. The eight PCAs are:

- PCA 1: Fundamental Nanoscale Phenomena and Processes
- PCA 2: Nanomaterials
- PCA 3: Nanoscale Devices and Systems
- PCA 4: Instrumentation Research, Metrology, and Standards for Nanotechnology
- PCA 5: Nanomanufacturing
- PCA 6: Major Research Facilities and Instrumentation Acquisition
- PCA 7: Environment, Health, and Safety
- PCA 8: Education and Societal Dimensions

In addition to the PCAs, the NNI has established three NSIs to foster meaningful interagency collaboration:

- Nanotechnology for Solar Energy Collection and Conversion
- Sustainable Nanomanufacturing: Creating the Industries of the Future
- Nanoelectronics for 2020 and Beyond

Unlike the agency budgets or PCAs, NSIs do not provide a complete crosscut of all NNI activity; there is much support for nanotechnology that is not captured within an NSI. They represent areas within the overall NNI activity where there is particular opportunity for rapid progress through collaborative actions across agencies. These initiatives are consistent with the President's Strategy for American Innovation[3] and are intended to serve as springboard programs for the rapid advancement of nanoscience and technology toward commercialization.[4] The President's 2013 Budget includes a total of $306 million for the initiatives, with $112 million for Nanotechnology for Solar Energy Collection and Conversion, $84 million for Sustainable Nanomanufacturing, and $110 million for Nanoelectronics for 2020 and Beyond.

Several trends in budget allocations across PCAs (Figure 1), which are highlighted in the NNI FY 2013 Supplement to the President's Budget, represent significant changes since the publication of PCAST's previous review of the NNI.[5]

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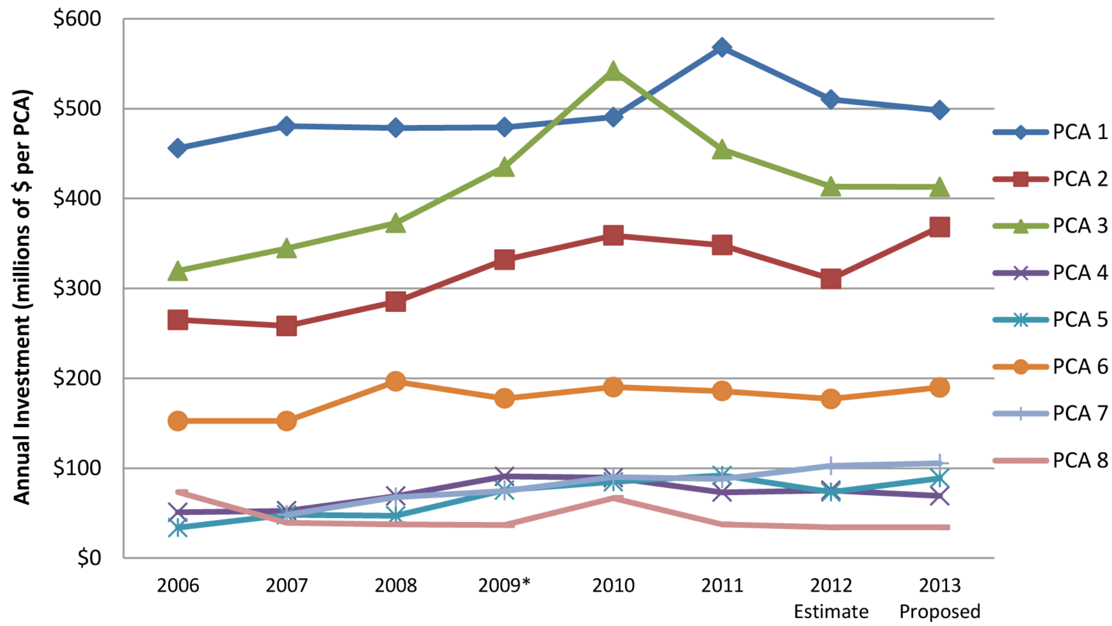
3. "A Strategy for American Innovation: Driving towards Sustainable Growth and Quality Jobs," White House website, http://www.whitehouse.gov/administration/eop/nec/StrategyforAmericanInnovation.
4. "Nanotechnology Signature Initiatives," National Nanotechnology Initiative website, http://www.nano.gov/html/research/signature_initiatives.html.
5. "National Nanotechnology Initiative," Supplement to the President's FY 2012 Budget, http://www.nano.gov/sites/default/files/pub_resource/nni_2012_budget_supplement.pdf.

**Figure 1. Annual NNI investment per PCA, 2006-2013**

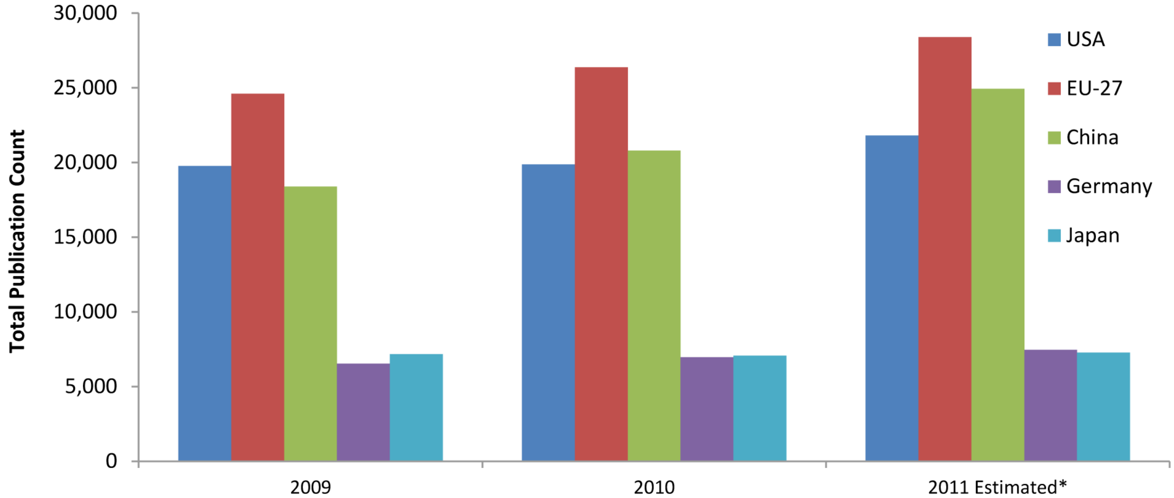



*Source:* NNI Supplement to the President's Budget (2007–2013).
*Not including ARRA funding.

Funding under PCAs 1, 2 and 3, which account for nearly 75 percent of the total NNI funding request, has decreased 8.0 percent from $1.39 billion in 2010 to $1.28 billion in the 2013 request. Agency officials report that the NNI investment in nanomanufacturing (PCA 5) rose 4.8 percent from $84.8 million in 2010 to $88.9 million in 2013. This captures increased investments associated with the NSI on Sustainable Nanomanufacturing as well as increased investments at the NSF ($29.3 million in the 2010 actual budget to $52.8 in the 2013 request). While fundamental research (PCA 1) remains the largest single NNI investment category ($498 million in the 2013 budget), the more applied research in nanodevices and systems (PCA 3) and in nanomanufacturing (PCA 5) now totals over $500 million combined, as some areas of nanotechnology mature and applications develop. The funding level for PCA 7, Environment, Health, and Safety (EHS), increased by 16 percent, from $90.2 million in 2010 to $105 million in the 2013 request.

As initial Federal investments in nanotechnology mature, more attention is being paid to the outputs from these research activities. Early research in nanoscience and nanotechnology has resulted in both publication and patenting, which has further enabled researchers to investigate the effects of these national investments on an international scale. Publication rates in nanotechnology, which can be used as an indicator of research productivity, show that the United States is falling in its share of total nano-related publications but still leads in publishing in three top science journals (*Science*, *Nature*, and *Proceedings of the National Academy of Sciences*) (Figure 2 and Appendix D).

**Figure 2. Publication counts for nanotechnology articles in Web of Science, 2009–2011 (SCI, SSCI, and A&HCI)**




*Source:* L. Kay, P. Shapira, J. Youtie, and A. L. Porter, Program on Nanotechnology Research and Innovation System Assessment Georgia Institute of Technology, Atlanta, Georgia, with support from the National Science Foundation (NSF) through the Center for Nanotechnology in Society (Arizona State University; Award No. 0937591) [Data as of January 2012].

*Note:* Search based on S. Arora, A. L. Porter, Y. Youtie, and S. Shapira, Capturing new developments in nanotechnology scientific output: A search strategy for publication records. STIP White Paper, Atlanta, Georgia, 2011.

*Annualized publication counts based on number of country-level publications identified as of 22 August 2011. Additional 5% added to account for publications expected to be released in the next calendar year (i.e., in early 2012).

Figure 2 provides publication counts for nanotechnology articles from 2009 to 2011.[6] Publication counts are reported for the top five nanotechnology publication-producing countries for all journals collected in Thomson Reuters Web of Science (Science Citation Index [SCI], Social Science Citation Index [SSCI], Arts and Humanities Citation Index [A&HCI]). The United States, the 27 European Union (EU-27) member nations, and China outpace the rest of the world in numbers of publications produced. Of additional importance, the number of papers produced globally that cite nano-publications with U.S. authorship remains high. Through 2010, the United States held the largest percentage of nanotechnology citations. Citation counts corresponding to nanotechnology publication counts presented in Figure 2 appear in Appendix Figures D-1 and D-2.

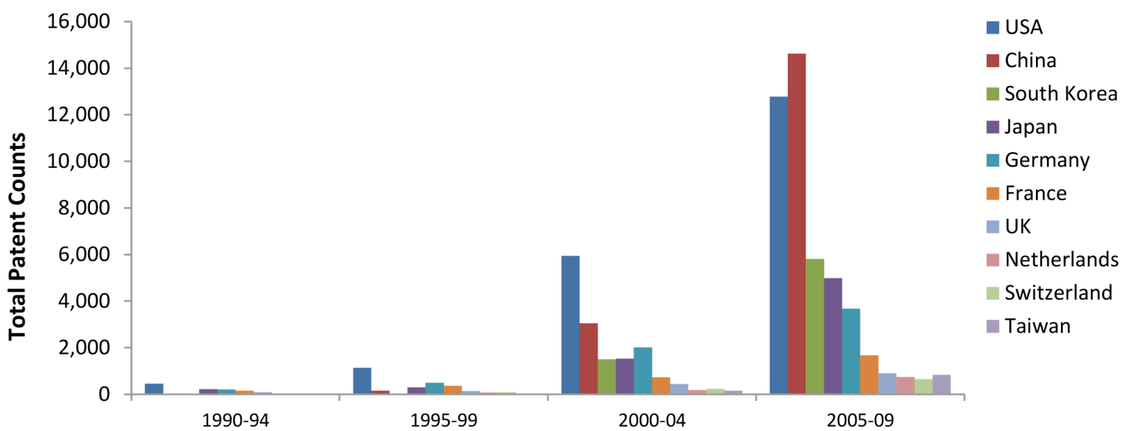
Researchers and firms from the United States continue to claim the highest number of nanotechnology priority patents internationally, outnumbering the second place EU-27 bloc by almost 3,000 filings in 2005–2009 (Figure 4). However, South Korean and Chinese nanotechnology patent applications (measured by assignee country) are increasing quickly. Figures 3 and 4 show counts of patent applications by assignee country over five-year increments. Figure 3 includes all patent applications filed, whereas Figure 4 restricts assignee patent counts to only documents that report priority filing. A priority patent is one in which the intellectual property holder is recognized as the first to file and therefore receives exclusive, if time-limited, rights to the intellectual property internationally.

6. Based on definition of "nanotechnology" by A. L. Porter, J. Youtie, P. Shapira, and D. Schoeneck, "Refining Search Terms for Nanotechnology," *Journal of Nanoparticle Research*, 10 (5): 715–728.

A more accurate illustration of global nanotechnology intellectual property rights requires considering that priority patent applications indicate which countries will successfully hold the intellectual property pertaining to a technology patent family. This is particularly relevant when analyzing the discrepancies between counts of all patent applications and priority patent applications. Priority patent figures show a sharp fall in China's ranking from first place when considering all patent applications to eighth place when considering priority patents only. Moreover, patent counts are based on the analysis of patent documents that refer to nanotechnology-relevant topics (such as methods, materials, or processes) and do not yet indicate whether or not the technologies are ultimately commercially viable. The United States continues to lead in the race to nanotechnology commercialization; it holds the highest number of priority patents by almost 5,000 filings in the time period 2005–2009. Figure 4 also aggregates European countries into one category (EU 27), and it illustrates counts of priority patent applications in nanotechnology globally, considering the importance of the EU-27 as a single community.

Additional nanotechnology bibliometrics data appear in Appendix D.

