Statement of Dr. E. Clayton Teague

Director, National Nanotechnology Coordination Office

to the

Committee on Science, Space and Technology

Subcommittee on Research and Science Education

United States House of Representatives Hearing

on

Nanotechnology: Oversight of the National Nanotechnology Initiative and Priorities for the Future

April 14, 2011

Chairman Brooks, Ranking Member Lipinski, and Members of the Committee, it is my distinct privilege to be here with you today to discuss the National Nanotechnology Initiative and the contributions of Federal agencies to sustaining U.S. leadership in nanoscale science, engineering and technology.

For more than a decade, the National Nanotechnology Initiative or NNI has set the pace around the globe for enabling ground-breaking interdisciplinary research, innovation, and infrastructure development in the scientifically and economically powerful domain of nanotechnology. As the primary interagency program for coordinating Federal research and development in nanotechnology, the NNI has catalyzed remarkable advances in electronics, medicine, energy, manufacturing, and many other areas, enabling a broad spectrum of applications that range from the evolutionary to the extraordinary. Integrated with these R&D efforts to advance nanotechnology has been world leading research by NNI member agencies to understand and address the environmental, health, and safety aspects of nanotechnology, intended to simultaneously protect public health and the environment and to promote nanotechnology commercialization..

Starting with a roughly $500 million investment by half-a-dozen agencies in 2001, the NNI has developed into an engine of innovation that has drawn 25 Federal departments and agencies into fruitful collaboration resulting in their investing a total of over $14 billion cumulatively (2001 to 2010) in one of the world's fastest-moving areas of science and engineering. As described in the 2011 NNI Strategic Plan, the NNI provides an excellent and effective platform for communication, coordination, and collaboration. It adds great value to the member agencies, their missions and responsibilities.

The President's 2012 Budget provides $2.1 billion for the National Nanotechnology Initiative (NNI) in 15 agency budgets, an increase of $217 million over the 2010 funding level. These investments will advance our understanding of nanoscale phenomena and our ability to engineer nanoscale devices and systems that address national priorities and global challenges in such areas as renewable energy, next-generation electronics, and sustainable manufacturing consistent with the President's *A Strategy for American Innovation*.

At the same time, the NNI investment sustains vital support for fundamental, groundbreaking R&D and research infrastructure including world-class science centers, networks, and user facilities, as

well as education and training programs that collectively constitute a major wellspring of innovation in the United States.

Nanotechnology 101

Nanotechnology deals with the science of the very, very small. A nanometer is one-billionth of a meter, or roughly the width of ten atoms lined up in a row. A sheet of paper is about 100,000 nanometers thick. All told, nanotechnology is the understanding and control of matter at nanoscale dimensions—meaning approximately 1 to 100 nanometers in width—including imaging, measuring, modeling, and manipulation.

At those scales, quantum phenomena begin to dominate the behavior of materials and, unlike at larger scales, properties such as a materials size can determine its electrical, optical, magnetic, and thermodynamic behavior. As a result, ordinary materials may exhibit extraordinary properties, giving rise to materials that are far stronger than any other known material yet lighter than aluminum; self-cleaning paint; lightning-fast electronic components; highly efficient devices for collecting and storing energy; molecular structures that can sense environmental contaminants; and injectable agents that can track and kill tumors.

One last characteristic I'd like to note about nanotechnology: it is, by definition, an interdisciplinary area of study. Scientists across historically separate disciplines of chemistry, physics, materials science, biology, and engineering find themselves working shoulder to shoulder in this emerging field—the sort of cross-fertilization and collaboration that helps drive some of the extraordinary innovation being generated in this field.

Let me focus in a little more detail on two areas of application that are illustrative of nanotechnology's great potential: materials science and biomedicine.

Nanotechnology has arguably demonstrated its most significant advances in the realm of materials technologies. The archetypal example is the carbon nanotube, discovered over two decades ago. These nanotubes are extremely light weight, strong man-made carbon molecules with many other useful mechanical, electrical, chemical, and optical properties. Carbon nanotubes—think of them as super-thin sheets of carbon, just one atom thick, rolled into microscopic tubes or straws—exhibit unique structural properties (they are light and strong), electrical capacities (they can conduct electricity more efficiently than many metal wires), and optical quirks (they can be designed to photoluminesce when they detect tiny amounts of targeted materials). As such they are already showing great potential for a broad range of applications in the fields of materials science and electronics, and are already in use for radiation- resistant data storage devices.

Application of carbon nanotube-based lightweight and strong materials have already produced large (52 foot long) boats that have fuel consumption rates of 2.5 nautical miles per gallon as opposed to the 2 gallons per nautical mile consumption rate of comparably sized conventional boats. Bullet proof vests with higher resistance to penetration and that are far lighter than any currently available are another example of using these materials. Other nanomaterials are resulting in commercially available quantum-dot based light-emitting diode light sources that have a light color comparable to incandescent lights yet have a light output efficiency six times that of incandescent lights.

In the biomedical domain, nanotechnology is already helping medical researchers and clinicians develop real-time imaging and detection of biological targets at cellular and even molecular levels. But the goal, and the potential, is to go further than that. One of the ultimate goals of what is today being called "nanobiotechnology" research is the development of multifunctional nanoscale platforms that are able to simultaneously detect molecular changes in the body that are indicative of

a disease; deliver a drug or a combination of drugs with unprecedented control and high specificity; and then monitor the effectiveness of the drug delivery through imaging or some other modality such as monitoring of a biomarker for the disease. Such multifunctional platforms can also lead to major developments in personalized medicine with individualized therapies (for example, by providing more effective treatments with minimal adverse reactions).

Multiple sources have come to the conclusion that these and other nanotechnology-enabled products will be valued at up to $3 trillion by the end of the decade[1]. Such potential economic growth will depend on developing the necessary workforce. A study funded by the National Science Foundation projects that 6 million nanotechnology workers will be needed worldwide by 2020, with 2 million of those jobs in the United States. NNI member agencies are responding to this need by sponsoring educational and training programs at universities, community colleges, and vocational schools.

The State of the National Nanotechnology Initiative (NNI)

As previously mentioned, nanotechnology R&D is inherently multidisciplinary and its rate of progress depends on strong interagency communication, coordination, and collaboration to leverage expertise throughout the Federal government. Since 2001, Federal agencies have been combining and coordinating their efforts to accelerate discovery, development, and deployment of nanotechnology to further both agency missions and the broader national interest. Congress recognized the importance of a coordinated Federal program for nanotechnology R&D in 2003 with its enactment of the 21st Century Nanotechnology Research and Development Act (Public Law 108-153), which authorized in law the structure of the NNI, its missions, and its responsibilities.

Today the NNI involves the nanotechnology-related activities of the 25 agencies shown below, 15 of which (in bold) have specific budgets for nanotechnology R&D, as described in the NNI Supplement to the President's 2012 Budget:

- **Consumer Product Safety Commission (CPSC)**
- **Department of Defense (DOD)**
- **Department of Energy (DOE)**
- **Department of Homeland Security (DHS)**
- **Department of Justice (DOJ)**
- **Department of Transportation (DOT, including the Federal Highway Administration, FHWA)**
- **Environmental Protection Agency (EPA)**
- **Food and Drug Administration (FDA, Department of Health and Human Services)**
- **Forest Service (FS, Department of Agriculture)**
- **National Aeronautics and Space Administration (NASA)**
- **National Institute for Occupational Safety and Health (NIOSH, Department of Health and Human Services/Centers for Disease Control and Prevention)**
- **National Institute of Food and Agriculture (NIFA, Department of Agriculture)**
- **National Institute of Standards and Technology (NIST, Department of Commerce)**
- **National Institutes of Health (NIH, Department of Health and Human Services)**
- **National Science Foundation (NSF)**
- Bureau of Industry and Security (BIS, Department of Commerce)
- Department of Education (ED)
- Department of Labor (DOL, including the Occupational Safety and Health Administration, OSHA)

[1] Lux Research, *Nanomaterials State of the Market Q3 2008: Stealth Success, Broad Impact* (Lux Research, Inc., NY, NY, July 2008) and Roco, Mirkin, and Hersam, *Nanotechnology Research Directions for Societal Needs*. (WTEC, 2010)

- Department of State (DOS)
- Department of the Treasury (DOTreas)
- Director of National Intelligence (DNI)
- Nuclear Regulatory Commission (NRC)
- U.S. Geological Survey (USGS, Department of the Interior)
- U.S. International Trade Commission (USITC)
- U.S. Patent and Trademark Office (USPTO, Department of Commerce)

The NNI is managed within the framework of the National Science and Technology Council (NSTC), the Cabinet-level council by which the President coordinates science and technology policy across the Federal Government. The Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the NSTC's Committee on Technology coordinates planning, budgeting, program implementation, and review of the initiative. The NSET Subcommittee is composed of representatives from agencies participating in the NNI.

The National Nanotechnology Coordination Office (NNCO), which I lead, acts as the primary point of contact for information on the NNI; provides technical and administrative support to the NSET Subcommittee; supports the subcommittee in the preparation of multiagency planning, budget, and assessment documents, including an annual supplement to the President's budget; develops, updates, and maintains the NNI website, http://www.nano.gov; and provides public outreach on behalf of the NNI.

The NSET Subcommittee has established four working groups to support key NNI activities that the subcommittee recognizes will benefit from focused interagency attention:

- Global Issues in Nanotechnology (GIN)
- Nanotechnology Environmental and Health Implications (NEHI)
- Nanomanufacturing, Industry Liaison, and Innovation (NILI)
- Nanotechnology Public Engagement and Communication (NPEC)

The NNI Strategic Plan is the framework that guides the nanotechnology R&D and innovation efforts of the 25 NNI member agencies. The most recent Plan, released in February 2011, aims to ensure that advances in nanotechnology R&D and their applications to agency missions continue unabated in this emerging field. It facilitates achievement of the NNI vision by laying out targeted guidance for agency leaders, program managers, and the research community regarding planning and implementation of nanotechnology R&D investments and activities. Informed by feedback and recommendations from a broad array of stakeholders and extensive interagency deliberation, the Strategic Plan represents the consensus of the participating agencies as to the high-level goals and priorities of the NNI and specific objectives for at least the next three years. It sets out the 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."

The NNI was created to efficiently and effectively manage innovative research for economic benefit, national security, and the greater public good. Toward this overall NNI vision, the plan specifies four goals aimed at achieving that overall vision:

1. Advance a world-class nanotechnology research and development program.
2. Foster the transfer of new technologies into products for commercial and public benefit.
3. Develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology.

4. Support responsible development of nanotechnology.

For each of the goals, the plan identifies specific objectives for achieving these goals. The plan also lays out eight NNI investment categories ("Program Component Areas" or PCAs), each aimed at helping to achieve one or more of the above goals. Since the PCAs were established in 2004, they have helped to organize and track categories of NNI investments:

1. Fundamental nanoscale phenomena and processes
2. Nanomaterials
3. Nanoscale devices and systems
4. Instrumentation research, metrology, and standards for nanotechnology
5. Nanomanufacturing
6. Major research facilities and instrumentation acquisition
7. Environment, health, and safety
8. Education and societal dimensions

In addition, to accelerate nanotechnology development in support of the President's priorities and the recently revised *A Strategy for American Innovation*, OSTP and the NNI member agencies have identified three Nanotechnology Signature Initiatives that are part of a new model of specifically targeted and closely coordinated interagency, cross-sector collaboration designed to accelerate innovation in areas of national priority. The three initial nanotechnology signature initiative topics are: Sustainable Nanomanufacturing; Nanotechnology for Solar Energy Collection and Conversion; and Nanoelectronics for 2020 and Beyond. Agencies are proposing more than $300 million in the 2012 Budget for these signature initiatives, drawn from their agency budgets. (More information on each of the initiatives can be found in the Strategic Plan and the FY 2012 NNI budget supplement.)

The interagency task forces supporting each signature initiative have identified thrust areas within each of the proposed initiative topics and have identified specific agency programs that are involved. Finally, each nanotechnology signature initiative task force has selected key research targets for each thrust area associated with near-and long-term expected outcomes, to help evaluate progress on an ongoing basis. The NSET Subcommittee anticipates incorporating participation and input from industry and other stakeholders on current and future nanotechnology signature initiatives.

In order to inform Congress, Federal agencies, and the American public about the Federal Government's interagency, coordinated efforts in nanotechnology, the NNCO annually publishes an NNI supplement to the President's budget and makes it publicly available soon after the February release of the President's budget. The NNI Supplement to the President's 2012 Budget summarizes NNI programmatic activities for 2010 and 2011, as well as those proposed for 2012. NNI budgets for 2010–2012 are presented by agency and by Program Component Area. NNI investments represent the sum of the nanotechnology-related funding allocated by each of the participating agencies. Each agency determines its budget for nanotechnology R&D in coordination with the Office of Management and Budget (OMB), the Office of Science and Technology Policy (OSTP), and Congress.

The NNI Supplement to the 2012 President's Budget Request provides full details of agency proposals for their NNI investments, as well as information on the use of Small Business Innovation Research (SBIR) and Small Business Technology Transfer Research (STTR) program funds to support nanotechnology research and commercialization activities. The supplement also discusses activities that have been undertaken and progress that has been made toward achieving the four

goals set out in the NNI Strategic Plan and highlights external reviews of the NNI and how their recommendations are being addressed.

The NNI also benefits from extensive oversight by the Congress and by external groups. The recent March 2010 report by the President's Council of Advisors on Science and Technology (PCAST), functioning in its role as the National Nanotechnology Advisory Panel (NNAP), provides an objective overview of the effectiveness of the NNI to date and lists recommendations for strengthening the program and maintaining U.S. leadership in this field internationally. Many of these recommendations for the NNCO are already being implemented.

OSTP and NNCO actions to respond to the NNAP recommendations include: 1) the FY 2011 NNCO Budget includes a new position for an Industrial and State Liaison with primary responsibilities to enhance communications between the NNI member agencies and the business community and between the NNI member agencies and the regional, state, and local nanotechnology initiatives; 2) the NNCO Director is negotiating with the National Research Council (NRC) to include some components of the NNAP recommendation that the NNCO should track relevant metrics to measure the outcomes and impacts of NNI programs into the next assessment of the NNI (the NRC is requested to: "Assess the suitability of current procedures and criteria for determining progress towards NNI goals, suggest definitions of success and associated metrics."); 3) OSTP has designated two new appointments at the NNCO – the NNCO Director to serve as the Coordinator for Standards and the NNCO Deputy Director to serve as Coordinator for EHS Research; and 4) as called for in the 2010 NNI Strategic Plan, the NNCO is working with NNI member agencies to create and maintain a database of resources available from the Federal government to public and private sectors.

The NSET Subcommittee member agencies discussed but did not agree with the NNAP recommendation to fund NNCO at about $5 million annually, or 0.3 percent of agency contributions to the NNI. Instead, as NNCO Director I proposed staffing and actions to address those recommendations that are within the roles and responsibilities spelled out in the Memorandum of Understanding establishing the NNCO and in the 21st Century Nanotechnology R&D Act.

In closing, the United States must continue to lead the way in nanotechnology and emerging technology innovation. The Nation's economic growth and global competitiveness depend on it. The NNI reflects a firm Federal commitment to broad-based support of integrated, coordinated R&D on nanotechnology applications and implications, which will help America out-innovate, out-educate, and out-build the rest of the world.

This concludes my general overview of the NNI, including the NNI Supplement to the President's 2012 Budget, the most recent assessment of the NNI by the NNAP, and the updated NNI Strategic Plan. I will now proceed to address the specific questions that were posed to me in the formal letter from the chairman inviting me to testify at this hearing:

Committee Invitation Letter Questions

Question 1: Why are Federal investments in nanotechnology R&D of importance to the U.S.? What fields of science and engineering continue to present the greatest opportunities for breakthroughs in nanotechnology, and what industries are most likely to be affected by those breakthroughs in both the near-term and the longer-term?

Nanotechnology has the potential to profoundly change our economy and improve our standard of living, in much the same way as information technology advances have revolutionized our lives and the economy over the past two decades. While some nanotechnology products are beginning to

come to market, many major applications for nanotechnology are still 5-10 years away. Private investors look for short-term returns on investment, generally in the range of 1-3 years. Consequently, Government support for nanotechnology research and development in its early stages is required to ensure that the United States can maintain a competitive position in the worldwide nanotechnology marketplace while realizing nanotechnology's full potential. Increasing investments in nanotechnology R&D by NNI participating agencies also reflect the potential for this research to support diverse agency missions and responsibilities.

This funding has a remarkable return on investment when viewed in terms of expected job creation and the potential for significant economic growth. As mentioned earlier, a study funded by the National Science Foundation projects that 6 million nanotechnology workers will be needed worldwide by 2020, with 2 million of those jobs in the United States[2]. Multiple sources have come to the conclusion that nanotechnology-enabled products will be valued at up to $3 trillion by the end of the decade[3]. Nanotechnology will continue to create many jobs requiring college degrees and higher education, but it also will create jobs that can be filled through training and vocational programs, including community colleges and 2-year degrees. In fact, many nanotechnology companies report that they are hiring PhDs for routine characterization jobs, which could be more suitably filled by skilled technicians. In response to this growing need, community colleges across the country are launching nanotechnology programs, with currently around 60 such programs nationwide.

Federal investments also mirror the efforts being made through regional, state, and local nanotechnology initiatives across the country. Since the inception of the NNI, a number of highly successful regional and state initiatives have been developed in the U.S. and continue to thrive today. There are currently more than 30 active regional, state, and local nanotechnology initiatives in the U.S.[4], many of which participated in a 2009 NNI workshop on regional programs. The consensus at the workshop was clear: regional and state initiatives are counting on the leadership of the NNI to help drive a nationwide effort in nanotechnology.

The Federal Government does not single out any particular fields of science and engineering or industries that are most likely to benefit from the nanotechnology advances. However, in a study commissioned by the NNI, Lux Research[5] has identified four industry sectors most likely to be impacted by nanotechnology in the near term:

- Advanced healthcare and pharmaceutical applications, which are slowly entering the market
- The transportation sector – including automotive, airplane, and shipping – which offers a huge potential for nanotechnologies, particularly nanotechnology-enabled composites and electrical materials
- Manufacturing, industrial materials, and consumer products (including everything from nanotechnology-enabled lubricants to nanoporous insulation to carbon nanotube-reinforced fishing rods)

---

[2] Roco, Mirkin, and Hersam, *Nanotechnology Research Directions for Societal Needs*. (WTEC, 2010)

[3] Lux Research, *Nanomaterials State of the Market Q3 2008: Stealth Success, Broad Impact* (Lux Research, Inc., NY, NY, July 2008) and Roco, Mirkin, and Hersam, *Nanotechnology Research Directions for Societal Needs*. (WTEC, 2010)

[4] Nanoscale Science, Engineering, and Technology Subcommittee (NSET), *Regional, State, and Local Initiatives in Nanotechnology: Report of the National Nanotechnology Initiative Workshop*, April 1-3, 2009 (NSET, Washington, DC, 2011)

[5] *Valuing U.S. Nanotechnology Impact for Future NNI Action*, draft of November 2010; public version forthcoming.

- The electronics industry, which highlights some of the most broadly adopted nanotechnology-enabled products and processes, and where long-term research is underway (in close cooperation with the NNI) that could enable major new advances that are a decade or more away.

Question 2: What is the position of U.S. research and development in nanotechnology relative to that of other countries? What key factors influence U.S. performance in the field, and what trends exist among those factors?

The United States is not the only country to recognize the tremendous economic potential of nanotechnology. At least 60 countries now have national nanotechnology strategies and policies[6]. Estimates from 2008 showed the governments of the European Union (EU) and Japan invested approximately $1.7 billion and $950 million, respectively, in nanotechnology research and development. The governments of China, Korea, and Taiwan invested approximately $430 million, $310 million, and $110 million, respectively[7]. This compares to 2008 U.S. Government spending of $1.55 billion[8], placing us second to the E.U. countries. In a more recent report, Lux Research has estimated that government investments by the European Union and several of its member countries combined totaled more than $2.6 billion in 2010, compared to $2.1 billion in the United States (Federal and state/local governments combined, presumably).[9]

More importantly, all the data now points to an undeniable trend. While U.S. funding for nanotechnology has been steadily increasing, other countries are significantly ramping up their investments. In the case of China, the increase in investments in nanotechnology is virtually exponential. Furthermore, recent analyses of the number of nanotechnology citations, patents, and publications show that we are very quickly being surpassed by other nations in an area where, until recently, we had a strong lead[10]. This has the potential of putting our national security at risk, since technological superiority has been a foundation of our national security strategy since World War II. We are now at a crossroads; with the continued support of the NNI, the U.S. will play a major role in what is unfolding as the next economic and technological revolution; without it the U.S. is likely to fall behind in this race.

Question 3: What is the federal government's role in facilitating the commercialization of nanotechnology innovations as compared to private industry? How would an early regulatory regime affect the growth of the nanotechnology commercial industry?

A1: Industry has the primary responsibility for commercialization of nanotechnology innovations. However, the Federal Government does have roles to play in facilitating this, including the following:

- Funding basic research in nanoscale science and technology, to keep the pipeline flowing with new innovations for consideration by industry.

---

[6] Nanoscale Science, Engineering, and Technology Subcommittee (NSET), *Regional, State, and Local Initiatives in Nanotechnology: Report of the National Nanotechnology Initiative Workshop*, April 1-3, 2009 (NSET, Washington, DC, 2011)

[7] Roco, Mirkin, and Hersam, *Nanotechnology Research Directions for Societal Needs*. (WTEC, 2010)

[8] Nanoscale Science, Engineering, and Technology Subcommittee (NSET), *National Nanotechnology Initiative (NNI) Supplement to the President's FY 2010 Budget*, (NSET, Washington, DC, 2009)

[9] *Nanotechnology Funding: Corporations Grab the Reins*, April 2011.

[10] President's Council of Advisors on Science and Technology (PCAST), *Report to the President and Congress on the Third Assessment of the National Nanotechnology Initiative*, (PCAST, Washington, DC, 2010)

- Working closely with industry to accelerate the development of applications of nanotechnology that are critical to the national interest, particularly with respect to manufacturing, energy, medicine, national defense and homeland security. Hence mission agencies such as the Department of Defense, the Department of Homeland Security, the Department of Energy, and NASA are increasingly seeing opportunities for the application of nanotechnology to their agency missions, and are supporting both basic and applied research towards realizing those opportunities. NSF and other agencies have developed research and education programs to support nanotechnology innovation and partnerships with industry, such as the Nanoelectronics Research Initiative.
- Funding research on the health and safety aspects of nanomaterials and working with industry to facilitate safety in the workplace.
- Providing a clear regulatory pathway that industry can follow in pursuing the commercialization of nanotechnology innovations. To the extent practicable, Federal regulation and oversight should provide sufficient flexibility to accommodate new evidence and learning and to take into account the evolving nature of information related to emerging technologies and their applications. For example, NIH and FDA have a new underway that is designed to move medical products through the translational pipeline to the marketplace more rapidly and efficiently.
- Promoting fair international trade in nanotechnology-enabled products and processes.
- Supporting the protection of intellectual property both domestically and internationally, *i.e.*, through the U.S. Patent and Trademark Office (USPTO).
- Providing funds for small businesses to take advantage of nanotechnology innovations, through the Small Business Innovation Research (SBIR) and Small Business Technology Transfer Research (STTR) programs.
- Serving as an "early adopter" of key nanotechnology innovations, *e.g.*, in the application of carbon nanotubes to satellite power cables, ballistic protection, and weight reduction, where initial purchases by the Government of high-value-added nanotechnology products can help to create the opportunity for later development of commercial markets for similar products.
- Funding the development of novel nanomanufacturing technologies that could be applied to a wide variety of commercial products, and where the lack of appropriate mass-production techniques would otherwise preclude large-scale markets for these products.
- Working closely with industry to conduct joint roadmapping and R&D activities targeted at key areas of precompetitive nanotechnology research and applications, to bring expertise from industry, academia, and government laboratories collectively to bear on "hard problems" currently impeding the development of large-scale national security applications or commercial markets.
- Establishing and/or sustaining user facilities, cooperative research centers, and regional initiatives to provide industry, and in particular small business, with opportunities to accelerate the transfer of nanoscale science from discovery to commercial products.

A2: Transparent, consistent, and scientifically-based regulations decrease uncertainty about the economic opportunities. Well-designed regulations, which minimize uncertainty, promote product development and commercialization, a fact often confirmed by industry. Last month, March 2011, the White House Emerging Technologies Interagency Policy Coordination Committee (ETIPC) released a memorandum to the heads of executive departments and agencies outlining broad principles to guide the development and implementation of policies for oversight of emerging technologies at the agency level. In addition to ensuring that regulation and oversight of emerging technologies be based on the best available scientific evidence, the principles also state that where possible, regulatory approaches should promote innovation while also advancing regulatory objectives, such as protection of health, the environment, and safety. [11]

At present, the NNI regulatory agencies continue to review their existing authorities against our current scientific understanding of the human and environmental impact of size and emergent properties of nanoscale materials. They are employing existing product evaluation strategies where appropriate, and modifying them if necessary, to ensure the safety of the American people. Regulatory agencies are also working with their industrial stakeholders to assist them navigating the nanotechnology regulatory landscape.

Additionally, the revised and soon-to-be-released NNI Environmental, Health, and Safety (EHS) Research Strategy was developed not only to protect public and occupational health and the environment but also foster technological advancements that benefit society. The regulatory agencies shared leadership for development of the EHS research framework with the research agencies. These actions, in combination, are designed to minimize scientific uncertainty, maximize regulatory authority, and promote growth of the U.S. nanotechnology commercial industry.

Question 4: What is the workforce outlook for nanotechnology? What is the federal government's role and how can it, along with universities; help ensure there will be enough people with the relevant skills to meet the Nation's needs for nanotechnology research and development and for the manufacture of nanotechnology-enabled products?

As mentioned above (Question 1), a recent study funded by NSF has concluded that approximately 6 million nanotechnology workers (researchers and manufacturing workforce) will be needed worldwide by 2020, of which 2 million will be in the United States.[12]

The Federal Government's roles in helping meet these needs include the following:

- Funding research that in turn supports graduate education. (Industry representatives have commented to us that they view this as the primary way in which NNI-funded research benefits industry, by filling the pipeline with future nanotechnology researchers who will be available for industry to hire when they are needed.) As the question implies, this requires working in strong partnerships with universities.
- Including nanotechnology as part of a federal-wide K-12 and postsecondary STEM education strategy that includes rigorous curriculum development, dissemination and evaluation.

[11] See: http://www.whitehouse.gov/sites/default/files/microsites/ostp/etipc-memo-3-11-2011.pdf

[12] Roco, Mirkin, and Hersam, eds. 2010. *Nanotechnology Research Directions for Societal Needs in 2020*. