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Nanotechnology: A Policy Primer

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Summary

Nanoscale science, engineering, and technology—commonly referred to collectively as nanotechnology—is believed by many to offer extraordinary economic and societal benefits. Congress has demonstrated continuing support for nanotechnology and has directed its attention particularly to three topics that may affect the realization of this hoped for potential: federal research and development (R&D) in nanotechnology; U.S. competitiveness in the field; and environmental, health, and safety (EHS) concerns. This report provides an overview of these topics and two others: nanomanufacturing and public understanding of and attitudes toward nanotechnology.

The development of this emerging field has been fostered by significant and sustained public investments in nanotechnology R&D. Nanotechnology R&D is directed toward the understanding and control of matter at dimensions of roughly 1 to 100 nanometers. At this size, the properties of matter can differ in fundamental and potentially useful ways from the properties both of individual atoms and molecules, on the one hand, and of bulk matter, on the other. Since the launch of the National Nanotechnology Initiative (NNI) in 2000, Congress appropriated approximately $21.8 billion for nanotechnology R&D through FY2016. President Obama has requested $1.4 billion in NNI funding for FY2017, up $8.7 million (0.6%) from the FY2016 level and down $469.4 million (24.5%) from its regular appropriation peak of $1.913 billion in FY2010.

While more than 60 nations established similar programs after the launch of the NNI, it appears that several have moved away from centralized, coordinated nanotechnology-focused programs (e.g., the United Kingdom, Japan, Russia), some in favor of market- or application-oriented topic areas (e.g., health care technologies). By one estimate, in 2012, total annual global public R&D investment was $7.5 billion, down from $8.3 billion in 2010; corporate nanotechnology R&D spending in 2012 was an estimated $10 billion. Data on economic outputs used to assess competitiveness in mature technologies and industries, such as revenues and market share, are not broadly available for assessing nanotechnology. As an alternative, data on inputs (e.g., R&D expenditures) and non-financial outputs (e.g., scientific papers or patents) may provide insight into the current U.S. position and serve as bellwethers of future competitiveness. By these criteria, the United States appears to be the overall global leader in nanotechnology, though some believe the U.S. lead may not be as large as it was for previous emerging technologies. In recent years, China and the countries of the European Union have surpassed the United States in the publication of nanotechnology papers.

Some research has raised concerns about the safety of nanoscale materials. There is general agreement that more information on EHS implications is needed to protect the public and the environment; to assess and manage risks; and to create a regulatory environment that fosters prudent investment in nanotechnology-related innovation. Nanomanufacturing—the bridge between nanoscience and nanotechnology products—may require the development of new technologies, tools, instruments, measurement science, and standards to enable safe, effective, and affordable commercial-scale production of nanotechnology products. Public understanding and attitudes may also affect the environment for R&D, regulation, and market acceptance of products incorporating nanotechnology.

In 2003, Congress enacted the 21st Century Nanotechnology Research and Development Act (P.L. 108-153) providing a legislative foundation for some of the activities of the NNI, addressing concerns, establishing programs, assigning agency responsibilities, and setting authorization levels. In the 114th Congress, Subtitle B of H.R. 1898 (America Competes Reauthorization Act of 2015) would reauthorize the NNI. Previous efforts to enact comprehensive NNI reauthorization legislation in the 110th Congress, 111th Congress, and 113th Congress were unsuccessful.

Contents

Figures

Tables

Appendixes

Contacts

Overview

Congress continues to demonstrate interest in and support for nanotechnology due to what many believe is its extraordinary potential for delivering economic growth, high-wage jobs, and other societal benefits to the nation. To date, Congress has directed its attention particularly to three topics that may affect the United States' realization of this hoped for potential: federal research and development (R&D) investments under the National Nanotechnology Initiative (NNI); U.S. international competitiveness in nanotechnology; and environmental, health, and safety (EHS) concerns. This report provides a brief overview of these topics and two other subjects of interest to Congress: nanomanufacturing and public attitudes toward, and understanding of, nanotechnology.[1]

Nanotechnology R&D is directed toward the understanding and control of matter at dimensions of roughly 1 to 100 nanometers. At this size, the physical, chemical, and biological properties of materials can differ in fundamental and potentially useful ways from both the properties of individual atoms and molecules, on the one hand, and bulk matter, on the other hand.

In 2000, President Clinton launched the NNI to coordinate federal R&D efforts and promote U.S. competitiveness in nanotechnology. Congress first funded the NNI in FY2001 and provided increased regular appropriations for nanotechnology R&D for each year through FY2010.[2] From FY2010 to FY2016, however, overall NNI funding has declined by $478 million (25.0%); during the same period, overall federal R&D funding fell by less than one percent. President Obama's proposed funding of $1.443 billion for nanotechnology R&D for FY2016 is essentially the same as the FY2015 level.

In 2003, Congress enacted the 21st Century Nanotechnology Research and Development Act (P.L. 108-153). The act provided a statutory foundation for the NNI, established programs, assigned agency responsibilities, and authorized agency funding levels for FY2005 through FY2008. Though no funding has been explicitly authorized for the NNI beyond FY2008, Congress has continued to appropriate funds to agencies for nanotechnology research, and the executive branch continues to operate and report on the NNI, as coordinated by the Nanoscale Science, Engineering, and Technology (NSET) subcommittee of the National Science and Technology Council (NSTC).

Federal R&D investments are focused on advancing understanding of fundamental nanoscale phenomena and on developing nanomaterials, nanoscale devices and systems, instrumentation, standards, measurement science, and the tools and processes needed for nanomanufacturing. NNI appropriations also fund the construction and operation of major research facilities and the acquisition of instrumentation. The NNI also supports research directed at identifying and managing potential environmental, health, and safety impacts of nanotechnology, as well as its ethical, legal, and societal implications.

Most current applications of nanotechnology are evolutionary in nature, offering incremental improvements to existing products and generally modest economic and societal benefits. For

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[1] For additional information on these issues, see CRS Report RL34401, *The National Nanotechnology Initiative: Overview, Reauthorization, and Appropriations Issues*; CRS Report RL34493, *Nanotechnology and U.S. Competitiveness: Issues and Options*; and CRS Report RL34614, *Nanotechnology and Environmental, Health, and Safety: Issues for Consideration*, all by John F. Sargent; and CRS Report RL34332, *Engineered Nanoscale Materials and Derivative Products: Regulatory Challenges*, by Linda-Jo Schierow.

[2] Funding under the American Recovery and Reinvestment Act of 2009 (P.L. 111-5) provided, among other things, a one-year boost in NNI funding, bringing total funding to $2.213 billion in FY2009.

example, nanotechnology is being used in microchips to improve speed and energy use while reducing size and weight; in display screens to improve picture quality, provide wider viewing angles, and longer product lives; in automobile bumpers, cargo beds, and step-assists to reduce weight, increase resistance to dents and scratches, and eliminate rust; in clothes to increase resistance to staining, wrinkling, and bacterial growth and to provide lighter-weight body armor; and in sporting goods, such as baseball bats and golf clubs, to improve performance.[3]

In the longer term, proponents of nanotechnology believe it may deliver revolutionary advances with profound economic and societal implications. The applications they discuss involve various degrees of speculation and varying time-frames. The examples below suggest a few of the areas where revolutionary advances may emerge, and for which early R&D efforts may provide insights into how such advances may be achieved. As yet, however, most of these examples are at an early stage of development.

- **Detection and treatment technologies for cancer and other diseases.** Current nanotechnology disease detection efforts include the development of sensors that can identify biomarkers—such as altered genes,[4] receptor proteins that are indicative of newly-developing blood vessels associated with early tumor development,[5] and prostate specific antigen (PSA)[6]—that may provide an early indicator of cancer.[7] One approach uses carbon nanotubes and nanowires to identify the unique molecular signals of cancer biomarkers. Another approach uses nanoscale cantilevers—resembling a row of diving boards—treated with molecules that bind only with cancer biomarkers. When these molecules bind, the additional weight bends the cantilevers indicating the presence and concentration of these biomarkers. Nanotechnology holds promise for showing the presence, location, and/or contours of cancer, cardiovascular disease, or neurological disease. Current R&D efforts employ metallic, magnetic, and polymeric nanoparticles with strong imaging characteristics attached to an antibody or other agent that binds selectively with targeted cells. The imaging results can be used to guide surgical procedures and to monitor the effectiveness of non-surgical therapies in killing the disease or slowing its growth. Nanotechnology may also offer new cancer treatment approaches. For example, nanoshells with a core of silica and an outer metallic shell can be engineered to concentrate at cancer lesion sites. Once at the sites, a harmless energy source (such as near-infrared light) can be used to cause the nanoshells to heat, killing the cancer cells they are attached to.[8] Another treatment approach targets delivery of tiny amounts of a chemotherapy drug to cancer cells. In this approach the drug is encapsulated within a nanoshell that is engineered to bind with an antigen on the cancer cell.

[3] National Nanotechnology Initiative website, Benefits and Applications, http://www.nano.gov/you/nanotechnology-benefits.

[4] See, for example, National Institutes of Health, U.S. National Library of Medicine website, "Multiplexed Fluorescence Imaging of Tumor Biomarkers in Gene Expression and Protein Levels for Personalized and Predictive Medicine," Mark Q. Smith et al., March 12, 2013, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3594694/

[5] National Cancer Institute website, Nanotechnology in Clinical Trials, http://nano.cancer.gov/learn/now/clinical-trials.asp.

[6] Ibid.

[7] National Institutes of Health, U.S. National Library of Medicine website, "Biomarkers in cancer screening, research and detection: present and future: a review," S. Kumar et al., September-October 2006, http://www.ncbi.nlm.nih.gov/pubmed/16966157.

[8] National Cancer Institute website, Nanoshells, http://nano.cancer.gov/learn/understanding/nanotech_nanoshells.asp.

Once bound, the nanoshell dissolves, releasing the chemotherapy drug, killing the cancer cell. Such a targeted delivery approach could reduce the amount of chemotherapy drug needed to kill the cancer cells, reducing the side effects of chemotherapy.[9] A more recent advance may enable a nanoparticle to carry three or more different drugs and release them "in response to three distinct triggering mechanisms."[10]

- **Renewable power.** Nanoscale semiconductor catalysts and additives show promise for improving the production of hydrogen from water using sunlight. The optical properties of these nanoscale catalysts allow the process to use a wider spectrum of sunlight. Similarly, nanostructured photovoltaic devices (e.g., solar panels) may improve the efficiency of converting sunlight into electricity by using a wider spectrum of sunlight. Improved hydrogen storage, a key challenge in fuel cell applications, may be achieved by tapping the chemical properties and large surface area of certain nanostructured materials. In addition, carbon nanotube fibers have the potential for reducing energy transmission losses from approximately 7% (using copper wires) to 6% (using carbon nanotube fibers), an equivalent annual energy savings in the United States of 24 million barrels of oil.[11]
- **Water treatment.** Nanotechnology approaches—such as nanosorbents, nanocatalysts, bioactive nanoparticles, nanostructured catalytic membranes, and nanoparticle enhanced filtration—may enable improved water quality in both large-scale water treatment plants and point-of-use systems.[12] Nanotechnology water desalination and filtration systems may offer affordable, scalable, and portable water filtration systems. Filters employing nanoscale pores work by allowing water molecules to pass through, but prevent larger molecules, such as salt ions and other impurities (e.g., bacteria, viruses, heavy metals, and organic material), from doing so. Some nanoscale filtration systems also employ a matrix of polymers and nanoparticles that serve to attract water molecules to the filter and to repel contaminants.[13]
- **High-density memory devices, faster data access.** A variety of nanotechnology applications may hold the potential for improving the density of memory storage and accelerate access speed to stored data.[14]

[9] National Cancer Institute, http://nano.cancer.gov/resource_center/tech_backgrounder.asp. Nanotech News, *Nanoparticles Enhance Combination Chemotherapy and Radiation Therapy*, April 2012, http://nano.cancer.gov/action/news/2012/apr/nanotech_news_2012-4-2f.asp; Nanotech News, *First-Of-Its-Kind Self-Assembled Nanoparticle for Targeted and Triggered Thermo-Chemotherapy*, December 2012, http://nano.cancer.gov/action/news/2012/dec/nanotech_news_2012-12-13b.asp; and National Cancer Institute, NCI Alliance for Nanotechnology in Cancer, 2011 NCI Alliance Annual Bulletin, Joe Alper, *Nanoparticles Deliver Drug Cocktails to Tumor*, 2011.

[10] Massachusetts Institute of Technology, MIT News, "Targeting Cancer with a Triple Threat," April 15, 2014, https://newsoffice.mit.edu/2014/nanoparticles-can-deliver-three-cancer-drugs-at-once-0415.

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

[12] Anita Street, Richard Sustich, Jeremiah Duncan, Nora Savage, eds., *Nanotechnology Applications for Clean Water: Solutions for Improving Water Quality*, 2nd ed. (Elsevier, 2014).

[13] Abraham, M., "Today's Seawater is Tomorrow's Drinking Water," University of California at Los Angeles, November 6, 2006; and NNI website, Benefits and Applications, http://www.nano.gov/you/nanotechnology-benefits.

[14] EurekAlert!, American Association for the Advancement of Science, "Memory Breakthrough Could Bring Faster Computing, Smaller Memory Devices and Lower Power Consumption," http://www.eurekalert.org/pub_releases/2013-08/thuo-mbc081413.php; and IBM Research, Silicon Integrated Nanophotonics, http://researcher.ibm.com/researcher/ (continued...)

- **Higher crop yields and improved nutrition.** Higher crop yield might be achieved using nanoscale sensors that detect the presence of a virus or disease-infecting particle. Early, location-specific detection may allow for rapid and targeted treatment of affected areas, increasing yield by preventing losses.[15] Nanotechnology also offers the potential for improved nutrition. Some companies are exploring the development of nanocapsules that release nutrients targeted at specific parts of the body at specific times.[16]
- **Self-healing materials.** Nanotechnology may offer approaches that enable materials to "self-heal" by incorporating, for example, nanocontainers of a repair substance (e.g., an epoxy) throughout the material. When a crack or corrosion reaches a nanocontainer, the nanocontainer could be designed to open and release its repair material to fill the gap and seal the crack.[17]
- **Toxin and pathogen sensors.** Microfluidic and nanocantilever sensors (discussed earlier) may be engineered to detect specific pathogens (e.g., bacteria, virus) or toxins (e.g., sarin gas, hydrogen cyanide) by detecting their unique molecular signals or through selective binding with an engineered nanoparticle.[18]
- **Environmental remediation.** The high surface-to-volume ratio, high reactivity, and small size of some nanoscale particles (e.g., nanoscale iron) may offer more effective and less costly solutions to environmental contamination. By injecting engineered nanoparticles into the ground, these characteristics can be employed to enable the particles to move more easily through a contaminated site and bond more readily with targeted contaminants.[19]

Nanotechnology is also expected by some to make substantial contributions to federal missions such as national defense, homeland security, and space exploration and commercialization.

U.S. private-sector nanotechnology R&D funding (corporate and venture capital) is estimated to be more than twice the amount of U.S. public funding.[20] In general, the private sector's efforts focus on translating fundamental knowledge and prototypes into commercial products; developing new applications incorporating nanoscale materials; and developing technologies,

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view_project.php?id=2757.

[15] *Nanoscale Science and Engineering for Agriculture and Food Systems*, draft report on the National Planning Workshop, submitted to the Cooperative State Research, Education, and Extension Service of the U.S. Department of Agriculture, July 2003.

[16] Kole, Chittaranjan, Kole, Phullara et al., "Nanobiotechnology Can Boost Crop Production and Quality: First Evidence from Increased Plant Biomass, Fruit Yield and Phytomedicine Content in Bitter Melon," *BMC Biotechnology*, PubMed, April 26, 2013, http://www.ncbi.nlm.nih.gov/pubmed/23622112?dopt=Abstract&holding=f1000,f1000m,isrctn; and Wolfe, Josh. "Safer and Guilt-Free Nano Foods," Forbes.com, August 10, 2005.

[17] Antoni P. Tomsia, Maximilien E. Launey, and Janice S. Lee et al., "Nanotechnology Approaches for Better Dental Implants," *International Journal of Oral Maxillofac Implants*, 2011, pp. 25-49.White, Scott R. and Geubelle, Philippe H., "Self-Healing Materials: Get Ready for Repair-and-Go," *Nature Nanotechnology*, Vol. 5, pp. 247-248, 2010, http://www.nature.com/nnano/journal/v5/n4/abs/nnano.2010.66.html; Berger, Michael. "Nanomaterial Heal Thyself," Nanowerk Spotlight, June 13, 2007, http://www.nanowerk.com/spotlight/spotid=2067.php.

[18] "Nanotechnology for Sensors and Sensors for Nanotechnology," Nanotechnology Signature Initiative, National Science and Technology Council, July 9, 2012, http://www.nano.gov/sites/default/files/pub_resource/sensors_nsi_2012_07_09_final_for_web.pdf.

[19] EPA website, http://epa.gov/ncer/nano/research/nano_remediation.html.

[20] Hilary Flynn, David Hwang, and Michael Holman, *Nanotechnology Update: Corporations Up Their Spending as Revenues for Nano-Enabled Products Increase*, Lux Research, Inc., February 2014.

methods, and systems for commercial-scale manufacturing. Many other nations and firms around the world are also making substantial investments in nanotechnology.

With so much potentially at stake, some Members of Congress have expressed concerns about the U.S. competitive position in nanotechnology R&D and U.S. success in translating R&D results to commercial products. These concerns have led to an increased focus on barriers to commercialization efforts, including the readiness of technologies, systems, and processes for large-scale nanotechnology manufacturing; potential environmental, health, and safety (EHS) effects of nanoscale materials; public understanding and attitudes toward nanotechnology; and other related issues.

This report provides an overview of the NNI, federal R&D investments in nanotechnology, U.S. competitiveness in nanotechnology, and EHS-related issues.

The National Nanotechnology Initiative

President Clinton launched the National Nanotechnology Initiative in 2000, establishing a multi-agency program[21] to coordinate and expand federal efforts to advance the state of nanoscale science, engineering, and technology, and to position the United States to lead the world in nanotechnology research, development, and commercialization. In FY2016, the NNI includes 11 federal departments and independent agencies and commissions with budgets dedicated to nanotechnology R&D, as well as 9 other federal departments and independent agencies and commissions with responsibilities for health, safety, and environmental regulation; trade; education; training; intellectual property; international relations; and other areas that might affect nanotechnology.[22] The Environmental Protection Agency and the Food and Drug Administration both conduct nanotechnology R&D and have regulatory responsibilities.

Congress has played a central role in the NNI, providing appropriations for the conduct of nanotechnology R&D, establishing programs, and creating a legislative foundation for some of the activities of the NNI through enactment of the 21st Century Nanotechnology Research and Development Act of 2003. The act authorized appropriations for FY2005 through FY2008 for NNI activities at five agencies: the National Science Foundation (NSF), Department of Energy (DOE), National Aeronautics and Space Administration (NASA), Department of Commerce (DOC) National Institute of Standards and Technology (NIST), and Environmental Protection Agency (EPA).

Congress has continued its active engagement in the NNI through hearings, proposed authorizing legislation, and annual appropriations. While many provisions of the 21st Century Nanotechnology Research and Development Act have no sunset provision, FY2008 was the last year for which it authorized appropriations.

Legislation to amend and reauthorize the act was introduced in the 114th Congress, 113th Congress, 111th Congress, and 110th Congress. No comprehensive reauthorization legislation was introduced in 112th Congress. In the 114th Congress, Subtitle B of H.R. 1898, the America COMPETES Reauthorization Act of 2015, would reauthorize the National Nanotechnology

[21] The original six NNI agencies were the NSF, DOD, DOE, NIST, NASA, and NIH.

[22] Previously the NNI counted more than 20 participating agencies, however departments with multiple participating agencies are now counted as a single participant. For example, four agencies of the Department of Commerce participate in the NSET subcommittee—the National Institute of Standards and Technology, Economic Development Administration, Bureau of Industry and Security, and U.S. Patent and Trademark Office—but are only counted as a single participating department.

Initiative. In the 113th Congress, bills were introduced in the House and Senate that sought to amend the 21st Century Nanotechnology Research and Development Act. In the House bill, the National Nanotechnology Initiative Amendments Act of 2014 was incorporated as part of H.R. 4159, the America COMPETES Reauthorization Act of 2014, which was referred to two committees and multiple subcommittees. No further action was taken on the bill. In the Senate, the National Nanotechnology Initiative Amendments Act of 2014 was incorporated as part of S. 2757, the America COMPETES Reauthorization Act of 2014. S. 2757 was referred to the Senate Committee on Commerce, Science, and Transportation and no further action was taken. During markup of the Frontiers in Innovation, Research, Science, and Technology Act of 2014 (H.R. 4186) by the House Committee on Science, Space, and Technology, an amendment to add a title reauthorizing the NNI was defeated. Earlier efforts to reauthorize the 21st Century Nanotechnology Research and Development Act are discussed in CRS Report RL34401, *The National Nanotechnology Initiative: Overview, Reauthorization, and Appropriations Issues*, by John F. Sargent Jr.

Structure

The NNI is coordinated within the White House through the National Science and Technology Council's NSET subcommittee. The NSET subcommittee is comprised of representatives from 20 federal departments and agencies, the Office of Science and Technology Policy (OSTP), and the Office of Management and Budget. (A list of NSET subcommittee member agencies is provided in the **Appendix**.) The NSET subcommittee has two working groups: National Environmental and Health Implications (NEHI) Working Group; and Nanomanufacturing, Industry Liaison, and Innovation (NILI) Working Group. Two previous working groups—Global Issues in Nanotechnology (GIN) Working Group and Nanotechnology Public Engagement and Communications (NPEC) Working Group—were eliminated.[23] Based on a 2010 recommendation by the President's Council of Advisors on Science and Technology (PCAST), the NSET subcommittee has designated coordinators for four broad areas—global issues; standards development; environmental, health, and safety research; and education, engagement, and societal dimensions—to "track developments, lead in organizing activities, report periodically to the NSET subcommittee, and serve as central points of contact for NNI information in the corresponding areas."[24] The National Nanotechnology Coordination Office (NNCO) provides administrative and technical support to the NSET subcommittee.

Funding

This section provides information on NNI funding by agency and by program component area (PCA).

Funding by Agency

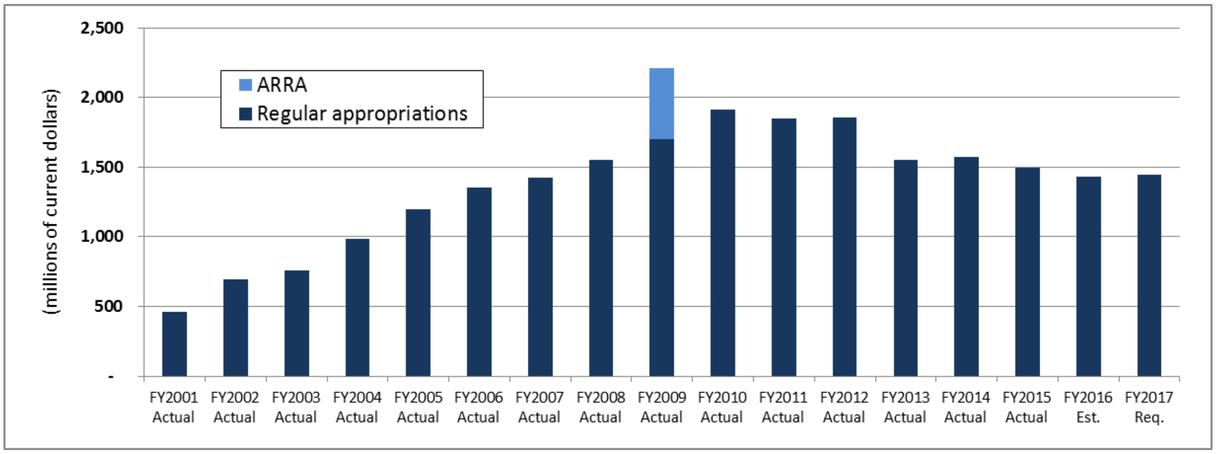
Funding for the NNI is provided through appropriations to each of the NNI-participating agencies. The NNI has no centralized funding. Overall NNI funding is calculated by aggregating the nanotechnology-related expenditures of each agency. Funding remains concentrated in the original six NNI agencies (see footnote 21), which account for 94.2% of NNI funding in FY2016.

[23] The NSET subcommittee "periodically reviews the need for existing or new working groups in terms of focus, intended participation, and scope." NSET, NSTC, *National Nanotechnology Initiative Strategic Plan*, February 2014, p. 52, http://nano.gov/sites/default/files/pub_resource/2014_nni_strategic_plan.pdf.

[24] NSET, NSTC, *National Nanotechnology Initiative Strategic Plan*, February 2014, pp. 53-54.

For FY2016, Congress appropriated an estimated $1.435 billion for nanotechnology R&D, down $61.6 million (4.1%) in current dollars from the FY2015 level of $1.913 billion. The FY2016 appropriation is also down $478.1 million (25.0%) from peak regular appropriation funding in FY2010 (see **Figure 1**). The decrease is 32.2% in inflation-adjusted dollars (see **Figure 2**).[25] In total, Congress has appropriated approximately $22.3 billion for the NNI from FY2001 to FY2016. President Obama has requested $1.443 billion for nanotechnology R&D in FY2016, essentially the same as the estimated total appropriated for FY2015. NNI funding by agency is detailed in **Table 1**.

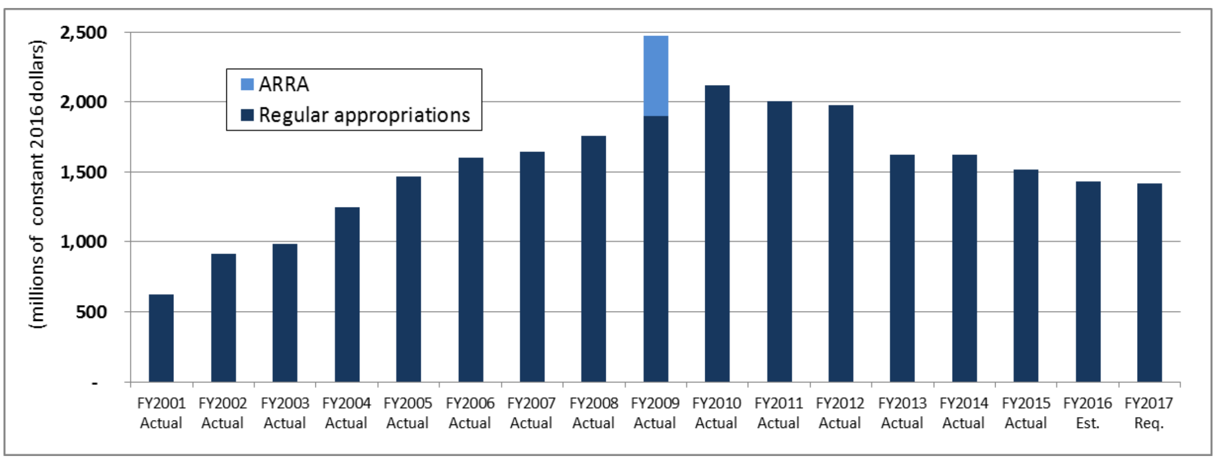
Figure 1. Total NNI Funding in Current Dollars, FY2001-FY2017 (Request)



Source: CRS analysis of NNI data.

Note: ARRA = American Recovery and Reinvestment Act of 2009.

Figure 2. Total NNI Funding in Constant FY2016 Dollars, FY2001-FY2017 (Request)



Source: CRS analysis of NNI data.

Notes: ARRA = American Recovery and Reinvestment Act of 2009. Dollars adjusted using GDP (Chained) Price Index data obtained from Office of Management and Budget, *Budget of the United States Government, Fiscal Year 2017,* Historical Tables, Table 10.1, adjusted to FY2016 dollars.

[25] Total NNI funding was higher in FY2009 when regular appropriations and American Recovery and Reinvestment Act (ARRA) funding are counted.

Table 1. NNI Funding by Agency, FY2001-FY2017

(in millions of current dollars)

Agency	FY2001 Actual	FY2002 Actual	FY2003 Actual	FY2004 Actual	FY2005 Actual	FY2006 Actual	FY2007 Actual	FY2008 Actual	FY2009 Actual	FY2009 ARRA
National Science Foundation	150	204	221	256	335	360	389	409	409	101
National Institutes of Health[a]	40	59	78	106	165	192	215	305	343	73
Department of Energy[b]	88	89	134	202	208	231	236	245	333	293
Department of Defense[c]	125	224	220	291	352	424	450	460	459	
NIST	33	77	64	77	79	78	88	86	93	43
Environmental Protection Agency	5	6	5	5	7	5	8	12	12	
Food and Drug Administration									7	
NASA	22	35	36	47	45	50	20	17	14	
Dept. of Homeland Security		2	1	1	1	2	2	3	9	
Other Agencies	1	1	2	4	8	11	17	18	24	
TOTAL[d]	464	697	760	989	1,200	1,351	1,425	1,554	1,702	511

Agency	FY2010 Actual	FY2011 Actual	FY2012 Actual	FY 2013 Actual	FY2014 Actual	FY2015 Actual	FY2016 Est.	FY2017 Request
National Science Foundation	429	485	466	421	465	490	415	415
National Institutes of Health[a]	457	409	456	459	410	364	382	382
Department of Energy[b]	374	346	314	314	309	313	330	362
Department of Defense[c]	440	425	426	170	190	143	134	131
NIST	115	96	95	91	98	84	80	82
Environmental Protection Agency	18	17	18	15	16	15	14	15
Food and Drug Administration	7	10	14	16	9	11	12	11
NASA	20	17	19	16	22	14	11	6
Dept. of Homeland Security	22	9	19	14	25	28	21	2
Other Agencies	33	33	31	34	31	35	36	38
TOTAL[d]	1,913	1,847	1,857	1,550	1,574	1,496	1,435	1,443

Source: NNI website, http://www.nano.gov/. Figures for FY2012 and FY2017 from annual NNI budget supplements, National Science and Technology Council, Executive Office of the President (EOP).

a. According to NIH, the agency has adopted the Research, Condition, and Disease Categorization (RCDC) system to provide more consistent and transparent information to the public about NIH research. The shift to the RCDC process of categorization changes the way individual research projects are assigned to categories. This change will result in some differences in total dollar amounts between the 2008 reports and those issued in previous years. Any difference, whether an increase or decrease in funding levels, does not necessarily reflect a change in the amount of money the NIH received from Congress or a change in the actual content of the NIH research portfolio. For more information, please go to: http://report.nih.gov/rcdc/reasons/default.aspx. Funding for other Department of Health and Human Services agencies (i.e., the Food and Drug Administration and National Institute for Occupational Safety and Health) is included in the figure for "Other Agencies."

b. According to NSTC, funding levels for DOE include the combined budgets of the Office of Science, the Office of Energy Efficiency and Renewable Energy, the Office of Fossil Energy, and the Advanced Research Projects Agency for Energy.

c. According to NSTC, the Department of Defense actual figures for FY2006 and beyond include congressionally directed funding. The extent to which such funding is included or not included in reporting of funding in earlier fiscal years is uncertain.

d. Numbers may not add to total due to rounding of agency budget figures.

Funding by Program Component Area

The 21st Century Nanotechnology R&D Act of 2003 called for the NSET Subcommittee to develop categories of investment called Program Component Areas (PCA) to provide a means by which Congress and the executive branch can be informed of and direct the relative investments in these areas. The PCAs cut across the needs and interests of individual agencies and contribute to the achievement of one or more of the NNI's goals.

The 2004 NNI *Strategic Plan* identified seven PCAs. The 2007 NNI *Strategic Plan* split the seventh PCA, Societal Dimensions, into two PCAs: Environment, Health, and Safety; and Education and Societal Dimensions. In 2014, the NSET Subcommittee revised its taxonomy for PCAs "to accommodate the maturation of the Initiative, the enhanced emphasis on applications, and the greater participation by agencies and communities that are not focused primarily on R&D."[26] The revision reduces the number of PCAs from eight to five.[27]

Table 2 provides a funding breakout using the new PCA structure for FY2013-FY2017 (request).

Table 2. Funding by Program Component Area, FY2013-FY2017 (Request)

(in millions of current dollars)

PCA	FY2013 Actual	FY2014 Actual	FY2015 Actual	FY2016 Estimated	FY2017 Request
Nanotechnology Signature Initiatives	$ 279.9	$272.8	$283.6	171.6	158.3
- Nanotechnology for Solar Energy Collection and Conversion	*73.6*	*73.2*	*66.7*	*0*	*0*
- Sustainable Nanomanufacturing	*34.7*	*47.2*	*44.9*	*36.7*	*37.4*
- Nanoelectronics for 2020 and Beyond	*87.3*	*78.6*	*95.5*	*81.8*	*69.8*
- Nanotechnology Knowledge Infrastructure	*7.5*	*15.9*	*27.9*	*23.2*	*22.1*
- Nanotechnology for Sensors and Sensors for Nanotechnology	*76.8*	*58.0*	*48.6*	*29.8*	*29.0*
Foundational Research	581.3	548.9	521.6	572.8	601.0
Nanotechnology-enabled Applications, Devices, and	361.4	418.8	374.5	365.0	349.5
Research Infrastructure and Instrumentation	212.5	231.6	219.9	231.2	234.6
Environment, Health, and Safety	115.1	102.1	96.7	94.1	100.1
Total	**$1,550.2**	**$1,574.3**	**$1,496.3**	**$1,434.7**	**1,443.4**

Source: NSET Subcommittee, NSTC, EOP, Supplements to the President's Budget, FY2014-FY2017.

Notes: Totals may differ from the sum of the components due to rounding.

[26] NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative Strategic Plan,* February 2014, http://nano.gov/sites/default/files/pub_resource/2014_nni_strategic_plan.pdf.

[27] The five PCAs are: Nanotechnology Signature Initiatives; Foundational Research; Nanotechnology-enabled Applications, Devices, and Systems; Nanotechnology-enabled Applications, Devices, and Systems; and Research Infrastructure and Instrumentation. A description of the new PCAs and a chronology of NNI funding by PCA since FY2001 is available in CRS Report RL34401, *The National Nanotechnology Initiative: Overview, Reauthorization, and Appropriations Issues*, by John F. Sargent Jr.

Selected Issues

The remainder of this report discusses four issues of congressional interest with respect to nanotechnology: U.S. competitiveness; environmental, health, and safety implications; nanomanufacturing; and public attitudes and understanding.

U.S. Competitiveness

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

Nevertheless, many nanotechnology experts assert that the United States, broadly speaking, is the global leader in nanotechnology. Some experts believe, however, that in contrast to many previous emerging technologies—such as semiconductors, satellites, software, and biotechnology—the U.S. lead is narrower, and the investment level, scientific and industrial infrastructure, technical capabilities, and science and engineering workforces of other nations are more substantial.

Some organizations do occasionally produce estimates of global R&D and product revenues for nanotechnology. In the absence of formal data collection, these figures often depend on subjective estimates of nanotechnology's contribution to a particular industry or product. While some products are defined by their nanotechnology properties (for example, nanoscale silver used for antibacterial purposes), many products incorporate nanotechnology as only a part of their functionality (for example, nanoscale gates in semiconductors) thus rendering an assessment of the value of nanotechnology in a particular product subjective (i.e., what percentage of semiconductor revenues should be attributed to nanotechnology).

In 2014, Lux Research, Inc., an emerging technologies consulting firm, produced a report, *Nanotechnology Update: Corporations Up Their Spending as Revenues for Nano-enabled Products Increases,* that included an estimate of revenues from nanomaterials, nano-intermediates, and nano-enabled products.[28] The report, funded in part by the National Science Foundation and the National Nanotechnology Coordination Office, estimates that total global revenues from nano-enabled products reached $731 billion in 2012, up from $339 billion in 2010. Of the 2012 revenues, the United States accounted for $236 billion, or about one-third of total global sales, about the same as Europe ($235 billion) and about 10% higher than Asia ($214 billion). Other countries—aggregated by Lux Research as "Rest of the World"—accounted for an estimated $47 billion. Subsequently, Lux Research projected global revenue from nanotechnology-enabled products would grow to nearly $3.7 billion in 2018.[29]

An alternative mechanism for gauging a nation's competitive position in emerging technologies—in the absence of periodic, comprehensive, and reliable economic output data (e.g.,

[28] Nano-intermediates include, for example, nano-based coatings, fabrics, memory and logic chips, contrast media, optical components, orthopedic materials, and superconducting wire that are incorporated into nano-enabled products, such as cars, clothing, aircraft, computers, consumer electronic devices, and pharmaceuticals.

[29] Patrick Marshall, "Nanotechnology: Will the Science of Atom-Size Objects Reshape the Economy?," *CQ Researcher,* CQ Press, June 10, 2016.

revenues, market share, trade)—is the use of inputs (e.g., public and private research investments) and non-financial outputs (e.g., scientific papers, patents). By these measures (discussed below), the United States appears to lead the world, generally, in nanotechnology. However, R&D investments, scientific papers, and patents may not provide reliable indicators of the United States' current or future competitive position. Scientific and technological leadership may not necessarily result in commercial leadership or national competitiveness for a variety of reasons:

- Basic research in nanotechnology may not translate into viable commercial applications.
- Basic research results are generally available to all competitors.
- U.S.-based companies may conduct production and other work outside of the United States.
- U.S.-educated foreign students may return home to conduct research and create new businesses.
- U.S. companies with leading-edge nanotechnology capabilities and/or intellectual property may be acquired by foreign competitors.
- U.S. policies or other factors may prohibit nanotechnology commercialization, make it unaffordable, or make it less attractive than foreign alternatives.
- Aggregate national data may be misleading as countries may establish global leadership in niche areas of nanotechnology.

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

Global Funding

The United States has led, and continues to lead, all nations in known public investments in nanotechnology R&D, though the estimated U.S. share of global public investments has fallen as other nations have established similar programs and increased funding. In its 2014 report, Lux Research estimated total (public and private) global nanotechnology funding for 2012 to be approximately $18.5 billion, of which the United States accounted for approximately $6.6 billion (36%). In 2010 corporate R&D accounted for a majority of global nanotechnology funding for the first time.[30] Cientifica, a privately held nanotechnology business analysis and consulting firm, estimated global public investments in nanotechnology in 2010 to be approximately $10 billion per year, with cumulative global public investments through 2011 reaching approximately $67.5 billion. Cientifica also concluded that the United States had fallen behind both Russia and China in nanotechnology R&D funding on a purchasing power parity (PPP) basis (which takes into account the price of goods and services in each nation), but still led the world in real dollar terms (adjusted on a currency exchange rate basis).[31]

Private investments in nanotechnology R&D come from two primary sources, corporations and venture capital (VC) investors. According to Lux Research, between 2010 and 2012 corporate spending on nanotechnology R&D increased fastest in the United States (32%), followed by Asia

[30] *OECD /NNI International Symposium on Assessing the Economic Impact of Nanotechnology, Background Paper 2: Finance and Investor Models in Nanotechnology,* Working Party on Nanotechnology, Organization for Economic Cooperation and Development, March 16, 2012, p. 4.

[31] *Global Funding of Nanotechnologies and Its Impact,* Cientifica, July 2011, available at http://cientifica.eu/blog/wp-content/uploads/downloads/2011/07/Global-Nanotechnology-Funding-Report-2011.pdf.

(11%), and Europe (3%). All other nations, collectively, increased funding by 22%.[32] Total global corporate nanotechnology R&D spending in 2012 was an estimated $9.4 billion (in PPP dollars), led by the United States ($4.1 billion), Japan ($2.3 billion), Germany ($707 million), China (approximately $400 million), and Korea ($474 million).[33]

According to Lux Research, venture capital funding for nanotechnology fell 27% in 2012, from an estimated $793 million in 2011 to $580 million in 2012. The United States accounted for more than $400 million of VC funding, nearly 70% of total global VC funding, followed by the United Kingdom with more than $100 million in 2012.[34] Lux Research previously reported that the amount of venture capital funding in Europe was one-fifth that of the North American level.[35]

Scientific Papers

The publication of peer-reviewed scientific papers is considered by some to be an indicator of a nation's scientific leadership. A study by the National Bureau of Economic Research in 2005 reported that the U.S. share of nanotechnology papers was a world-leading 24%, but that this represented a decline from approximately 40% in the early 1990s, concluding:

> Taken as a whole these data confirm that the strength and depth of the American science base points to the United States being the dominant player in nanotechnology for some time to come, while the United States also faces significant and increasing international competition.[36]

Reflecting the same trend, the number of papers in the Science Citation Index (SCI)[37] related to nanotechnology discoveries rose from 18,085 in 2000 to approximately 65,000 in 2008, a compound annual growth rate (CAGR) of 17.3%. The U.S. share of these papers grew at a somewhat slower pace (13.8% CAGR) from 5,342 in 2000 to approximately 15,000 in 2008, reducing the U.S. share from 29.5% in 2000 to approximately 23.1% in 2008.[38]

In more recent year, the number of nanotechnology papers published by China and the European Union has exceeded that of the United States. (See **Figure 3**.)

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[32] *Nanotechnology Update: Corporations Up Their Spending as Revenues for Nano-enabled Products Increases,* Lux Research, Inc., February 2014.

[33] Ibid.

[34] Ibid.

[35] *OECD /NNI International Symposium on Assessing the Economic Impact of Nanotechnology, Background Paper 2: Finance and Investor Models in Nanotechnology,* Working Party on Nanotechnology, Organization for Economic Cooperation and Development, March 16, 2012, p. 4.

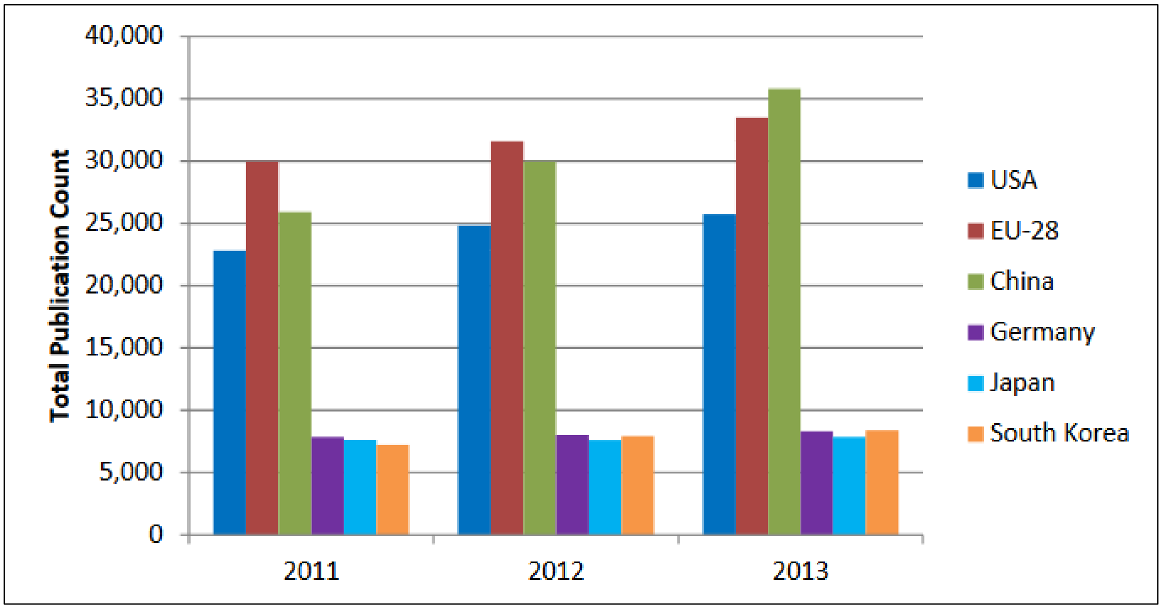
[36] Zucker, L.G. and M.R. Darby. "Socio-Economic Impact of Nanoscale Science: Initial Results and Nanobank," National Bureau of Economic Research, March 2005.

[37] The Science Citation Index, a product of Thomson Reuters Corporation, provides bibliographic and citation information from more than 3,700 scientific and technical journals published around the world.

[38] Mihail C. Roco, "The long view of nanotechnology development: the National Nanotechnology Initiative at 10 years," Journal of Nanoparticle Research, February 2011, p. 429. Growth rates and U.S. percentages of total publications calculated by CRS.

Figure 3. Number of Published Nanotechnology Papers for Selected Countries

2011-2013



Source: Executive Office of the President, Office of Science and Technology Policy, *Report to the President and Congress on the Fifth Assessment of the National Nanotechnology Initiative*, October 2014, https://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST/pcast_fifth_nni_review_oct2014_final.pdf.

Notes: EU-28 refers to the 28 nations of the European Union.

One measure of the importance of a scientific paper is the number of times it is cited in other papers. An analysis by Evaluametrics, Ltd. reports that nanotechnology papers attributed to the United States are much more frequently cited than those attributed to China, the nations of the European Union and the rest of the world as a whole. This held true overall and separately in each of the four disciplines examined (biology, chemistry, engineering, and physics). The U.S. lead was particularly pronounced in biology. China fell below the world average number of citations in each discipline, as well as overall. The European Union performed near the world average in engineering and physics, and somewhat higher in chemistry.

Patents

Patent counts—assessments of how many patents are issued to individuals or institutions of a particular country—are frequently used to assess technological competitiveness. By this measure, the U.S. competitive position in nanotechnology appears to be strong. A 2007 U.S. Patent and Trademark Office analysis of patents in the United States and in other nations stated that U.S.-origin inventors and assignees/owners have

- the most nanotechnology-related U.S. patents by a wide margin;
- the most nanotechnology-related patent publications globally, but by a narrower margin (followed closely by Japan); and

- the most nanotechnology-related inventions that have patent publications in three or more countries (31.7%), followed by Japan (26.9%), Germany (11.3%), Korea (6.6%), and France (3.6%).[39]

Environmental, Health, and Safety Implications

Some of the unique properties of nanoscale materials—for example their small size and high ratio of surface area to volume—have given rise to concerns about their potential implications for health, safety, and the environment. While nanoscale particles occur naturally and as incidental by-products of other human activities (e.g., soot), EHS concerns have been focused primarily on nanoscale materials that are intentionally engineered and produced.[40]

Environmental, health, and safety (EHS) concerns include both direct consequences of nanotechnology for health, safety, and the environment, and how uncertainty about EHS implications and potential regulatory responses might affect U.S. competitiveness. One such effect might be the discouragement of investment in nanotechnology due to the possibility of regulations that might bar products from the market, impose high regulatory compliance costs, or result in product liability claims and clean-up costs.

Much of the public dialogue about risks associated with nanotechnology has focused on carbon nanotubes (CNTs) and other fullerenes (molecules formed entirely of carbon atoms in the form of a hollow sphere, ellipsoid, or tube) since they are currently being manufactured and are among the most promising nanomaterials. These concerns have been amplified by some research on the effects of CNTs on animals, and on animal and human cells. For example, researchers have reported that carbon nanotubes inhaled by mice can cause lung tissue damage;[41] that buckyballs (spherical fullerenes) caused brain damage in fish;[42] and that buckyballs can accumulate within cells and potentially cause DNA damage.[43] On the other hand, work at Rice University's Center for Biological and Environmental Nanotechnology conducted in 2005 found cell toxicity of CNTs to be low and that toxicity can be reduced further through simple chemical changes to the CNT's surface.[44]

Among the potential EHS benefits of nanotechnology are applications that may reduce energy consumption, pollution, and greenhouse gas emissions; remediate environmental damage; cure, manage, or prevent deadly diseases; and offer new materials that protect against impacts, self-repair to prevent catastrophic failure, or change in ways that provide protection and medical aid to soldiers on the battlefield.

Potential EHS risks of nanoscale particles in humans and animals depend in part on their potential to accumulate, especially in vital organs such as the lungs and brain, that might harm or kill, and to diffuse in the environment and potentially harm ecosystems. For example, several products on

[39] Eloshway, Charles. "Nanotechnology Related Issues at the U.S. Patent and Trademark Office," Workshop on Intellectual Property Rights in Nanotechnology: Lessons from Experiences Worldwide, Brussels, Belgium, April 2007.

[40] Some naturally occurring nanoparticles cause adverse health effects. Studies on the effects of naturally occurring particles are numerous and inform R&D on engineered nanoparticles.

[41] Lam, C.; James, J.T.; McCluskey, R.; and Hunter, R. "Pulmonary toxicity of single-wall carbon nanotubes in mice 7 and 90 days after intratracheal instillation," *Toxicological Sciences*, September 2003. Vol 77. No. 1. pp 126-134.

[42] Oberdörster, Eva. "Manufactured Nanomaterials (Fullerenes, C60) Induce Oxidative Stress in the Brain of Juvenile Largemouth Bass," *Environmental Health Perspectives*, July 2004. Vol. 112. No. 10.

[43] "Understanding Potential Toxic Effects of Carbon-Based Nanomaterials," *Nanotech News*, National Cancer Institute Alliance for Nanotechnology in Cancer, July 10, 2006.

[44] "Modifications render carbon nanotubes nontoxic," press release, Rice University, October 2005.

the market today contain nanoscale silver, an effective antibacterial agent. Some scientists have raised concerns that the dispersion of nanoscale silver in the environment could kill microbes that are vital to ecosystems.

Like nanoscale silver, other nanoscale particles might produce both positive and negative effects. For example, some nanoscale particles have the potential to penetrate the blood-brain barrier, a structure that protects the brain from harmful substances in the blood. Currently, the barrier hinders the delivery of therapeutic agents to the brain.[45] The characteristics of some nanoscale materials may allow pharmaceuticals to be developed to purposefully and beneficially cross the blood-brain barrier and deliver medicine directly to the brain to treat, for example, a brain tumor. Alternatively, other nanoscale particles might unintentionally pass through this barrier and harm humans and animals.

There is widespread uncertainty about the potential EHS implications of nanotechnology. A survey of business leaders in the field of nanotechnology indicated that nearly two-thirds believe that "the risks to the public, the workforce, and the environment due to exposure to nano particles are 'not known,'" and 97% believe that it is very or somewhat important for the government to address potential health effects and environmental risks that may be associated with nanotechnology.[46]

Many stakeholders believe that concerns about potential detrimental effects of nanoscale materials and products on health, safety, and the environment—both real and perceived—must be addressed for a variety of reasons, including the following:

- protecting and improving human health, safety, and the environment;
- enabling accurate and efficient risk assessments, risk management, and cost-benefit trade-offs;
- creating a predictable, stable, and efficient regulatory environment that fosters investment in nanotechnology-related innovation;
- ensuring public confidence in the safety of nanotechnology research, engineering, manufacturing, and use;
- preventing the negative consequences of a problem in one application area of nanotechnology from harming the use of nanotechnology in other applications due to public fears, political interventions, or an overly broad regulatory response; and
- ensuring that society can enjoy the widespread economic and societal benefits that nanotechnology may offer.

Policy issues associated with EHS impacts of nanotechnology include the magnitude, timing, foci, and management of the federal investment in EHS research; the adequacy of the current regulatory structures to protect public health and the environment; and cooperation with other nations engaged in nanotechnology R&D to ensure all are doing so in a responsible manner.

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[45] "Blood-Brain Barrier Breached by New Therapeutic Strategy," press release, National Institutes of Health, June 2007.

[46] "Survey of U.S. Nanotechnology Executives," Small Times Magazine and the Center for Economic and Civic Opinion at the University of Massachusetts-Lowell, Fall 2006.

Nanomanufacturing

Securing the potential economic and societal benefits of nanotechnology requires the ability to translate knowledge of nanoscience into market-ready nanotechnology products. Nanomanufacturing is the bridge connecting nanoscience and nanotechnology products. Although some nanotechnology products have already entered the market, these materials and devices have tended to require only incremental changes in manufacturing processes. Generally, they are produced in a laboratory environment in limited quantities with a high degree of labor intensity, high variability, and high costs. To make their way into safe, reliable, effective, and affordable commercial-scale production in a factory environment may require the development of new and unique technologies, tools, instruments, measurement science, and standards for nanomanufacturing.

Several federal agencies support nanomanufacturing R&D focusing on the development of scalable, reliable, cost-effective manufacturing of nanoscale materials, structures, devices, and systems. In its FY2014 budget supplement, the NNI reported nanomanufacturing R&D funding of eight agencies totaling $93.9 million in FY2013, and proposed funding of $100.3 million for FY2014. In its FY2015 budget supplement, the NNI changed its data collection and reporting taxonomy, eliminating the Nanomanufacturing program component area (PCA).[47] Under the new PCA taxonomy, nanomanufacturing R&D funding is included in the Nanotechnology Signature Initiatives[48] PCA under the subcategory "Sustainable Nanomanufacturing: Creating the Industries of the Futures" and may also be included as part of the figures reported for other PCAs, the Foundational Research PCA and Nanotechnology-Enabled Applications, Devices, and Systems PCA in particular. Since the other PCAs are not further parsed, it is not possible to identify total funding for nanomanufacturing R&D. The President's FY2016 budget proposes $42.6 million for the Sustainable Nanomanufacturing initiative in FY2016, with NSF ($26.4 million, 62% of total proposed funding), NIST ($6.8 million, 16%), and DOE ($3.0 million, 7%) accounting for the largest amount of funds.

In addition, some agencies seek to advance nanomanufacturing through non-R&D activities. For example, the National Institute for Occupational Safety and Health is seeking to stave off potential nanomanufacturing EHS problems by developing and disseminating case studies that demonstrate the utility of applying "Prevention through Design" principles to nanomanufacturing.

Public Attitudes and Understanding

What the American people know about nanotechnology and their attitudes toward it may affect the environment for research and development (especially support for public R&D funding), regulation, market acceptance of products incorporating nanotechnology, and, perhaps, the ability of nanotechnology to weather a negative event such as an industrial accident.

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[47] The 21st Century Nanotechnology Research and Development Act directed the NNI to develop and report nanotechnology R&D funding in finer detail using categories called "Program Component Areas," or PCAs.

[48] NNI Signature Initiatives are areas of particular focus—solar energy, next-generation electronics, and sustainable manufacturing—in which participating agencies have identified key opportunities and plan more intensive programmatic collaboration. There are currently five Signature Initiatives: Nanotechnology for Solar Energy Collection and Conversion; Sustainable Nanomanufacturing—Creating the Industries of the Future; Nanoelectronics for 2020 and Beyond; Nanotechnology Knowledge Infrastructure (NKI): Enabling National Leadership in Sustainable Design; and Nanotechnology for Sensors and Sensors for Nanotechnology—Improving and Protecting Health, Safety, and the Environment.

In 2009, the Woodrow Wilson International Center for Scholars Project on Emerging Nanotechnologies (PEN) reported results of a nationwide poll of adults that found 68% had heard little (31%) or nothing at all (37%) about nanotechnology, while only 31% said that they had heard a lot (9%) or some (22%).[49] In a 2007 poll, more than half of those surveyed felt they could not assess the relative value of nanotechnology's risks and benefits. Among those most likely to believe that the benefits outweigh the risks were those earning more than $75,000 per year, men, people who had previously heard "some" or "a lot" about nanotechnology, and those between the ages of 35 and 64. Conversely, those most likely to believe that the risks of nanotechnology outweigh the benefits included people earning $30,000 or less; those with a high school diploma or less; women; racial and ethnic minorities; and those between the ages of 18 and 34 or over age 65.[50] The 2007 PEN survey found a strong positive correlation between nanotechnology familiarity/awareness and perceptions that benefits will outweigh risks. However, the survey data also indicate that communicating with the public about nanotechnology in the absence of clear, definitive answers to EHS questions could create a higher level of uncertainty, discomfort, and opposition.

Congress expressed its belief in the importance of public engagement in the 21st Century Nanotechnology Research and Development Act of 2003 (15 U.S.C. §§7501-7502.). The act calls for public input and outreach to be integrated into the NNI's efforts. The NNI has sought to foster public understanding through a variety of mechanisms, including written products, speaking engagements, a web-based information portal (nano.gov), informal education, and efforts to establish dialogues with stakeholders and the general public. The NSET subcommittee has also established a Nanotechnology Public Engagement and Communications working group to develop approaches by which the NNI can communicate more effectively with the public.

Concluding Observations

The federal government has made sustained investments in nanotechnology under the NNI since FY2001. While numerous nanotechnology applications have been incorporated in commercial products, they have generally offered incremental improvements in product performance. Proponents assert that nanotechnology has the potential to bring revolutionary products to market, reshaping existing industries and creating new ones. These products may bring significant economic and social benefits to the United States and to the world; however, substantial research, development, and innovation-related hurdles remain before these benefits might be realized.

Congress may play an active role in addressing some or all of these hurdles. The issues Congress may opt to consider include budget authorization levels for the covered agencies; R&D funding levels, priorities, and balance across the program component areas; administration and management of the NNI; translation of research results and early-stage technology into commercially viable applications; environmental, health, and safety issues; ethical, legal, and societal implications; education and training for the nanotechnology workforce; metrology, standards, and nomenclature; public understanding; and international dimensions.

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[49] Peter D. Hart Research Associates, Inc., "Nanotechnology, Synthetic Biology, and Public Opinion: A Report of Findings Based on a National Survey Among Adults," conducted on behalf of Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars, September 22, 2009, http://www.nanotechproject.org/process/assets/files/8286/nano_synbio.pdf.

[50] Peter D. Hart Research Associates, Inc., "Awareness of and Attitudes Toward Nanotechnology and Federal Regulatory Agencies: A Report of Findings," conducted on behalf of Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars, September 2007.

Appendix. Department/Agency Members of the NSET Subcommittee

As of April 2014, the NSET subcommittee included the following member departments and agencies:

- Consumer Product Safety Commission†*
- Department of Agriculture
  - Agricultural Research Service†
  - Forest Service†
  - National Institute of Food and Agriculture†
- Department of Commerce
  - Bureau of Industry and Security
  - Economic Development Administration
  - National Institute of Standards and Technology†
  - U.S. Patent and Trademark Office
- Department of Defense†
- Department of Education
- Department of Energy†
- Department of Health and Human Services
  - Agency for Toxic Substances and Disease Registry
  - Food and Drug Administration†
  - National Institute for Occupational Safety and Health†
  - National Institutes of Health†
- Department of Homeland Security†
- Department of the Interior
- Department of Justice
- Department of Labor
- Department of State
- Department of Transportation†
- Department of Treasury
- Environmental Protection Agency†
- Intelligence Community
- National Aeronautics and Space Administration†
- National Science Foundation†
- Nuclear Regulatory Commission*
- U.S. International Trade Commission*

† *Indicates a federal department, independent agency, or commission with a budget dedicated to nanotechnology research and development.*

* *Indicates an independent commission that is represented on NSET but is non-voting.*

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