Overview of the U.S. National nanotechnology initiatives

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Abstract

The science, engineering and technology of nanotechnology open a new world of opportunity for the development of new materials, devices and systems that may revolutionize life on earth and beyond. The realization this enormous potential requires dedicated research, development and risk management. The United States was the first major country to commit officially to the new field of nanotechnology when it launched its National Nanotechnology Initiative in 2001. The Initiative has received a federal investment of over $20 billion during the past 14 years and it operates a world-wide research and development program funded annually at more than $1.5 billion. This paper provides an overview of the NNI by describing the Initiative's organizational structure, program goals, major research and development components, federal agency participation, program component areas, nanotechnology signature initiatives, and funding. The international significance of the NNI is considered relative to its standing among the major industrial nations that engage in nanotechnology research and development programs. Current research activities and achievements are listed for the energy, health and environment areas of NNI, and the overall status and future promise of the program are summarized.

Keywords: National Nanotechnology Initiative (NNI); Management Structure; Program Funding; Nanotech nology Signature Initiatives

Introduction

Nanotechnology is the technology of the very small. A nanometer is one-billionth of a meter. A sheet of paper would be about 100,000 nanometers thick. Nanotechnology is concerned with the understanding and control of matter with dimensions between 1 and 100 nanometers, which is known as the nanoscale.

The U.S. National Nanotechnology Initiative (NNI) is the United States' official Federal program for coordinating U.S. investment in nanotechnology science, engineering, technology and related activity. The initiative was first announced on January 20, 2000 when President Clinton, in an address to the California Institute of Technology, revealed a plan to include $500M for nanotechnology research in his 2001 Congressional budget request [1]. NNI was officially launched in 2001 with an annual budget of $464M and the participation of eight agencies, and with a vision of "*a future in which the ability to understand and control matter at the nanoscale leads to a revolution in technology and industry that benefits society"*[2]. NNI has grown into a major initiative of the U.S. government with a Fiscal Year 2014 budget of $1.7 billion and a proposed Fiscal Year 2015 budget of over $1 .5 billion applied across 27 participating federal departments and agencies, reflecting nanotechnology activity. Cumulatively, the United States has committed nearly $21 billion to NNI during the period 2001 to date (including the 2015 budget request) [3]. NNI is a priority within US R&D funding. A 2014 R&D priorities document lists nine multiagency R&D priorities for the 2014 U.S. federal budget: advanced manufacturing; clean energy; global climate change; R&D for informed policy making and management; information technology R&D; nanotechnology (the NNI); biologic innovation; science, technology, and mathematics education (STEM); and innovation and commercialization [4].

NNI Program Goals

The NNI website lists four goals for the National Nanotechnology Initiative [5]:

• Advance a world class nanotechnology research and development program.

- Foster the transfer of new technologies into products for commercial and public benefit.
- Develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance the nanotechnology.
- Support responsible development of nanotechnology.

Goal 1 seeks to achieve and maintain U.S. leadership in nanotechnology by supporting cutting edge research and development to achieve positive program outcomes. This involves a multidisciplinary approach involving the basic sciences and engineering. The goal of fostering technology transfer is directed towards increasing U.S. competiveness and strengthening national security by improving existing products and processes and creating new ones. The goal assists the nanotechnology-based business community and supports international engagement in support of responsible commerce. The third goal is focused on the development of talented and well trained human resources along with a strong physical R&D infrastructure to support the advancing of technology. The fourth goal seeks to understand and manage the risks of nanotechnology while achieving possible benefits. This goal addresses the environmental and safety risks associated with nanotechnology and includes research and development to mitigate those risks. Figure 1 summarizes the goals and defines the principal objectives in support of the goals.

Program Structure

Program Management

Figure 2 shows the management structure of the NNI program. The NNI management structure shown in the figure is documented in various government publications, and the description below is based on the documentation with original references provided by the Congressional Research Service [6].

The NNI is coordinated within the Office of the President through the National Science and Technology Council (NSTC), a Cabinet-level council that coordinates technology policies across the federal government. Operational coordination is provided through the Nanoscale Science, Engineering, and Technology Subcommittee (NSET) of NCTC's Committee on Technology.