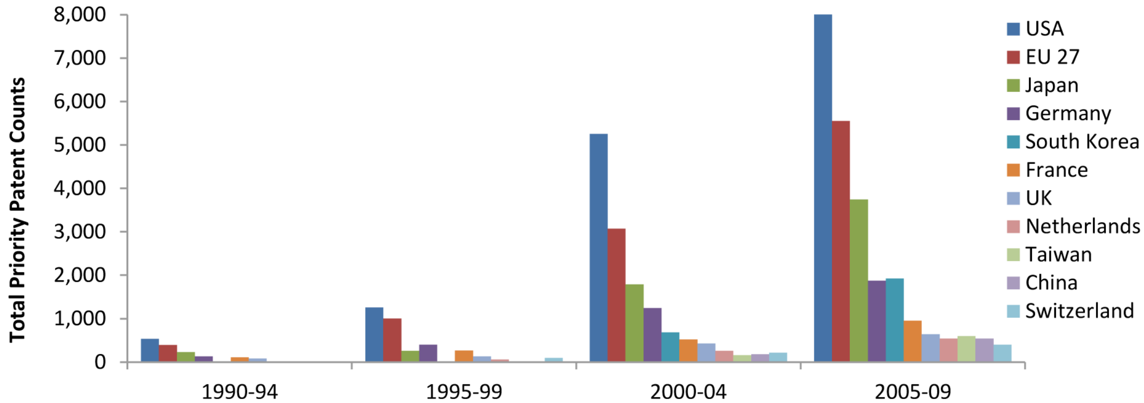
**Figure 3. Counts of patent applications in nanotechnology in PATSTAT, by year and assignee country, 1990–2009**




*Source:* L. Kay, P. Shapira, J. Youtie, and A. L. Porter, Program on Nanotechnology Research and Innovation System Assessment Georgia Institute of Technology, Atlanta, Georgia, with support from the National Science Foundation (NSF) through the Center for Nanotechnology in Society (Arizona State University; Award No. 0937591) [Data as of January 2010]. PATSTAT stands for the Patent Statistical Database, which is maintained by the European Patent Office.

*Note:* Based on definition of "nanotechnology" by A. L. Porter, J. Youtie, P. Shapira, and D. Schoeneck, "Refining Search Terms for Nanotechnology," *Journal of Nanoparticle Research*, 10 (5): 715–728.

**Figure 4. Counts of priority patent applications in nanotechnology in PATSTAT, by year and assignee country, 1990–2009**




*Source:* L. Kay, P. Shapira, J. Youtie, and A. L. Porter, Program on Nanotechnology Research and Innovation System Assessment Georgia Institute of Technology, Atlanta, Georgia, with support from the National Science Foundation (NSF) through the Center for Nanotechnology in Society (Arizona State University; Award No. 0937591) [Data as of January 2010]. PATSTAT stands for the Patent Statistical Database, which is maintained by the European Patent Office.

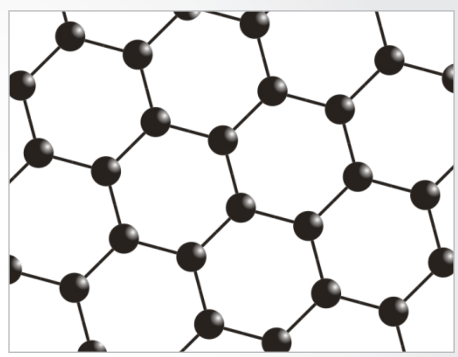
*Note:* Based on definition of "nanotechnology" by A. L. Porter, J. Youtie, P. Shapira, and D. Schoeneck, "Refining Search Terms for Nanotechnology," *Journal of Nanoparticle Research*, 10 (5): 715–728. Priority applications are patent documents in PATSTAT that report priority sequence of "1."

# Initiative Developments Since 2010

PCAST's 2010 assessment found that "U.S. leadership in nanotechnology is threatened by several aggressively investing competitors such as China, South Korea, and the European Union. In response to this threat, the report recommends a number of changes in Federal programs and policies, with the goal of assuring continued U.S. dominance in the decade ahead."[7] The report presented recommendations in three broad categories—program management, nanotechnology outcomes, and EHS—each with a number of specific recommendations for NNCO and Federal agencies. This assessment addresses progress toward these specific recommendations through an examination of government documents, expert presentations, and evidence provided by NNCO and agency officials.

PCAST recognizes the positive efforts undertaken by the Federal agencies and offices involved in the NNI toward addressing the recommendations made in the 2010 PCAST assessment (see Appendix E for the full list of recommendations). Of particular note are the expanded efforts of the NNCO in the area of commercialization and the release of a focused research strategy for addressing the EHS implications of nanotechnology. Additionally, there have been many advances coming out of the federally-funded programs some of which are already moving on to commercialization phases. In this section, we highlight three such advances beginning with the Nobel prize winning graphene example.,

### Graphene: The Material of the Future



Source: Wikimedia

The 1985 discovery at Rice University of a new form of pure carbon, the soccer-ball shaped C60 molecule known as buckminsterfullerene, renewed interest in carbon research and garnered the Nobel Prize in Chemistry just eleven years later. The spheroidal molecule's tubular relatives, carbon nanotubes have generated even more attention and focus due to their extraordinary physical and chemical properties. Now, there's excitement over the two-dimensional hexagonal, crystalline carbon material called graphene. While scientists have known about graphene for decades, it was only in 2004 that graphene flakes were isolated and imaged and their electrical conductivity characterized. For this achievement, Andre Geim and Konstantin Novoselov were awarded the 2010 Nobel Prize in Physics.

At one atom thick, graphene is ultimately thin, nearly completely transparent, and super strong yet flexible. Graphene is more than one hundred times stronger than steel of an equivalent thickness, ten times more thermally conductive than copper, and slightly more electrically conductive than copper. Its electrical conductivity recommends it as a potential replacement for silicon in transistors; its smaller size profile would allow a higher transistor density on a chip, enabling even greater miniaturization of computer components than is possible with silicon-based technologies. The combination of transparency, thinness, and electrical conductivity has led to predictions that graphene will ultimately replace the expensive and fragile

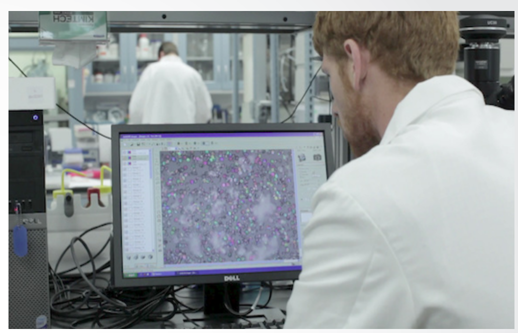
7. Executive Office of the President, President's Council of Advisors on Science and Technology, "Report to the President and Congress on the Third Assessment of the National Nanotechnology Initiative," March 12, 2010, p. vi.

indium-tin-oxide material used in many touch screens. Add in graphene's flexibility and one can envision it enabling the development of computer displays that can be rolled up like a newspaper.

For these possibilities to be realized, however, several material challenges must be addressed. Specifically needed is a method for scaling the production of graphene and a way to alter the graphene so that it acts as a semiconductor for use in computers. The Federal Government has sponsored 20 Small Business Innovation Research (SBIR/STTR) awards relating to graphene research in the last three years. Of these awards, two sponsor Phase II research into the development of specific material processing and characterization technologies for scaling graphene production. Phase I awards focus on overcoming barriers to commercial application of graphene in technologies including supercapacitors for energy storage in hybrid electric vehicles and sensors for chemical explosives.

In support of PCAST's 2010 recommendations, DOE has initiated programs that include industrial partners to overcome technological barriers to nanotechnology commercialization. NIST plans to start the Advanced Manufacturing Technology Consortia in FY 2013 to speed up the development and commercialization of new products and services, including nanotechnology, and NIH has created the National Center for Advancing Translational Sciences to accelerate translation of promising technologies and clinical studies. Finally, the NNCO has developed the Industry and State Liaison (ISL) position to serve as a point of contact for the private sector. The NSET Nanomanufacturing, Industry Liaison, and Innovation (NILI) Working Group is developing mechanisms to incorporate industrial input in NNI planning through public-private partnerships and is developing an agenda that focuses on job creation and state outreach.

**Liquidia: Nano-enabled Vaccines and Therapeutics**



Courtesy: Liquidia Technologies

Liquidia Technologies in Research Triangle Park, North Carolina, is developing highly precise nanoparticle-based vaccines and therapeutics for the prevention and treatment of human disease. It leverages techniques from the semiconductor industry to fabricate particles in a highly regular manner that can mimic the properties of viruses and other biological entities. With its proprietary PRINT technology, Liquidia has exquisite control over particle size, shape, and composition and can prepare a wide variety of highly functional materials for drug delivery and adjuvant therapy purposes. Its first products in vaccines (influenza and malaria) and its emerging products for treating respiratory disease (COPD and pulmonary hypertension) are enabled by the recent transition of its PRINT nanoparticle technology to a manufacturing process that is compliant with current Good Manufacturing Practices (cGMP). Liquidia was founded in 2004 by Professor Joseph M. DeSimone from the University of North Carolina at Chapel Hill, whose research has been sponsored in part by the National Cancer Institute's Alliance for Nanotechnology in Cancer Centers of Cancer Nanotechnology Excellence (CCNE), NSF EArly-concept Grants for Exploratory Research (EAGER), and the NIH Director's Pioneer Award in 2009. Liquidia is on a rapid path to the clinic and has secured the first equity investment by the Bill & Melinda Gates Foundation and resources from a variety of major pharmaceutical companies. The company is backed by venture capital investment, led by Canaan Partners and New Enterprise Associates, both located in Menlo Park, California.

PCAST specifically notes the laudable effort undertaken by the NSET Subcommittee to create a standalone EHS strategy that is reflective of evolving research needs and strongly coupled to the strategic research plans of three relevant agencies. *NNI Environmental, Health, and Safety Research Strategy* was released in October 2011 by the Nanotechnology Environmental and Health Implications (NEHI) working group of the NSET Subcommittee. The strategy made significant progress toward the 2010 PCAST recommendation to provide cross-agency guidance by outlining plans for identifying research areas that align with agency missions. The plans utilize the NNI EHS Coordinator as a central facilitator across the NSET agencies and internationally and establish more frequent assessments of progress made toward the strategic goals by the NEHI working group.[8] The EHS Research Strategy aligns well with the findings of an independent panel of experts convened by National Research Council, whose January 2012 report, *A Research Strategy for Environmental, Health, and Safety Aspects of Engineered Nanomaterials (ENMs)*,[9] was already under review when the EHS Research Strategy was released. Specific areas of alignment between the two documents include recognition of the importance of a life cycle approach to assessing risks, the need for more research on human and environmental exposure to nanomaterials, better tools for measuring and tracking nanomaterials, and the need for cross-cutting informatics infrastructure for nanotechnology-related EHS research.

Additionally, the NNI continues to support a strong and growing portfolio of research on the societal implications of nanotechnology, nanotechnology education, and public outreach. In late 2010, the NSF released *Nanotechnology Research Directions for Societal Needs in 2020*, including a chapter on the responsible governance of nanotechnology for societal development. The NSF continues to support two Centers for Nanotechnology in Society dedicated to research on the societal dimensions of nanotechnology and public outreach. Currently, NSF supports the training and education of roughly 10,000 students and teachers in nanoscale science and engineering. NSF also funds the development of new curricula for nanotechnology education and is expanding the outreach of the National Center for Nanotechnology Applications and Career Knowledge.

Several major developments since the 2010 PCAST report will likely be important in the coming years. Two of these developments are examined in the following sections.

## Sunset of the First Class of Nanoscale Science and Engineering Centers

One notable development since the publication of the 2010 PCAST report is the sunsetting of the first class of National Science Foundation Nanoscale Science and Engineering Centers (NSECs) in August 2011.[10] These centers were created in 2001 with an initial five-year award and were renewed in 2006

8. National Science and Technology Council Committee on Technology Subcommittee on Nanoscale Science, Engineering, and Technology, "NNI Environmental, Health, and Safety (EHS) Research Strategy," 2011, http://www.nano.gov/sites/default/files/pub_resource/nni_2011_ehs_research_strategy.pdf.

9. National Research Council, Committee to Develop a Research Strategy for Environmental, Health, and Safety Aspects of Engineered Nanomaterials, "A Research Strategy for Environmental, Health, and Safety (EHS) Aspects of Engineered Nanomaterials (ENMs)," 2012, http://www.nap.edu/catalog.php?record_id=13347.

10. The centers are NSEC for Integrated Nanopatterning and Detection Technologies; NSEC for Nanoscale Systems in Information Technologies; NSEC for Science of Nanoscale Systems and their Device Applications; Center for Electronic Transport in Molecular Nanostructures; Center for Biological and Environmental Nanotechnology; and NSEC for the Directed Assembly of Nanostructures.

### Workforce Development

Courtesy: NACK Center

With the support of the NSF's Advanced Technology Education (ATE) program, Penn State has developed a nation-wide partnership of research universities and community colleges that is bringing meaningful core-skills nanotechnology workforce education to technical and community colleges across the United States. This partnership, the NSF National Nanotechnology Applications and Career Knowledge (NACK) Network, fosters (1) resource sharing among community colleges and research universities for nanotechnology workforce development, (2) the availability of course materials, for web or in-class use, covering a core-set of industry-recommended nanotechnology skills and (3) broad student preparation for careers in the wide spectrum of industries utilizing micro- or nanotechnology. NACK has created and offers continually updated, free-of-charge core-skills course lecture and lab materials, web-accessible equipment capability, and faculty development workshop curricula. Since the inception of the nationwide effort in 2008, NACK research university-community college partnership hubs have been set-up and are functioning in Puerto Rico, New York, Indiana, Minnesota, Texas, and Washington State. Others are underway and these are in addition to the hub comprised of 30 Pennsylvania schools and funded by the State of Pennsylvania since 1998. To-date, there have been over 800 graduates from the nanotechnology core-skill classes offered by the NACK hubs, 20,881 web downloads of NACK educational materials, and 957 educators who have completed professional development workshops. The Penn State nanotechnology workforce development programs began as a Pennsylvania-focused activity with the founding of Pennsylvania Nanofabrication Manufacturing Technology (NMT) Partnership funded by the State in 1998. In 2003 the additional component of an NSF ATE regional center for nanotechnology workforce education was added. In 2008 this NSF ATE activity evolved into the NACK Network nationwide workforce development partnership. By creating education pathways from high school to skilled manufacturing careers across the country, the NACK Network is working to train the U.S. nanotechnology manufacturing workforce.

for an additional five years. In May 2011, a team of NSF-funded researchers published a report entitled, "Assessment of Fifteen Nanotechnology Science and Engineering Centers' Outcomes and Impacts: Their contribution to NNI Objectives and Goals".[11] This team found evidence of NSEC contributions to world-class nanotechnology R&D through citation of the NSECs' published outputs by global research organizations, the presence of NSEC publications in the highest impact journals, citations of early NSEC papers being among the most highly cited papers in the field, and a very significant spillover effect of center research into adjacent fields that underscores the interdisciplinary nature of NSEC research. The team also concluded that the centers had been successful in fostering the transfer of new technologies into products, citing the rich and collaborative links between NSECs and industrial partners, and the fact that a core of top high-technology firms came to rely on the centers as an R&D resource. While this

11. J. Rogers, J. Youtie, A. Porter, and P. Shapira, "Assessment of Fifteen Nanotechnology Science and Engineering Centers' (NSECs) Outcomes and Impacts: Their contribution to NNI Objectives and Goals," http://www.nsf.gov/crssprgm/nano/reports/Assessment_2011+May+12+of+NSEC+by+GaTech_FinalReport_56p_web.pdf.

research studied 15 NSECs, the report singled out several within the initial cohort of six centers for special recognition in key areas such as research performance, commercialization of NSEC research, education, and responsible development.

The centers serve as highly visible evidence within the international community of robust and coordinated U.S. support for nanotechnology in critical subject areas. Each of the old centers has been encouraged to competitively seek funding to sustain its efforts beyond the lifetime of its NSF grant. However, it is also important that any new cohort of centers exemplify an equal level of leadership, support of infrastructure, programs for training, and educational and public outreach as well as play a key role in the overarching strategic plan for nanotechnology as the old centers have.

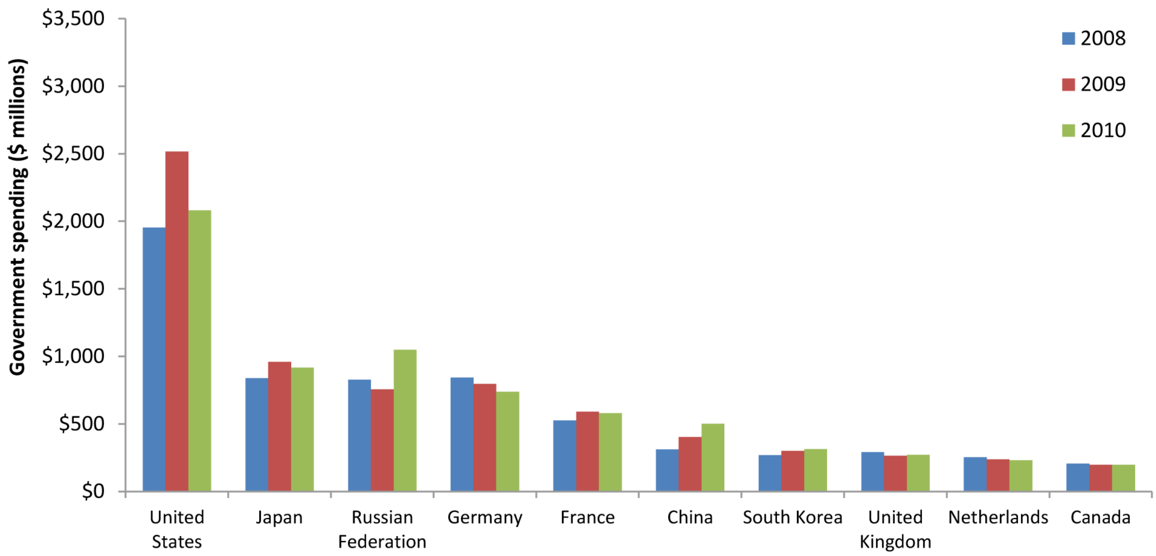
## International Developments

The Federal Government continues to invest more in nanotechnology R&D than any other single country (Figure 5). To date more than $16 billion has been invested in U.S. nanoscience and nanotechnology via the NNI. There has been concern that in addition to China, South Korea, and other early movers, the Russian Nanotech Corporation (RUSNANO) is now also rising as a major player, second only to the United States in its nanotechnology R&D spending. According to Lux Research, RUSNANO increased its funding by nearly 40 percent to $1.05 billion and has plans to increase even further to nearly $1.5 billion by 2015. Despite a significant surge in Russian spending in 2010 (Figure 5), bibliometrics data do not indicate a commensurate increase in scholarly or commercial output. It may be premature to assess the potential impact of Russian investment in nanoscale research and development. Within Europe, Germany is currently outspending its neighbors, and adopted the Nanotechnology 2015 Action Plan that serves as a high-technology strategy for Germany's Nanotechnology Initiative.[12] The United States is also the world leader in corporate and venture capital investments in nanotechnology (Figure 6 and Figure 7). Global commercial nanotechnology spending is up 7 percent in 2012 to $9 billion while venture capital investment is down nearly 22 percent in 2010.[13]

12. Federal Ministry of Education and Research (2011). Action Plan Nanotechnology 2015, http://www.bmbf.de/pub/akionsplan_nanotechnologie_2015_en.pdf.

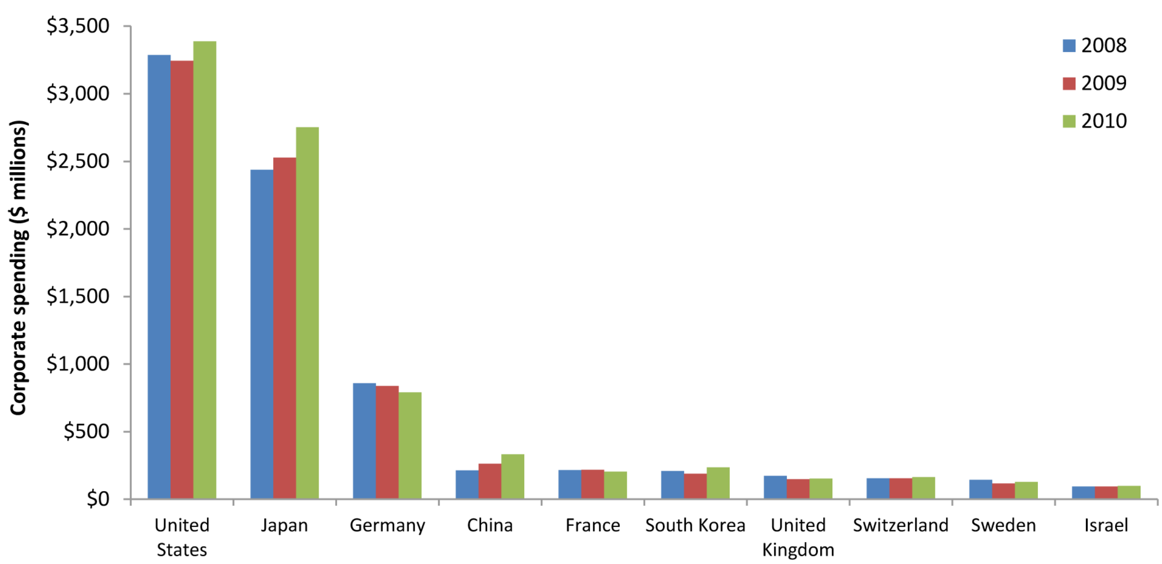
13. See also, M. Roco, "Nanotechnology: From Discovery to Innovation and Socioeconomic Projects," *Chemical Engineering Progress* May 2011, specifically Table 1, "Nanotechnology development can be characterized by a variety of indicators."

**Figure 5. Global governmental nanotechnology spending for top ten countries, 2008–2010**



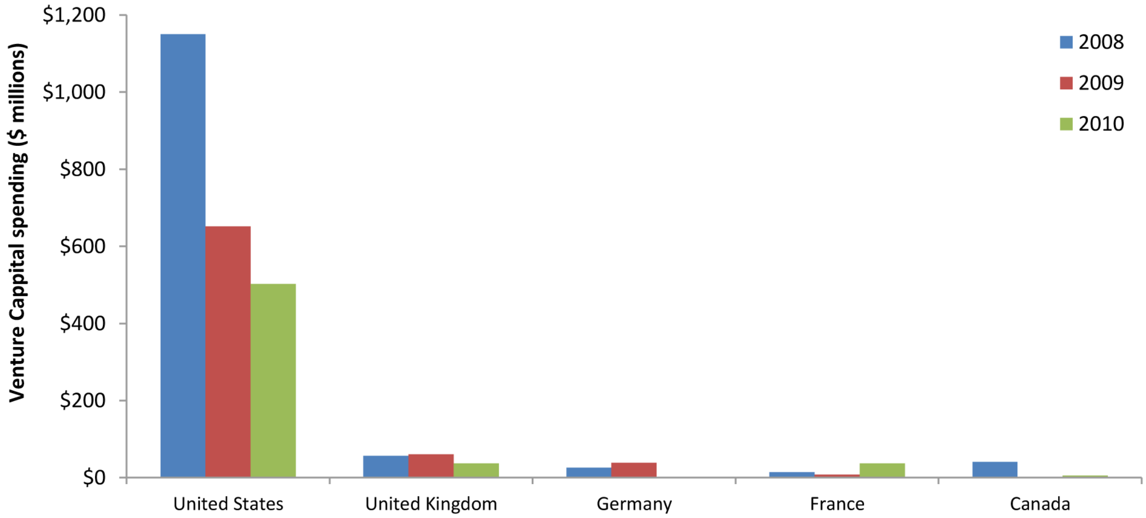

*Source:* A. Xue and D. Hwang, "Nanotechnology Funding: Corporations Grab the Reins," *Lux Research,* April 2011.

**Figure 6. Corporate nanotechnology spending for top ten countries, 2008–2010**




*Source:* A. Xue and D. Hwang, "Nanotechnology Funding: Corporations Grab the Reins," *Lux Research,* April 2011.

**Figure 7. Venture capital spending for top five countries, 2008–2010**




*Source:* A. Xue and D. Hwang, "Nanotechnology Funding: Corporations Grab the Reins," *Lux Research,* April 2011.
*Note:* No data were available for Germany's Venture Capital spending for 2010.

# Recommendations

In 2010, PCAST made recommendations (listed in Appendix E) to strengthen the role of the NNCO to act as a coordinating body for the NNI. While PCAST recognizes some improvement (described in the previous section, "Initiative Developments Since 2010") little progress has been made in the intervening time on several of these recommendations, which fall broadly into the following categories:

- *Strategic Planning:* the extent to which the overall NNI strategic plan has been effective at driving nanotechnology planning and resource allocation within the member agencies.
- *Program Management:* an assessment of additional actions that can be taken to strengthen the NNI leadership within the NSET and NNCO in areas of coordination and performance.
- *Metrics:* the extent to which metrics have been developed for measuring NNI outputs such as number of jobs created and the contribution of nanotechnology to the nation's economic growth.
- *Environmental, Health, and Safety Research:* an assessment of NNI progress toward understanding and managing the risks posed by nanotechnology to humans and the environment.

PCAST has determined that the NNI remains a successful cooperative venture. However, significant hurdles to an optimal structure and management of this broad initiative still persist. These hurdles include the level of authority that representatives appointed to NSET have within their home agencies to influence the budget allocations needed to meet NNI objectives, the inadequacy of mechanisms to solicit and act upon advice from outside of government, and the level of funding and capacity of the NNCO leadership to support the agencies in implementing programs that align with the NNI strategic plan. The lack of clear metrics for assessing the impacts of Federal investments in nanotechnology remains a concern, as do the still significant knowledge gaps that exist in the area of nanotechnology-related EHS impacts.

## Strategic Planning Recommendations

In 2010, PCAST was concerned with a perceived deficiency in the agencies' strategic planning process regarding the management of and budgeting for nanotechnology research and development. In

**Table 2. Agency-specific strategic research plans for nanotechnology**

| Agency | Title | Year |
|---|---|---|
| CDC | Strategic Plan for NIOSH Nanotechnology Research and Guidance | 2009 |
| EPA | Nanomaterial Research Strategy | 2009 |
| FDA | Nanotechnology Regulatory Science Research Plan | 2011 |

*Note:* These documents contain strategic language for each agency in regard to nanotechnology.

February 2011, the NSET Subcommittee produced an NNI strategic plan.[14] PCAST views this document as evidence of progress toward achieving a more cohesive overall strategy for the initiative; however, individual agency contributions lack the cohesion of an overarching framework. Table 2 lists the three NNI agency documents containing a commonly understood definition of a strategic research plan.

The process for producing the strategic plan is still agency-driven, which could limit the broader NNI vision to those objectives that agency officials feel are sufficiently within reach. Also lacking is a clear connection between the goals and objectives of the NNI strategic plan with those of individual agencies. PCAST recommends taking the following actions:

*NNCO in partnership with OSTP should work with the agencies to develop implementation plans for achieving the goals and objectives outlined in the 2011 NNI strategic plan.*
Most participating agencies do not have strategic planning documents for nanotechnology. Agency officials assert that they have engaged in strategic planning activities to an extent that makes sense for their individual missions. Given that many of the agencies do not have a dedicated nanotechnology program but instead distribute their nanotechnology activities and budgetary outlays across multiple organizational units, it may be unnecessary—and perhaps infeasible—to create documented agency-specific strategic plans that could be aligned with the overarching NNI strategic plan. As an alternative to standalone strategic planning documents prepared by each participating agency, PCAST recommends the development of a nanotechnology implementation plan by each agency. Such plans should align with and communicate in detail how the agency will meet the objectives of the NNI strategic plan. Implementation plans could be discussed and revised in consultation with external stakeholders as well as with PCAST.

*Ensure that senior agency officials capable of influencing funding decisions are participating fully and personally in strategic planning activities of the NSET. Officials at this level, in contrast to representatives active at the program or office level, could more effectively drive agency planning and budget allocations to meet NNI strategic directions.*
Many members of the NSET are leaders in program management within their agencies. Some of these individuals, do not have direct influence over funding allocations, but they communicate NNI priorities back to the decision-makers in their agencies. Moreover, most agencies have no direct budget line dedicated to nanoscale science and engineering. Rather, each agency determines for itself how nanotechnology is supported, by which programs and offices, and how resources are allocated relevant to its mission, often via an internal committee that reviews and suggests directions for the next budget year. This flexible arrangement acknowledges the importance of independence when planning agency activities but results in the suboptimal implementation of the broader NNI strategic plan. Ensuring that senior leaders, especially from the top six agencies of the NNI, engage directly and fully in the strategic planning process is one mechanism through which NNI objectives may gain the attention and commitment of those in a position to influence budget allocations. Under this arrangement, NSET representatives at the program level would continue to play a critical role in coordination, communication, and strategic planning activities.

14. National Science and Technology Council Committee on Technology, Subcommittee on Nanoscale Science, Engineering, and Technology, "National Nanotechnology Initiative Strategic Plan," 2011, http://www.nano.gov/sites/default/files/pub_resource/2011_strategic_plan.pdf.

*The Nanotechnology Signature Initiatives should be fully supported in NNI budgets. To this end, we recommend that the Office of Management and Budget increase funding to these initiatives.*
PCAST recognizes that the three existing NSIs play an enabling and foundational role in achieving both the objectives of the NNI and the larger strategic goal of global economic competitiveness over the next decade. As a result, during the next phase of strategic planning, agencies should consider the relevance of their nanotechnology investments to the existing NSIs and should commit the necessary resources to achieve these objectives. As these efforts continue, PCAST, through the recommendations that follow, re-emphasizes the importance of collecting and analyzing data about the outputs of NNI impacts broadly and the NSIs specifically so that their success can be measured in a transparent way.

*The NSET Subcommittee should create Nanotechnology Signature Initiatives in other priority areas such as homeland security/national defense and human health.*
The NSIs provide an effective way of focusing research across Federal agencies toward a common set of objectives to address a critical national need. In addition to fully supporting the three existing NSIs, the NSET Subcommittee should consider creating new NSIs in areas of homeland security/national defense and human health research. While excellent work is being done already in these areas by one or more agencies, the NSIs would provide a framework for establishing a common set of objectives in these areas and facilitating more extensive interagency collaboration.

## Program Management Recommendations

PCAST recognizes several actions taken by the NSET Subcommittee and NNCO since the publication of the 2010 NNI review. The identification of a dedicated NNCO staff person to coordinate nanotechnology-related EHS issues has already borne fruit in the publication of the 2011 NNI EHS Research Strategy. Likewise, there is now a position dedicated to liaising with industry and State stakeholders. To further these achievements, the NNCO should continue to broaden its impact and efficacy and improve its ability to coordinate and develop NNI programs and policies related to those programs. PCAST recommends OSTP take the following actions to facilitate these improvements:

*Appoint the NNCO director as co-chair of the NSET Subcommittee.*
The NNCO director currently is a non-voting member of the NSET Subcommittee. Appointing this person as co-chair, as is the case for another Presidential initiative, the Networking and Information Technology Research and Development (NITRD) Program, would enable the director to better coordinate with and support the agencies.

*Change the requirement that the NNCO director must come from within the government to allow external, non-Federal experts the opportunity to direct the NNCO.*
OSTP should recommend lifting the prohibition set forth in the 2001 Memorandum of Understanding (MOU) creating the NNCO that the NNCO director has to be a Federal employee. Enabling the NNCO in the future to engage talented leaders from outside of Federal service is one way to bring fresh perspectives and differing expertise into the management and coordination of the NNI. To be effective, such an individual must have a deep understanding of the cultures, missions, strategic priorities, and operations of the relevant Federal agencies.

*Create a standing PCAST Nanotechnology Steering Committee of experts from industry, academia, and non-governmental organizations to provide more frequent and in-depth guidance to the overall initiative and to the signature initiatives.*

Over the next decade, commercialization and translational activities will assume an increasingly important role in the success of the NNI. In contrast with support for upstream research, the locus for most of these activities lies outside of government. Therefore, advice and counsel from a broader set of non-Federal experts will be essential. PCAST recommends that a standing steering committee be created with experts from outside of government that meets regularly to provide more frequent external feedback to NSET and NNCO officials. This group could be modeled on the PCAST Advanced Manufacturing Partnership in which a PCAST member serves as an ex-officio member of an external group of leaders from industry and academia.[15] The inclusion of members from non-governmental organizations will further the NNI goals of advancing responsible nanotechnology.

*Dedicate 0.3 percent of NNI funding to the NNCO to ensure the appropriate staffing and budget to effectively develop, monitor, and assess NNI programs.*

Currently, the NNCO receives 0.16 percent of each participating agency's allocated nanotechnology budget. The NNAP recommended in 2010 that the NNCO receive 0.3 percent of each participating agency's nanotechnology budget. The NSET Subcommittee discussed, but did not support, such an increase because current funding is based on programmatic needs rather than a fixed percentage of the NNI budget. PCAST's recommendations for restructuring the NNCO will require increased capacity and, consequently, an increase in its budget. These activities include management of and funding for the external advisory group recommended herein; stronger engagement with the business community, academia, and non-governmental organizations during the creation of the agencies' implementation plans; and enhanced coordination with state and local governments. Additionally, the NNCO may consider working with agencies such as the Bureau of Economic Analysis (BEA) or the Census Bureau to enumerate and collect the underlying data needed for the proposed workforce metrics (see metrics recommendation, below). It is reasonable for the NNCO budget to double in size over the next 3 years as it takes on more activities in support of the agencies.

*Work with the NNCO director to develop a plan for increasing the NNCO budget in line with its new responsibilities.*

OSTP should consider tasking the PCAST Nanotechnology Steering Committee recommended above as an advisory board and making management and budgetary discussions part of the group's deliberations. This would provide additional guidance to the NNCO regarding its administrative role and budgetary needs.

15. About the Advanced Manufacturing Partnerships: http://www.whitehouse.gov/administration/eop/ostp/pcast/amp.

## Metrics Recommendations

In 2010, PCAST recommended the development of measures that could be used to track the progress of nanotechnology outcomes, and PCAST reiterates the importance of metrics development here. To document progress made as a result of Federal investments in nanotechnology, it is essential that there is transparency and consistency in how each agency interprets the Federal definition of nanotechnology. As there is currently flexibility in the way individual agencies operationalize the definition, PCAST recommends taking the following actions to facilitate the characterization and quantification of the Federal nanotechnology portfolio of investments. Such actions will facilitate the collection of metrics that then can be used to estimate economic returns resulting from the NNI.

*Agencies should develop a mission-appropriate definition of nanotechnology that enables the tracking of specific nanotechnology investments supported at the program level. The definition and funding details should be published in agency implementation plans to promote clarity.*

This recommendation enables each agency to develop a mission-appropriate definition of nanotechnology to characterize its nanotechnology portfolio. Requiring each agency to publish its definition and the resulting budget allocations will improve clarity across the Federal nanotechnology portfolio and ensure that nanotechnology investments are accurately characterized.

*The NNCO should track the development of metrics for quantifying the Federal nanotechnology portfolio and implement them to assess NNI outputs.*

Current Federal efforts to measure public and private investment, scientific productivity, and workforce have been inconsistent and decentralized. The publication of agency-specific data will enable the NNCO to consistently track nanotechnology investments across the Federal government and enable it to report NNI impacts with greater confidence and transparency.

There is an extensive and growing body of high-quality academic research that is already working toward the establishment of nanotechnology metrics by drawing upon bibliometrics data from the public domain (e.g., publication and patent data).[16] Bibliometrics data are used as indicators of productivity beyond academia, often in the absence of other metrics from the private sector. As nanotechnology continues to mature and move closer toward commercialization, efforts to more accurately capture economic returns are picking up pace. Examples include the March 2012 International Symposium on Assessing Economic Impacts of Nanotechnologies sponsored jointly by the NNI and the Organization for Economic Co-Operation and Development held in Washington, DC, as well as the upcoming 2012 National Research Council review of the NNI.

A final area in need of metrics development is in the quantification of the nanotechnology workforce. Accurately categorizing agency-level nanotechnology investments will facilitate the identification of nanotechnology trainees, including the academic, scientific, and professional nanotechnology workforce

16. *See* J. Youtie, P. Shapira, and A. L. Porter, "Nanotechnology Publications and Citations by Leading Countries and Blocs," *Journal of Nanoparticle Research* 10 (2008): 981–986 ; J. Wang and P. Shapira, "Funding Acknowledgement Analysis—An Enhanced Tool to Investigate Research Sponsorship Impacts: The Case of Nanotechnology," *Scientometrics* 87 (3): 563–586; L. Leydesdorff and I. Rafols "The Local Emergence and Global Diffusion of Research Technologies: An Exploration of Patterns of Network Formation" *Journal of the American Society for Information Science and Technology* 62 (5): 846–860; C. Huang and Y. Wu, "State-Led Technological Development: A Case of China's Nanotechnology Development," *World Development*, forthcoming.

for which there is currently a paucity of data.[17] One area where such tracking would have significant impact is in the identification of nanotechnology-related jobs for which there are no standard occupational codes. Good data on the workforce will enable the implementation of additional measures to identify and mitigate future threats to occupational health and safety.

PCAST recommends that NNCO serve as a central repository to collect these metrics and leverage advances in metrics-development to collect, track, and analyze data regarding publications, patents, educational activities, and the workforce to produce and publish its own statistics on behalf of the NSET. This undertaking is an integral component of cross-agency coordination of the Federal nanotechnology portfolio.

## Environment, Health, and Safety Recommendations

PCAST acknowledges the significant progress made by the NNI to address potential environmental, health, and safety (EHS) risks of nanotechnology. Funding for nanotechnology-related EHS research has increased at a greater rate than the overall NNI budget, growing from $35 million in 2005 to $105 million in the 2013 request. This was appropriate, even necessary, to correct the significant imbalance present in 2005 between fundamental and applied research directed at new discoveries and the risk research that will help lower barriers to commercialization. PCAST is concerned that the 2013 request for support of nanotechnology-related EHS is only a modest increase over the 2012 request of $103 million. In light of the extensive list of outstanding research needs identified in both NNI's and NRC's recent EHS strategic planning documents,[18] this is advisable only if significant improvements in coordination result in less redundancy among NNI agencies' nanotechnology-related EHS research portfolios and more effective multi-stakeholder, interagency, and international partnerships increase leverage of the Federal investments. The NSET should consider implementing the recommendation from the NRC EHS research strategy to direct $20–25 million toward informatics, partnerships, and instrumentation development without undercutting other research areas.

*The NSET should establish high-level, cross-agency authoritative and accountable governance of Federal nanotechnology-related EHS research so that the knowledge created as a result of Federal investments can better inform policy makers.*

PCAST acknowledges that the NSET has acted on our recommendation to identify a central coordinator for nanotechnology-related EHS research within NNCO. The EHS coordinator has done a laudable job developing and communicating the 2011 NNI EHS research strategy. However, there is still a lack of integration between nanotechnology-related EHS research funded through the NNI and the kind of information policy makers need to effectively manage potential risks from nanomaterials. The establishment of the Emerging Technologies Interagency Policy Coordination Committee (ETIPC) through OSTP has begun to bridge that gap, but without close integration between ETIPC and the NEHI working

17. J. Walsh and C. Ridge, "Knowledge Production and Nanotechnology: Characterizing American Dissertation Research, 1999-2009," *Technology in Society*, in press.

18. National Science and Technology Council Committee on Technology Subcommittee on Nanoscale Science, Engineering, and Technology, "NNI Environmental, Health, and Safety (EHS) Research Strategy," 2011, http://www.nano.gov/sites/default/files/pub_resource/nni_2011_ehs_research_strategy.pdf; and Committee to Develop a Research Strategy for Environmental, Health, and Safety Aspects of Engineered Nanomaterials; National Research Council, "A Research Strategy for Environmental, Health, and Safety (EHS) Aspects of Engineered Nanomaterials (ENMs)," 2012, http://www.nap.edu/catalog.php?record_id=13347.

group, the gap may not be sufficiently narrowed. OSTP and the NSET Subcommittee should expand the charter of the NEHI working group to enable the group to address cross-agency nanotechnology-related policy issues more broadly.

*The NSET should increase investment in cross-cutting areas of EHS that promote knowledge transfer such as informatics, partnerships, and instrumentation development.*

The 2011 NNI EHS research strategy acknowledges the critical role that informatics, partnerships, and instrumentation development play in a comprehensive approach to addressing nanotechnology risks to human health and the environment. Nascent efforts in informatics should be supported so that advances can be accelerated in this critical cross-cutting area. Rather than continue to support the proliferation of databases that results from many new nano-EHS projects, the effort should be directed at enabling diverse communities to extract meaningful information from each other's work. New networks that connect researchers together, along with new tools for extracting information from Federally funded research, should be established and supported through the NNI. The findings of the December 2011 workshop to establish a Nanoinformatics 2020 Roadmap[19] in conjunction with the 2011 NNI EHS research strategy can serve as a guide for new work in this area.

Significant progress has been made in the area of partnerships with numerous examples of multistakeholder and interagency collaboration underway. One of these is the *Nanorelease Project,*[20] which brings together five NNI agencies, non-governmental organizations, a labor union, and several companies, among others, to develop methods for measuring the release of nanomaterials from commercial products. A specific area where better coordination could occur is in the area of occupational safety. The Occupational Safety and Health Administration (OSHA) should work with companies in a non-enforcement capacity to develop better tools for hazard communication similar to the National Institute of Occupational Health and Safety's (NIOSH) partnership program. This is especially important as the United States seeks to bring its hazard communication standard in alignment with the Globally Harmonized System of Classification and Labeling of Chemicals. Greater engagement by OSHA would also begin to address some of the difficulties companies face in implementing good health and safety programs in their nanomaterial workplaces. (See Appendix C.)

New modes of international cooperation, such as the joint funding of two environmental-impacts consortia by the EPA and the United Kingdom, have also emerged since the 2010 PCAST report. The NNI should increase funding for these cross-cutting activities to leverage the U.S. investment in nanotechnology-related EHS research.

19. About the Nanoinformatics 2011 workshop: http://www.nanotechinformatics.org/.
20. About the Nanorelease Project: http://www.ilsi.org/ResearchFoundation/Pages/NanoReleaseOverview.aspx.

# Conclusion

PCAST continues to see extraordinary value in the NNI to support the President's overall innovation strategy, meet critical national needs, revitalize our economy, and serve as a platform for educating the next generation of American scientists. The United States continues to lead the world in government support for, and corporate and venture capital investments in, nanotechnology R&D. If properly managed, the NNI has the potential to support the development of products and services that will benefit society in multiple areas. However, challenges remain in successfully translating laboratory discoveries into the marketplace. Among these are continued concerns over the health and safety risks of nanomaterials and a cohesive strategy for commercialization.

Substantial progress has been made since the release of the 2010 assessment of the NNI. NSET's publication of the NNI strategic plan marks a significant step toward enhanced coordination and cooperation between NNI participating agencies. PCAST encourages participating agencies to develop their own strategic and implementation plans tailored to specific mission needs within the plan's overarching framework. Since 2010, the NNCO has been active in the management of the NNI, establishing new positions to coordinate EHS research and to strengthen relationships with state, local, and industrial partners and publishing the 2011 NNI EHS research strategy. PCAST recognizes significant overall progress in the EHS area, and recommends continued attention to this area as well as public engagement, particularly as products move to market. The three existing Nanotechnology Signature Initiatives have played an important enabling and foundational role in achieving both the objectives of the NNI and the larger strategic goal of global economic competitiveness over the next decade. PCAST recommends further support for these initiatives and suggests potentially establishing initiatives in the areas of homeland security/national defense and human health.

PCAST recognizes that the NNI has been successful to date but that a significant amount of work remains to fully realize the potential of the NNI. By continuing to apply the recommendations in the 2010 assessment and following those put forth in this document, PCAST feels that NNI will continue to be a success and that the benefits of investments in nanotechnology will translate to the public. Enhanced cooperation among the participating agencies through the development of specific implementation plans within the framework of the NNI strategic plan and through coordination with the NNCO will allow the agencies to address challenges and hurdles in a robust manner and strengthen the overall outcomes of the NNI.

# Appendix A.
# Experts Providing Input to PCAST

**Sanjay Arora**
Georgia Institute of Technology

**Robert Celotta**
National Institute of Standards and Technology

**Yet-Ming Chiang**
Massachusetts Institute of Technology

**Cassandra Engemann**
University of California at Santa Barbara

**Linda Garlet**
IDA Science and Technology Policy Institute

**Piotr Grodzinski**
National Institutes of Health

**Barbara Herr Harthorn**
University of California at Santa Barbara

**Lori Henderson**
National Institutes of Health

**Patrick Herron**
Duke University

**Michael Holman**
Lux Research

**Evelyn Hu**
Harvard University

**Luciano Kay**
Georgia Institute of Technology

**Tim Lenoir**
Duke University

**Andrew Maynard**
University of Michigan

**Carlos Peña**
Food and Drug Administration

**Robert Pohanka**
National Nanotechnology Coordination Office

**Alan Porter**
Georgia Institute of Technology

**Mihail Roco**
National Science Foundation

**Nora Savage**
Environmental Protection Agency

**Andrew Schwartz**
Department of Energy

**Phil Shapira**
Georgia Institute of Technology

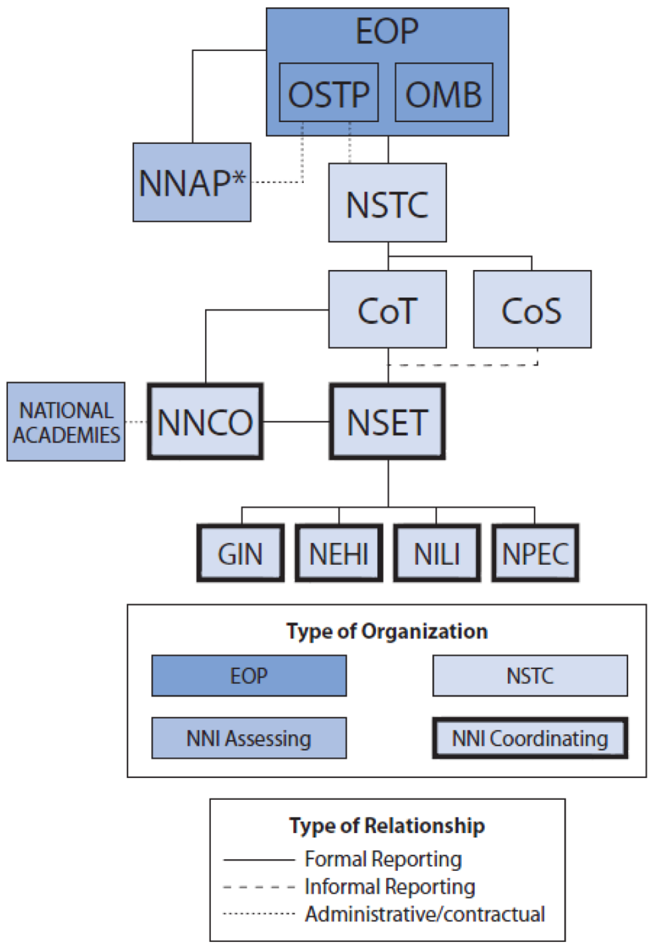
**Lewis Sloter**
Department of Defense

**Sally Tinkle**
National Nanotechnology Coordination Office

**Jan Youtie**
Georgia Institute of Technology

# Appendix B.
# NNI Organizational Chart

**Figure B-1. NNI organzational chart**




Source: National Science and Technology Council Committee on Technology Subcommittee on Nanoscale Science, Engineering, and Technology, "National Nanotechnology Initiative Strategic Plan," 2011, http:www.nano.gov/sites/default/files/pub_resource/2011_plan.pdf?q=nnistrategicplan2011.pdf.

*Executive Order 13349 designates the President's Council of Advisors on Science and Technology (PCAST) as the National Nanotechnology Advisory Panel (NNAP).

For acronym definitions within this chart, please see the Abbreviations Appendix at the end of the report.

# Appendix C.
# Nanotechnology-Related Environment, Health, and Safety Research

As new modes of manufacturing are developed and explored, the need to address occupational health and safety issues will take on even greater urgency. Efforts to address workplace safety issues are limited by the lack of research, lack of rigorous information about the identity and demographics of the workforce, and by current practices and attitudes of employers towards workplace risk issues. An analysis of nanotechnology environmental, health, and safety (nano-EHS) research indicates that 5 percent of the collected nano-EHS papers published between 2001 and 2011 are of high relevance to workplace health and safety.[21] (See Figure C-1.) In addition, publications in the area of potential exposure to nanomaterials represent 12 percent of nano-EHS papers published in the last decade. A recent survey found that 59 percent of U.S. nanomaterials companies do not monitor the workplace for nanoparticles[22] despite government recommendations to do so.[23] This survey revealed a number of other attitudes and practices that demonstrate little progress since the publication of an earlier industry survey performed in 2007. It is therefore critical that the appropriate Federal agencies engage with companies in a non-regulatory capacity to increase their awareness of and ability to use the latest knowledge and guidance being generated on this topic.

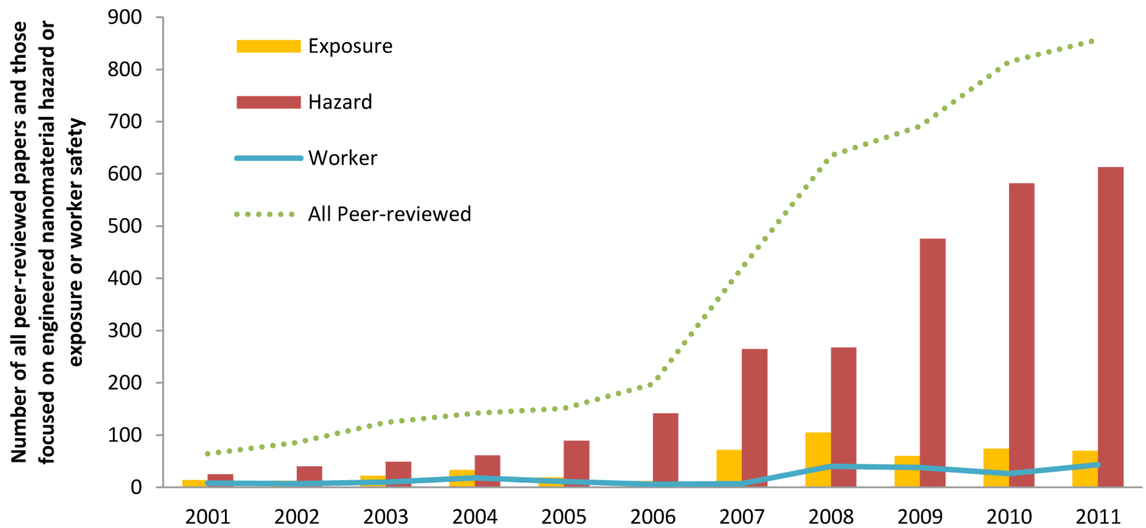
The following figures demonstrate the growth in nano-EHS related research and the current practices and attitudes of employers toward workplace safety issues. Figure C-1 shows the rate of publication of peer-reviewed nano-EHS research collected by the ICON Virtual Journal of Nano-EHS grew 18 percent between 2009 and 2001. Research of practical value to individuals charged with workplace safety, such as industrial hygienists, safety officers, and others (denoted by the category "Worker") lags a decade behind general nano-EHS research in terms of the number of publications per year. In addition, there continues to be a large knowledge gap in the area of potential exposure to nanomaterials (denoted by the category "Exposure"); these publications represent only 12 percent of papers published in the last decade. These knowledge gaps persist despite increasing investments in EHS research. Figure C-2 shows cross-agency investment in nanotechnology EHS research between 2004 and 2012.

21. International Council on Nanotechnology (ICON), Virtual Journal of NanoEHS, http://icon.rice.edu/virtualjournal.cfm.

22. C. D. Engeman, L. Baumgartner, B. M. Carr, A. M. Fish, J. Meyerhofer, T. A. Satterfield, P. A. Holden, and B. H. Harthorn, "Governance Implications of Nanomaterials Companies' Inconsistent Risk Perceptions and Safety Practices," *Journal of Nanoparticle Research* 14: 749. doi 10.1007/s11051-012-0749-0.

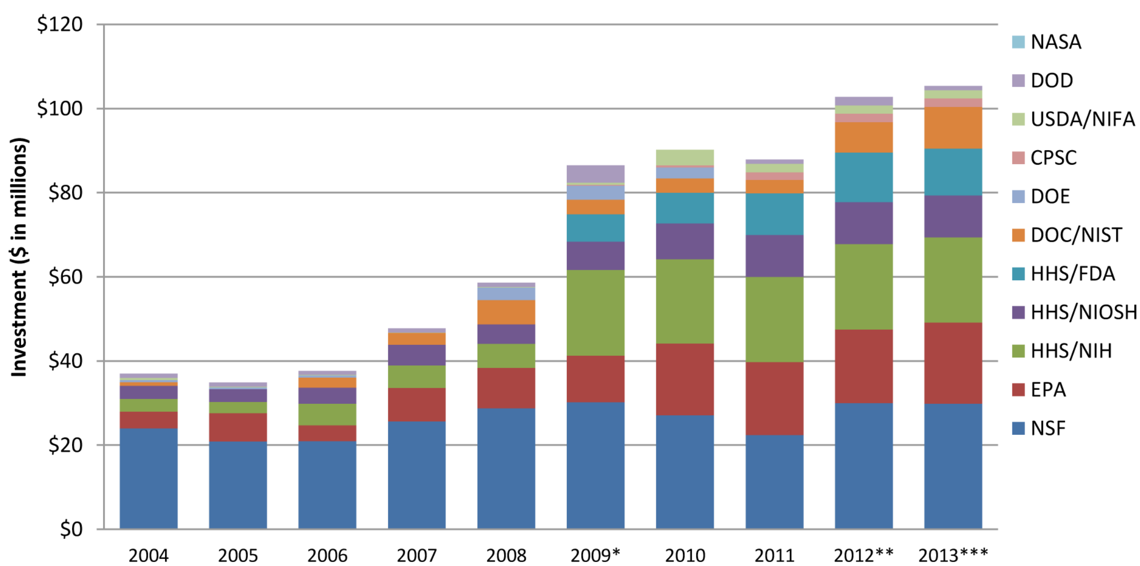
23. Department of Health and Human Services, National Institute for Occupational Safety and Health, "Approaches to Safe Nanotechnology, Managing the Health and Safety Concerns Associated with Engineered Nanomaterials," Publication No. 2009–125, March 2009.

**Figure C-1. Number of published, peer-reviewed papers listed in the ICON NanoEHS Virtual Journal**




*Source*: International Council on Nanotechnology, Rice University, Nano-EHS Analysis Tool, http://icon.rice.edu/report.cfm.
*Note:* Data do not sum to the "All peer-reviewed" total because all categories not shown.

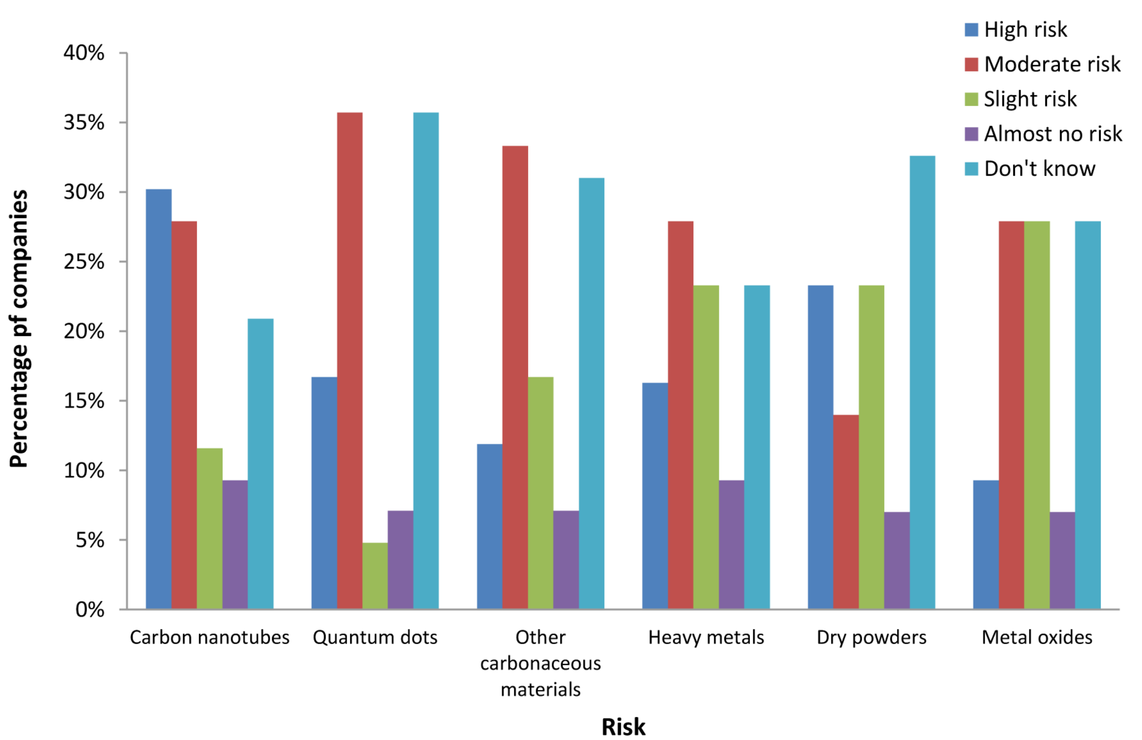
**Figure C-2. Cross-agency investment in nanotechnology EHS research, 2004–2012**




* Not including 2009 ARRA funding; ** 2012 figures are estimates; *** 2013 figures are proposed.

Of greater concern is the inconsistency between attitudes of employers towards risk and the role of regulation in mitigating risk revealed by a recent survey of nanotechnology employers.[24] Depending on the material type, between 37 percent and 58 percent of employers believe (i.e., agree or strongly agree) that nanomaterials pose moderate to high risks to human health and/or the environment (Figure C-3).While 84 percent believe that workplace safety should take priority over scientific and technological advances, 59 percent believe that waiting until safety studies are complete to commercialize nanotechnology will deprive society of too many potential benefits (Figure C-4). Fifty-six percent believe that lack of information is an impediment in implementing nano-specific health and safety practices (Figure C-5) yet 77 percent believe that businesses are better informed about their own workplace safety needs than are government agencies. As new knowledge of relevance to occupational health is being generated, OSHA should step up its efforts to work with companies to develop and implement responsible hazard communication and employee training programs using the most up-to-date information available.

**Figure C-3. Company views on risk across six types of nanomaterials**




24. C. D. Engeman, L. Baumgartner, B. M. Carr, A. M. Fish, J. Meyerhofer, T. A. Satterfield, P. A. Holden, and B. H. Harthorn, "Governance Implications of Nanomaterials Companies' Inconsistent Risk Perceptions and Safety Practices," *Journal of Nanoparticle Research*. 14: 749. doi 10.1007/s11051-012-0749-0.

**Figure C-4. Company attitudes toward risk and regulation**

Company participants' views on risk and regulation. Participants reported their level of agreement with eleven statements.

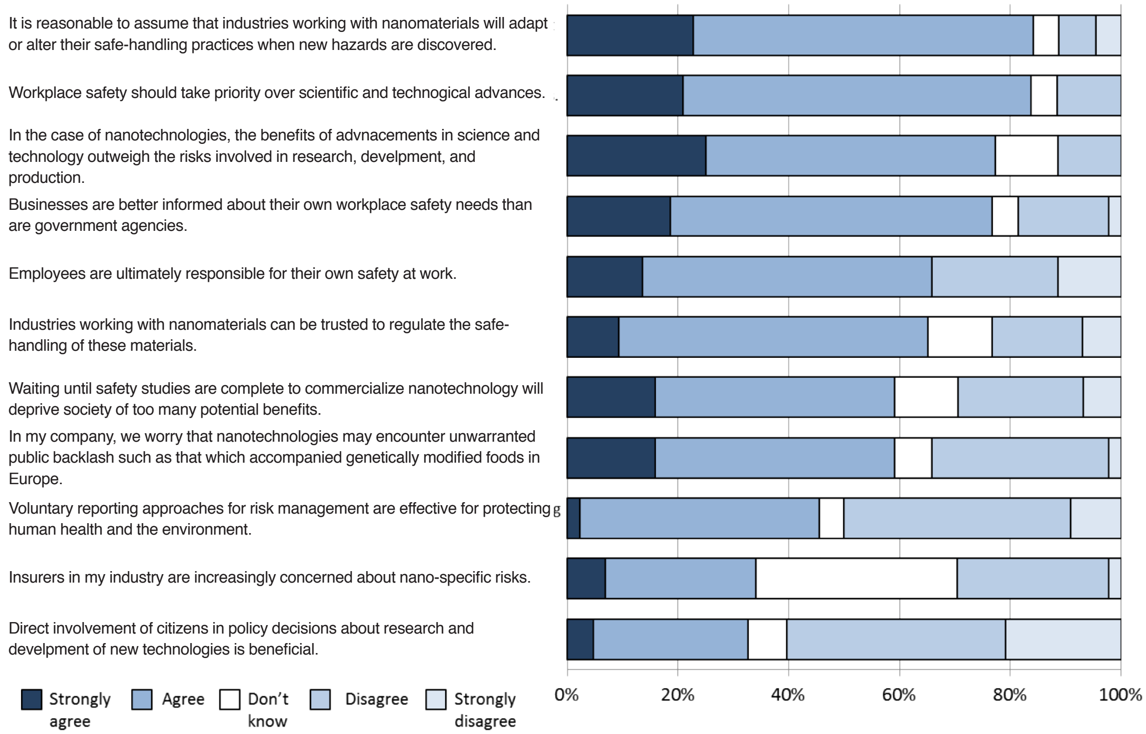
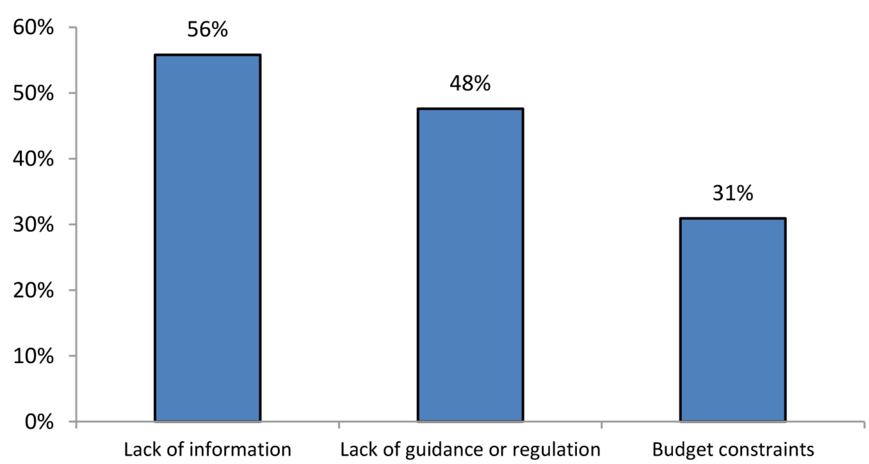


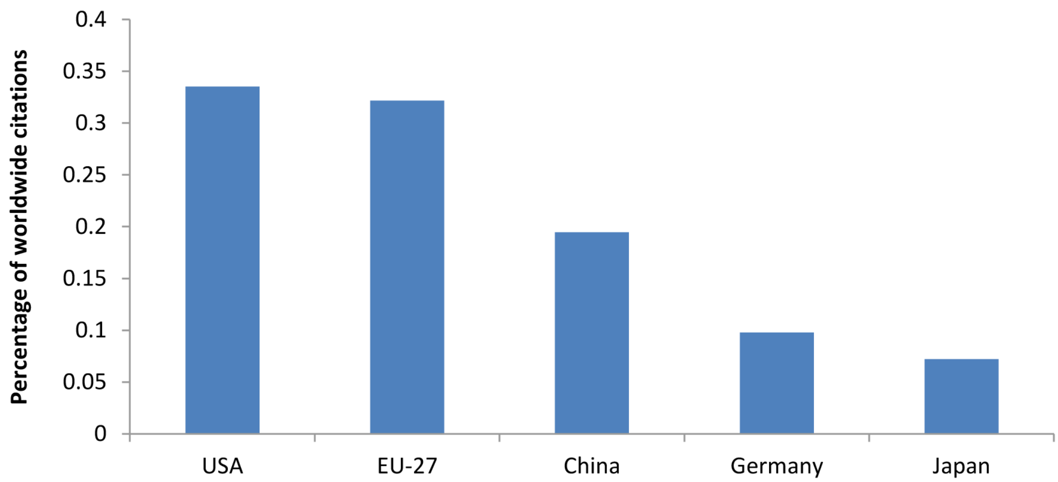

**Figure C-5. Company-identified impediments to implementing nano-specific health and safety practices**



# Appendix D.
# Additional Bibliometrics

Figure D-1 illustrates the percent of citation counts by country for nanotechnology publications produced in 2009. As citations to any given paper typically rise over time, this figure captures the percentage-based global distribution of cited nanotechnology papers for one point in time. This figure shows that highest share of global citations are attributed to papers published with authors in the U.S. and EU-27.

**Figure D-1. Percentage by country of worldwide citations for nanotechnology articles in Web of Science (SCI, SSCI, and A&HCI)**

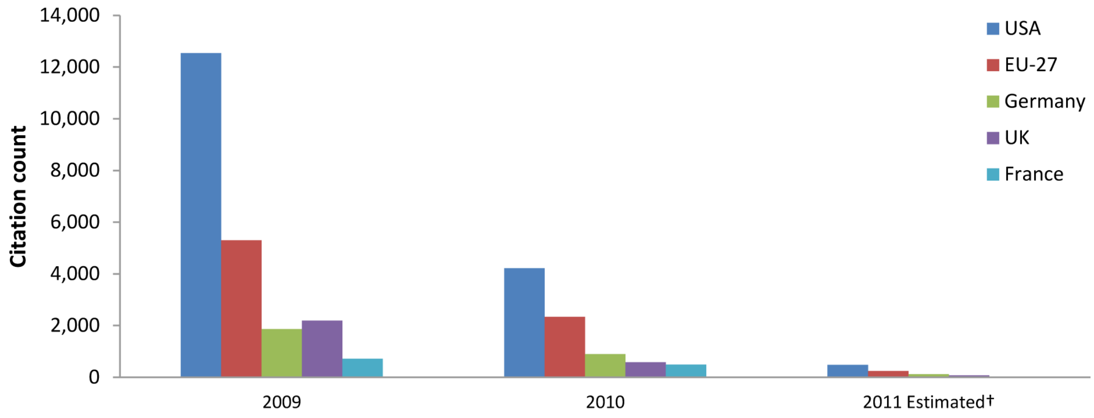



*Source:* L. Kay, P. Shapira, J. Youtie, and A. L. Porter, Program on Nanotechnology Research and Innovation System Assessment Georgia Institute of Technology, Atlanta, Georgia, with support from the National Science Foundation (NSF) through the Center for Nanotechnology in Society (Arizona State University; Award No. 0937591) [Data as of January 2010].

*Notes:* Search based on S. Arora, A. L. Porter, Y. Youtie, and S. Shapira, Capturing new developments in nanotechnology scientific output: A search strategy for publication records. STIP White Paper, Atlanta, Georgia, 2011. This figure shows percent distribution for nanotechnology publications in 2009 as of 22 August 2011.

Figures D-2 and D-3 illustrate citation and publication counts for selected journals. As one possible metric accounting for publication quality, three journals—*Science, Nature, and Proceedings of the National Academy of Sciences*—were selected; papers published in these journals are more often cited by other nanotechnology papers. The U.S. and EU-27 exhibit a large publication lead in these journals compared to their Asian counterparts and hold a dominate position in terms of global publishing rate. Due to a lag in uptake in usage, it is expected that the number of citation counts will continue to rise over time which helps to explain the appearance of a decline in citations after 2009 in Figure D-2.

**Figure D-2. Citation counts for nanotechnology articles from selected journals in Web of Science (SCI, SSCI, and A&HCI)**

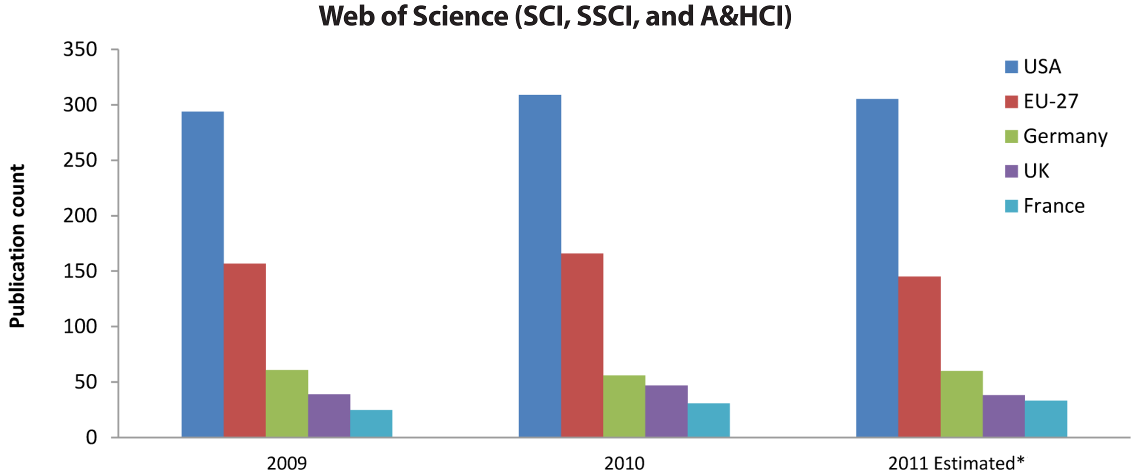



*Source:* L. Kay, P. Shapira, J. Youtie, and A. L. Porter, Program on Nanotechnology Research and Innovation System Assessment Georgia Institute of Technology, Atlanta, Georgia, with support from the National Science Foundation (NSF) through the Center for Nanotechnology in Society (Arizona State University; Award No. 0937591).

*Note:* Selected journals include *Science*, *Nature*, and *Proceedings of the National Academy of Science*. Search based on S. Arora, A. L. Porter, Y. Youtie, and S. Shapira, Capturing new developments in nanotechnology scientific output: A search strategy for publication records. STIP White Paper, Atlanta, Georgia, 2011.

†Annualized publication counts based on number of country-level publications identified as of 22 August 2011. Additional 7% added to account for publications expected to be released in the next calendar year (i.e., in early 2012).

**Figure D-3. Publication counts for nanotechnology articles from selected journals in Web of Science (SCI, SSCI, and A&HCI)**



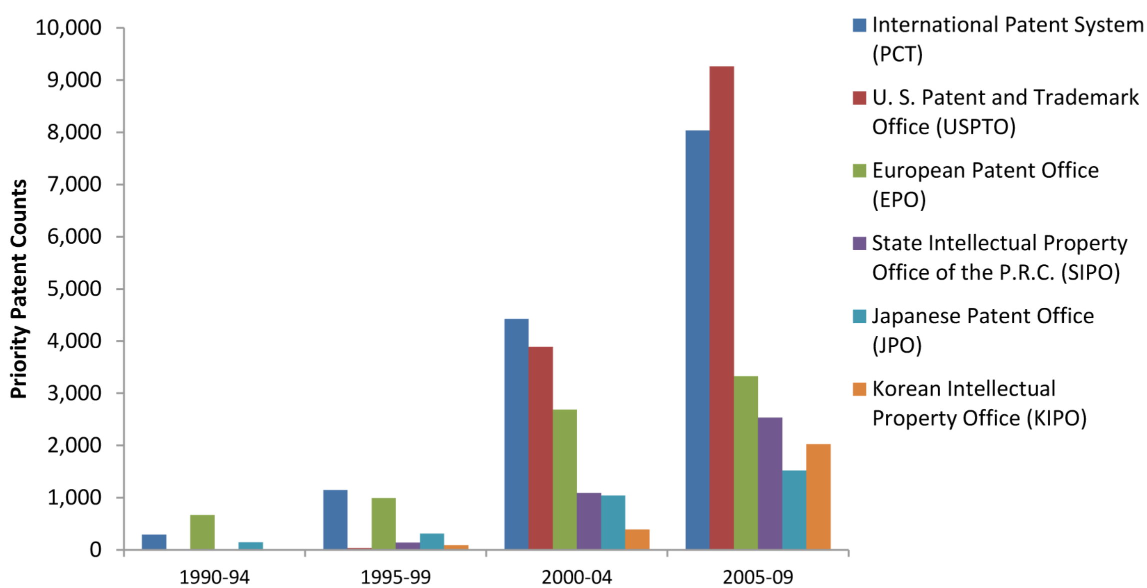

*Source:* L. Kay, P. Shapira, J. Youtie, and A. L. Porter, Program on Nanotechnology Research and Innovation System Assessment Georgia Institute of Technology, Atlanta, Georgia, with support from the National Science Foundation (NSF) through the Center for Nanotechnology in Society (Arizona State University; Award No. 0937591).

*Note:* Selected journals include *Science*, *Nature*, and *Proceedings of the National Academy of Science*. Search based on S. Arora, A. L. Porter, Y. Youtie, and S. Shapira, Capturing new developments in nanotechnology scientific output: A search strategy for publication records. STIP White Paper, Atlanta, Georgia, 2011.

*Annualized publication counts based on number of country-level publications identified as of 22 August 2011. Additional 7% added to account for publications expected to be released in the next calendar year (i.e. in early 2012).

Figure D-4 ranks patent authorities by the number of priority patents filed in five year increments. While nanotechnology patent filings grew in all patent authorities over the 20 year time span, U.S. filings grew significantly after the year 2000, eventually surpassing those filed in the International Patent System. The proliferation of patent filings in the United States could indicate a shifting trend in corporate filing strategies based upon factors such as filing fees, market, and/or competitive locations.

**Figure D-4. Counts of priority patent applications in nanotechnology in PATSTAT, by year and patent authority, 1990–2009**




*Source:* L. Kay, P. Shapira, J. Youtie, and A. L. Porter, Program on Nanotechnology Research and Innovation System Assessment Georgia Institute of Technology, Atlanta, Georgia, with support from the National Science Foundation (NSF) through the Center for Nanotechnology in Society (Arizona State University; Award No. 0937591) [Data as of January 2010].

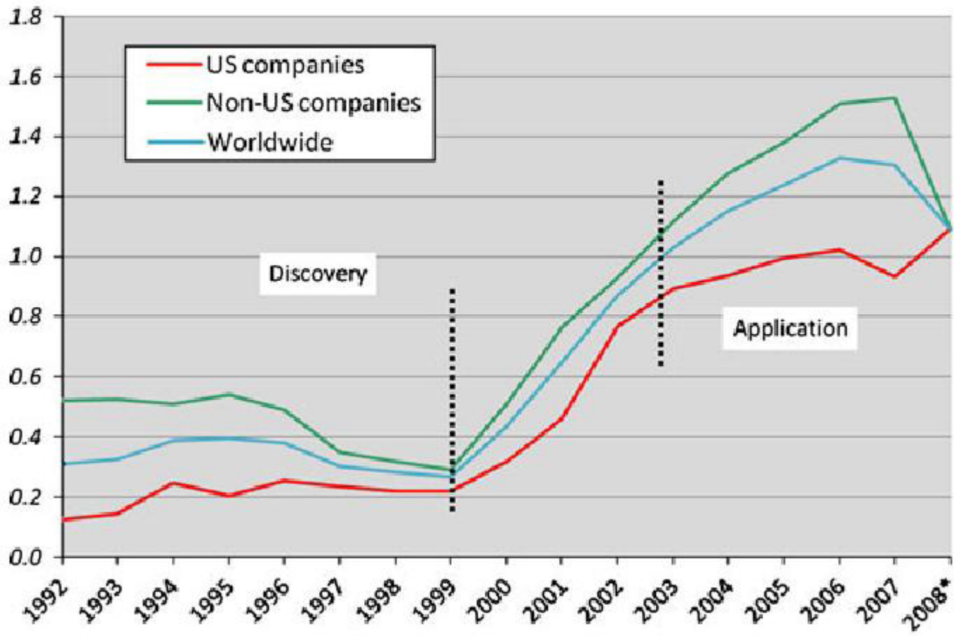
*Note:* Based on "nanotechnology" definition by A. L. Porter, J. Youtie, P. Shapira, and D. Schoeneck, "Refining Search Terms for Nanotechnology," *Journal of Nanoparticle Research*, 10(5): 715–728. Priority applications are patent documents in PatStat that report priority sequence of "1."

Figure D-5 highlights the ration of corporate nanotechnology patent filings to publications and shows a perceptible shift over time,[25] indicating a possible change in corporate emphasis from nanotechnology discovery to application in the early 2000s. U.S. companies exhibit a smaller ratio of patent filings-to-publications[26] than do non-U.S. companies, possibly indicating that U.S. corporations tend to publish more articles on average compared with the generation of patent applications than do non-U.S. companies.

25. P. Shapira, J. Youtie, and L. Kay, "National Innovation Systems and the Globalization of Nanotechnology Innovation," *Journal of Technology Transfer* 36: 587–604.

26. In Figure D-5, the Y-axis provides a ratio of corporate nanotechnology patent applications to corporate nanotechnology publications by year. The ratio is based on patent applications in worldwide patent offices and is then separated out by U.S. and foreign companies. Data were collected based on patent families, which minimizes the potential for technology duplication or double-counting.

**Figure D-5. Ratio of corporate nanotechnology patent applications to publications, 1992–2008**




**Source:** P. Shapira, J. Youtie, and L. Kay (2011) "National Innovation Systems and the Globalization of Nanotechnology Innovation," *Journal of Technology Transfer* 36: 587–604.

**Note:** At the time data were collected, 2008 was an incomplete year. As a result, data were annualized for number of worldwide patents, which produces a single ratio.

# Appendix E.
# 2010 PCAST Recommendations

## Program Management

### Recommendation 2-1: Strengthen the NNCO

The NNCO should broaden its impact and efficacy and improve its ability to coordinate and develop NNI programs and policies related to those programs. OSTP should facilitate these improvements by taking the following actions:

- Require each agency in the NNI to have senior representatives with decision-making authority participate in coordination activities of the NNI.
- Strengthen the NNCO to enhance its ability to act as the coordinating entity for the NNI.
- Mandate that the NNCO develop metrics for program outputs and that it works with the Bureau of Economic Analysis to develop metrics and to collect data on the economic impacts of the NNI.
- Appoint two individuals to the NNCO to lead interagency coordination of efforts in the areas of EHS research and standards development, respectively. Dedicate 0.3 percent of NNI funding to the NNCO to ensure the appropriate staffing and budget to effectively develop, monitor and assess NNI programs.

### Recommendation 2-2: Focus on Commercialization

In a budget planning process coordinated by OSTP, each agency should continually re-evaluate its NNI balance of investments among the PCAs, with an enhanced focus on commercialization, which would include maintaining the current level of investment in research and doubling the investment in nanomanufacturing (PCA5) over the next five years.

### Recommendation 2-3: Signature Initiatives

Each Signature Initiative's lead agency should develop coordinated milestones, promote strong educational components, and create public-private partnerships to leverage the outcomes of the initiatives. Each lead agency also should develop strategies for monitoring, evaluating, and disseminating outcomes.

### Recommendation 2-4: Education

The agencies of the NNI should continue making investments in innovative and effective education, and the NNCO should consider commissioning a comprehensive evaluation of the outcomes of the overall investment in NNI education.

### Recommendation 2-5: Societal Impacts

The NSET Subcommittee should develop a clear expectation and strategy for programs in the societal dimensions of nanotechnology. An effective program in societal implications would have well-defined areas of focus, clearly articulated outcomes as well as plans for assessing and evaluating those outcomes, and partnerships that leverage the value of its activities. Ultimately, the inclusion of such programs in the NNI has the goal of streamlining nanotechnology innovation and its positive impact on society, and the creation of new jobs, opportunities and a robust economy.

## Outputs

### Recommendation 3-1: Nanomanufacturing and Commercialization

The NSF, DOE, Department of DOD, NIST, and NIH should include a greater emphasis on manufacturing, and commercialization while maintaining or expanding the level of basic research funding in nanotechnology. Specifically, over the next five years, the Federal Government should double the funding devoted to nanomanufacturing (PCA5). In addition, the Federal Government should launch at least five government-industry-university partnerships, using the Nanoelectronics Research Initiative as a model. The Federal Government should also support at least five Signature Initiatives over the next two to three years, with each Signature Initiative funded at levels adequate to achieve its stated goals, presumably between $20 million and $40 million annually.

### Recommendation 3-2: Job Creation

The Department of Commerce and the Small Business Administration should advise the NNI on how to ensure that its programs create new jobs in the United States, including coordinating with State efforts, and economic impact should be an explicit metric in the second decade of the NNI.

### Recommendation 3-3: Workforce Retention

Congress and the Administration need to take steps to retain scientific and engineering talent trained in the United States by developing a program to provide U.S. Permanent Resident Cards for foreign individuals who receive an advanced degree in science or engineering at an accredited institution in the United States and for whom proof of permanent employment in that scientific or engineering discipline exists.

### Recommendation 3-4: Moving Nanotechnology to Market

The DOE, DOD, NIST, NIH, NCI, FDA, and NIST should clarify the development pathway and increase their emphasis on transitioning nanotechnology to commercialization, including making sustained meaningful investments in focused areas to help accelerate technology transfer to the marketplace.

## Environment, Health, and Safety

### Recommendation 4-1: Risk Identification

The NSET Subcommittee's NEHI working group should develop clear principles to support the identification of plausible risks associated with the products of nanotechnology.

### Recommendation 4-2: Strategic Planning

The NSET Subcommittee's NEHI working group should further develop and implement a crossagency strategic plan that links EHS research activities with knowledge gaps and decision-making needs within government and industry.

### Recommendation 4-3: Organizational Changes

The NSET Subcommittee and OSTP should foster administrative changes and communications mechanisms that will enable the NNI to better embrace the EHS issues associated with nanotechnology research, development, and commercialization.

- The NSET Subcommittee co-chairs should assign an individual to NNCO to oversee interagency efforts that address nanotechnology EHS.
- OSTP and the NSET Subcommittee should expand the charter of the NEHI working group to enable the group to address cross-agency nanotechnology-related policy issues more broadly.
- The NSET Subcommittee should explore mechanisms that enable the NEHI working group to more effectively receive input and advice from nongovernment experts in the field of emergent risks.

### Recommendation 4-4: Information Resources

The NSET Subcommittee's NEHI working group should develop information resources on crosscutting nanotechnology EHS issues that are relevant to businesses, health and safety professionals, researchers, and consumers.

# Appendix F.
# NSET Subcommittee

**Table F-1. NSET Subcommittee members and representatives**

| Position | Name |
|---|---|
| ***Members of NSET Subcommittee*** | |
| NSET Subcommittee Co-Chair | Lewis Sloter |
| NSET Subcommittee Co-Chair | Altaf Carim |
| NNCO Director | Robert Pohanka (Incoming Director) |
| NNCO Deputy Director and Coordinator for Environmental, Health, and Safety | Sally Tinkle |
| NSET Subcommittee Executive Secretary | Geoffrey M. Holdridge |
| ***Department and Agency Representatives*** | |
| Office of Science and Technology Policy (OSTP) | Altaf H. Carim |
| Office of Management and Budget (OMB) | Celinda Marsh |
| Agricultural Research Service (ARS/USDA) | Robert Fireovid |
| Bureau of Industry and Security (BIS/DOC) | Kelly Gardner |
| Consumer Product Safety Commission (CPSC) | Mary Ann Danello<br>Treye A. Thomas |
| Department of Defense (DOD) | Khershed Cooper<br>Akbar Khan<br>Gernot S. Pomrenke<br>Lewis Sloter<br>David M. Stepp |
| Department of Education (DOEd) | Pierce Hammond<br>Krishan Mathur |
| Department of Energy (DOE) | Harriet Kung<br>Mihal E. Gross<br>John C. Miller<br>Ravi Prasher<br>Andrew R. Schwartz<br>Brian G. Valentine |

| Position | Name |
|---|---|
| Department of Homeland Security (DHS) | Richard T. Lareau<br>Eric J. Houser |
| Department of Justice (DOJ) | Joseph Heaps |
| Department of Labor (DOL) | Janet Carter |
| Department of State (DOS) | Ken Hodgkins<br>Chris Cannizzaro |
| Department of Transportation (DOT) | Alasdair Cain<br>Jonathan R. Porter |
| Department of the Treasury (DOTreas) | John F. Bobalek |
| Director of National Intelligence (DNI) | Richard Ridgley |
| Environmental Protection Agency (EPA) | Nora F. Savage<br>Philip G. Sayre |
| Food and Drug Administration (FDA/DHHS) | Carlos Peña |
| Forest Service (FS/USDA) | World L.S. Nieh<br>Theodore H. Wegner |
| National Aeronautics and Space Administration (NASA) | Michael A. Meador |
| National Institute of Food and Agriculture (NIFA/USDA) | Hongda Chen |
| National Institute for Occupational Safety and Health (NIOSH/CDC/DHHS) | Charles L. Geraci<br>Vladimir V. Murashov |
| National Institute of Standards and Technology (NIST/DOC) | Lloyd J. Whitman |
| National Institutes of Health (NIH/DHHS) | Piotr Grodzinski<br>Lori Henderson |
| National Science Foundation (NSF) | Mihail C. Roco<br>Parag R. Chitnis<br>Thomas Rieker<br>Grace J. Wang |
| Nuclear Regulatory Commission (NRC) | Stuart Richards |
| U.S. Geological Survey (USGS) | Sarah Gerould |
| U.S. International Trade Commission (USITC) | Elizabeth R. Nesbitt |
| U.S. Patent and Trademark Office (USPTO/DOC) | David R. Gerk<br>Bruce Kisliuk |

Note: This list is current as of February 16, 2012. An updated list of members and representatives can be found at http://www.nano.gov/nset.

# Abbreviations

| | |
|---|---|
| A&HCI | Arts and Humanities Citation Index |
| ARPA-E | Advanced Research Projects Agency for Energy |
| ARRA | American Recovery and Reinvestment Act of 2009 |
| ATE | Advanced Technology Education |
| DOC | Department of Commerce |
| DOD | Department of Defense |
| DOE | Department of Energy |
| EERE | Energy Efficiency and Renewable Energy |
| EHS | Environment, Health, and Safety |
| ENM | Engineered Nanomaterials |
| EPA | Environmental Protection Agency |
| EU | European Union |
| FY | Fiscal Year |
| HHS | Department of Health and Human Services |
| ICON | International Council on Nanotechnology |
| ISL | Industry and State Liaison |
| MOU | Memorandum of Understanding |
| NACK | National Nanotechnology Applications and Career Knowledge |
| NASA | National Aeronautics and Space Administration |
| NEHI | Nanotechnology Environmental and Health Implications |
| NIH | National Institutes of Health |
| NILI | Nanomanufacturing, Industry Liaison, and Innovation |
| NIOSH | National Institute for Occupational Safety and Health |
| NIST | National Institute of Standards and Technology |
| NITRD | Networking and Information Technology Research and Development |
| NNAP | National Nanotechnology Advisory Panel |
| NNCO | National Nanotechnology Coordination Office |
| NNI | National Nanotechnology Initiative |
| NSEC | Nanoscale Science and Engineering Centers |

| | |
|---|---|
| NSET | National Science, Engineering, and Technology (Subcommittee) |
| NSI | Nanotechnology Signature Initiative |
| NSF | National Science Foundation |
| NSTC | National Science and Technology Council |
| OMB | Office of Management and Budget |
| OSHA | Occupational Health and Safety Administration |
| OSTP | Office of Science and Technology Policy |
| PATSTAT | Patent Statistical Database |
| PCA | Program Component Area |
| PCAST | President's Council of Advisors on Science and Technology |
| R&D | Research and Development |
| RUSNANO | Russian Nanotech Corporation |
| SCI | Science Citation Index |
| SSCI | Social Science Citation Index |