The NSET Subcommittee is comprised of representatives from 27 federal agencies and is led by an agency co-chair selected from one of the agencies. The National Nanotechnology Coordination Office (NNCO) provides administrative and technical support to NSET. NNI activities are managed among four working groups divided as follows: Nanotechnology Environmental and Health Implications (NEH I); Nanomanufacturing, Industry Liaison and Innovation (NILI); Global Issues in Nanotechnology; and Nanotechnology Public Engagement and Communications (NPEC). The working group structure provides coordination among the various research, policy and management programs and activities of the 27 agencies.

Federal Agency Participation

U.S Federal nanoscale R&D coordination began in the mid 1990's when staff from several agencies met regularly to discuss their plans and programs in nanoscale science and technology. The informal group was designated as the Interagency Working Group August on Nanotechnology (IWGN) under NSTC in September 1998. In August 1999, IWGN completed its first draft of a plan for an initiative in nanoscale science and technology, which was subsequently approved by the President's Council of Advisors on Science and Technology (PCAST) and the White House Office of Science and Technology (OSTP). In his budget submission to Congress, then-President Clinton raised nanotechnology-related research to the level of a federal initiative, officially referring to it as the National Nanotechnology Initiative [7].

Eight agencies, DOD, DOE, NIST, NSF, NASA, EPA, and DOJ, were funded under NNI in the 2001 budget. In 2003, Congress passed the 21st Century Nanotechnology Research and Development Act which authorized future funding for the initial agencies and provided a legislative framework for NNI.[10] Reauthorization of the legislation is still pending in Congress. However, NNI has continued to receive support from Congress and the White House and currently 27 agencies participate in the NNI and 16 of the agencies have received appropriated funds for nanotechnology R&D [7]. Table 1 lists each agency participating in NNI as of March 2010 [8].

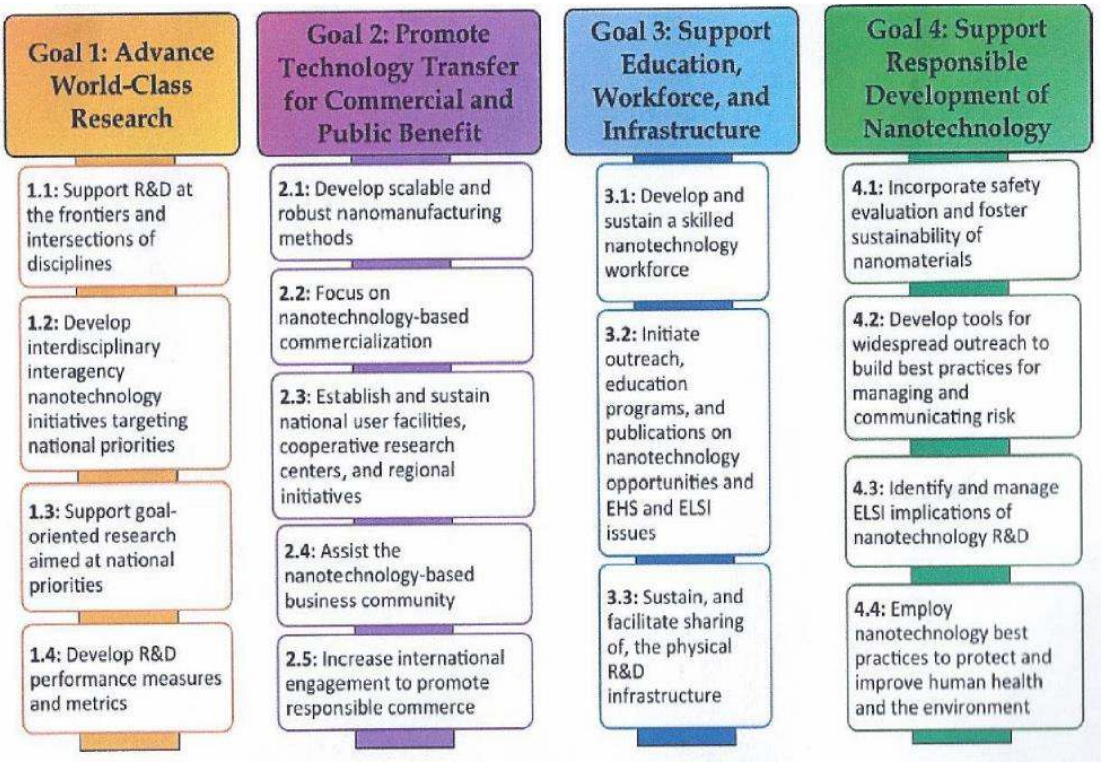

Figure 1: Goals and Objectives for Achieving NNI Vision

Figure 2: Management Structure of NNI program

Table 1: Federal Agency Participation in the NNI as of March 2010 L8]

Federal Agencies (15) With Budgets Dedicated To Nanotechnology Research And Development
• Consumer Product Safety Commission (CPSC) • Department of Homeland Security (DHS) • Department of Commerce (DOC) • National Institute of Standards & Technology (N IST) • Department of Defense (DOD) • Department of Energy (DOE) • Department of Transportation (DOT) • Federal Highway Administration (FHWA) • Environmental Protection Agency (EPA) • Department of Health and Human Services (HHS) • Food and Drug Administration • National Institutes of Health (NIH) • National Institute for Occupational Safety Health (NIOSH) • National Aeronautics & Space Administration (NASA) • National Science Foundation (NSF) • U.S. Department of Agriculture (USDA) • Agricultural Research Service (ARS) • Forest Service (FS) • National Institute of Food & Agriculture (NIFA)
Other Participating Agencies
• Department of Commerce • Bureau of Industry & Security (BIS) • Economic Development Administration (EDA) • U.S. Patent & Trademark Office (USPTO) • Department of Education (DOEd) • Department of Interior (DOI) • U.S. Geological Survey (USGS) • Department of Justice (DOJ) • Department of Labor • Occupational Safety & Health Administration (OSHA) • Department of State (DOS) • Department of the Treasury (DOTreas) • Director of National Intelligence (DNI) • Nuclear Regulatory Commission (NRC) • U.S. International Trade Commission (USITC)[1]

Program Funding

Figure 3 shows the growth in NNI funding since 2001. Funding growth was rapid during the period 2002-2009 and has been slower during the past several years. The flat grow may be directly attributable to the slowdown in the U.S and World economies during the period. President Obama requested $1 .702 billion in funding for NNI in FY2014 [9]. While 15 agencies would participate in the resulting programs, funding by agency varies significantly. Based on FY2012 estimated funding levels, five agencies accounted for 95% of NNI funding in FY2012:

- NSF (25.1%), which supports fundamental nanotechnology research across science and engineering disciplines;
- DOD(22.9%), whose investments in nanotechnology are aimed at addressing the department's national security mission;
- DOE(1 6.9%), which supports nanotechnology research providing a basis for new and improved energy efficiency, production, storage, and transmission technologies;

- NIH(29.6%), which emphasizes nanotechnology-based biomedical advances occurring at the intersection of biology and the physical sciences; and
- NIST (5.1%), which focuses on research in instrumentation, measurement, standards, characterization, and nanomanufacturing.

Nanotechnology Signature Initiatives

NNI's Nanotechnology Signature Initiatives (NSIs) are multi-disciplinary and multi-agency collaborations that are designed to accelerate research and development progress in targeted areas of national priority. The projects highlight research topics that show particular promise and significant opportunity. The topics are intended to be dynamic and to evolve over time. To date, five signature projects are underway in the following areas:

1. Sustainable Nanomanufacturing. The Sustainable Nanomanufactu ring NSI supports manufacturing technologies to integrate nanoscale building blocks into complex large scale systems. This NSI currently focuses on high-performance structural carbon-based nanomaterials, optical metamaterials, and cellulosic nanomaterials. Emphasis is on the design of scalable and sustainable nanomaterials and nanomanufacturing measurement technologies.
2. Solar Energy Collection and Conversion. This NSI seeks to understand energy conversion and storage phenomena at the nanoscale, to improve characterization of electronic properties of solar energy, and to improve solar energy collection and conversion. The principal focus is towards improving photovoltaic solar electricity and solar thermal energy generation, and solarto-fuel conversions.
3. Nanoelectronics for 2020 and Beyond. The Nanoelectronics for 2020 and Beyond NSI focuses on novel nanoscale fabrication processes and innovative concepts to produce materials, devices and systems to advance the field of nanoelectronics.
4. Nanotechnology Knowledge Infrastructure (NKI). The NKI signature initiative seeks to coordinate the nanoscale science, engineering, and technology communities around the interconnected elements of collaborative modeling that seeks to shorten the time from research to new product development.

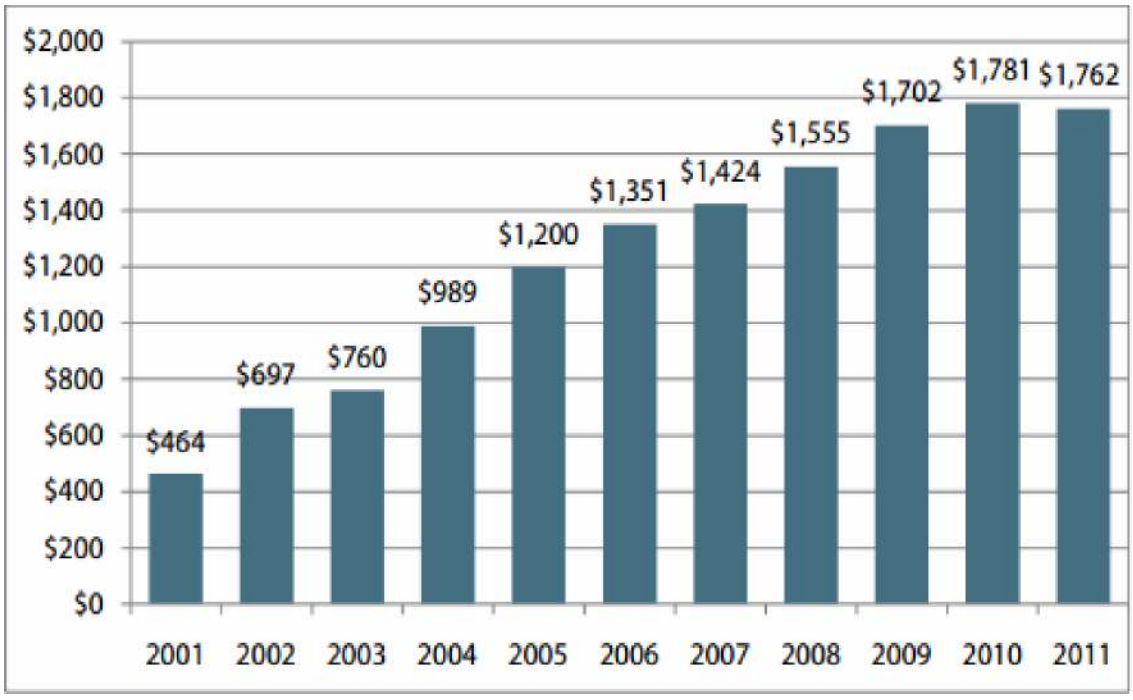

Figure 3. Growth in NNI Funding since 2001 [9]

5. Nanotechnology for Sensors and Sensors for Nanotechnology. This NSI is focused on the development of inexpensive, portable devices that can rapidly detect, identify, and quantify biological and chemical substances [10]

Funding levels for NSIs for 2013-2015 are provided in Table II.

Program Component Areas

Program Component Areas (PCAs) have been used since NNI program inception to classify and organize areas of research and development performed by NNI member agencies and coordinated by NSET. As part of the 2014 Strategic Plan update [2], NSET revised the definition of PCAs to align more closely with the state of development and accomplishments in NNI. The new PCAs are intended to be more broadly strategic and consistent with Federal research categories. The new PCA categories now consist of five components with the first one being the Nanotechnology Signature Initiatives (NSIs), and the remaining four becoming Foundational Research; Nanotech nology-Enabled Applications, Devices, and Systems; Research Infrastructure and Instrumentation; and Environmental, Health, and Safety [2].

The first Program Component Area, the Nanotechnology Signature Initiatives (NSIs), are discussed in the previous section. The remaining four PCAs are the following:

1. **Foundational Research**. Discovery and development of fundamental knowledge of physical, biological and engineering sciences that occur at the nanoscale. This PCA highlights the Initiative's fundamental research aimed at discovery and synthesis of novel nanoscale and nanostructured materials and their properties ranging across length scales and interface interactions. The research seeks to realize broad social, economic, ethical and legal implications of nanotechnology for society.
2. **Nanotechnology-Enabled Applications, Devices and Systems.** This PCA is focused on science and engineering applications that use nanoscience to enhance existing systems or create new ones to improve functionality or performance. Applications include metrology, scale up, manufacturing technology, and nanoscale reference materials and standards. Applications may result in nanoscale or larger systems.
3. **Research Infrastructure and Instrumentation.** This PCA is focused on development and integration of tools needed to advance nanotechnology research and commercialization including workforce development and next generation instrumentation. Workforce development is broadly based and may range from curriculum development to advanced training to support NNI human infrastructure.
4. **Environment, Health, and Safety.** The Environment, Health, and Safety (EHS) PCA is directed at understanding the environmental, health, and safety impacts of nanotechnology development; and with the development of risk management strategies to include risk assessment and risk mitigation. This PCA is supported by the work of environmental and health agencies that include EPA, DHS, NIH and FDA.

The Foundational Research PCA constitutes over a third of the total NNI investment portfolio for the current and recent periods 2013-2015. The area seeks to maintain a pipeline of new nanotechnology-based innovations, even as prior foundational research matures into applications.

Investments in Nanotechnology Signature Initiatives have grown since their inception, from some $250 million in 20011 to a requested over $290 million in the 2015 Budget. NSIs represent nearly 20% of the total NNI investments for 2013-2015. Also, cumulatively EHS investments during the decade 2005-2015 total over $900 million. Table II summarizes the total agency investments by Program Component Area.

The NNI agency programs include a broad array of R&D centers, user facilities, and networks dispersed across the U.S. Many of the centers and facilities are contracted to universities or private contractors. Two prominent EHS centers are the Centers for the Environmental Implications of Nanotechnology (CEIN) at the University of California, Los Angeles, and Duke University. Total funding to date for these centers is approximately $50 million. A listing of all R&D centers, user facilities, and networks is provided by Roco [8].

NNI in a Global Context

The relative importance and contributions of NNI may be appreciated by considering the context of NNI in the global framework of nanotechnology. Although scientists from many countries made early contributions to the field now known as nanotechnology, the United States was probably first to introduce a national nanotechnology research and development program with the introduction of NNI in 2001. Over the past decade many countries, have developed nanotechnology

programs and have allocated budgets to same. No formal country programs are known to exist in Africa, but significant government sponsored activity has occurred in South Africa and Nigeria where research activity is increasing. At this time, the US remains the leader in nanotechnology funded activity but other countries, notably Japan, Russia, Germany, and China are making great strides forward. Figures 4 and 5 show that as of 2010, the U.S. was spending at least twice the amount on nanotechnology as its nearest country, Japan. However, Japan's corporate expenditure on nanotechnology was over 2/3 of the U.S. expenditure. Also, as shown in Figure 6, the U.S. continues to dominate venture capital spending on nanotechnology as compared to other countries.

Table II: NNI Investments by Program Component Area, 2013-2015[10] Dollars in millions

Program Component Area	**Actual 2013**	**Estimated 2014**	**Proposed 2015**
1. **Nanotechnology**	279.9	298.1	291.3
Signature Initiatives			
1a Solar Energy	73.6	67.4	69.2
1b Nanomanufacturing	34.7	38.4	36.2
1c Nanoelectronics	87.3	76.7	71.5
1d NKI*****	7.5	32.1	26.2
1e Sensors	76.8	83.5	88.2
2. Foundational Research	581.3	539.8	530.4
3. Nanotechnology-Enabled	361.4	363.2	363
Applications, Devices			
and Systems			
4. Research Infrastructure	212.5	223.2	239.8
and Instrumentation			
5. Environment, Health	115.1	113.3	112.4
and Safety			
NNI Total	1550.2	1537.3	1539.9

* Nanotech nology Knowledge Infrastructure

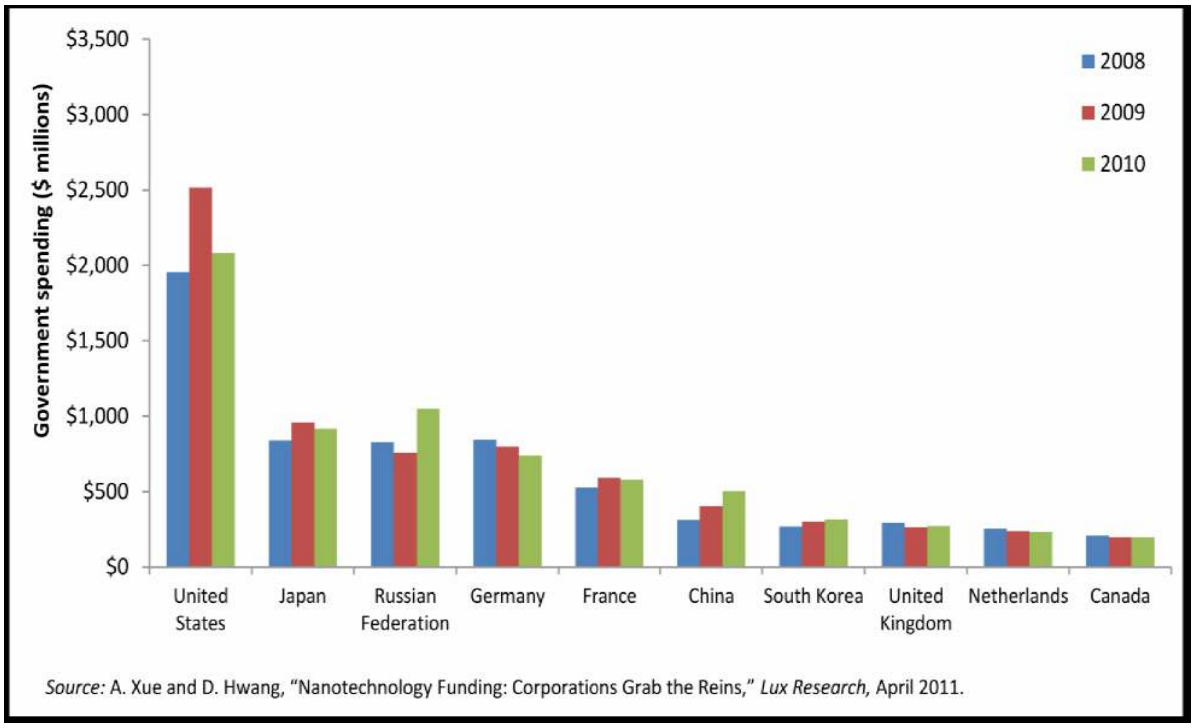

Figure 4: Global governmental nanotechnology spending for top ten countries, 2008–2010

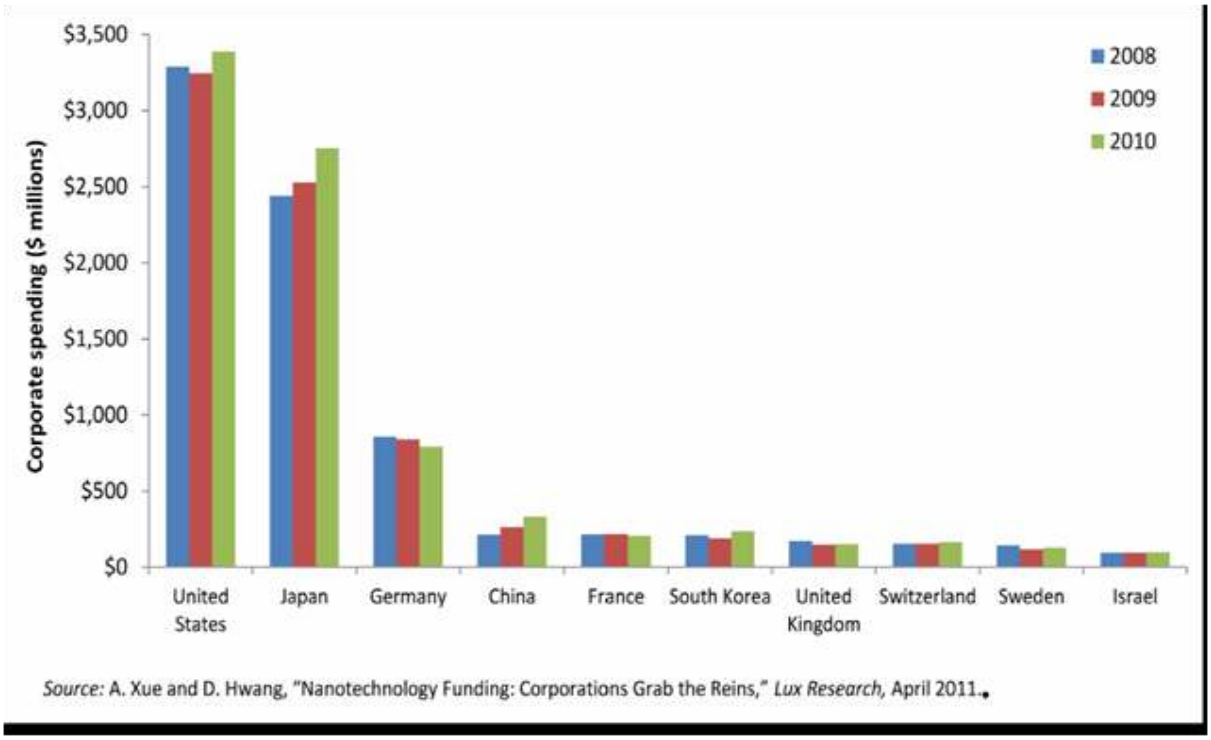

Figure 5. Corporate nanotechnology spending for top ten countries, 2008–2010

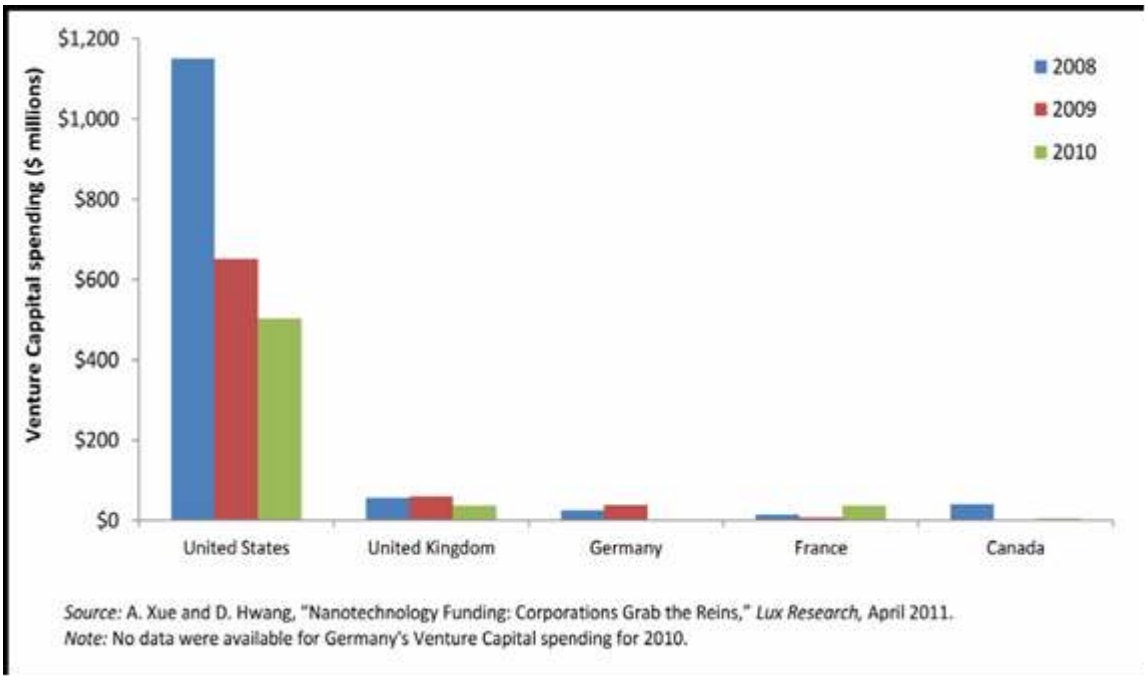

Figure 6. Venture capital spending for top five countries, 2008–2010

Conclusion

Nanotechnology is the technology of the small. A nanometer is one billionth of a meter and nanotechnology is concerned with the understanding and control of matter with dimensions between 1 and 100 nanometers in order to create materials and systems with fundamentally new properties and functions due to their small structure. The United States of America was the first major country to formally invest in the new technology when it initiated its National Nanotechnology Initiative (NNI) in 2001. Since then, the U.S. has invested more than $20 billion in the new technology and supports a world class research and development program of more than $1.5 billion annually. The NNI, through the coordinated involvement of 27 federal agencies, engages in strategic research to accelerate the discovery and application of nanotechnology to essentially all segments of life. The agencies have established an extensive system of nanotechnology research and education centers and are working effectively to maximize the effects of their single and unified efforts. The program supports academic work in scores of universities and also engages the private sector. The NNI raises the risk of environmental, safety and health hazards whose effects are largely unknown, and metrics required to assess the effectiveness of the Initiative are at an early stage of development. However, the large investment and promising research and development direction place the U.S. in a strong leadership position in nanotechnology and create a positive research and development model that developing countries may wish to study, and possibly emulate.

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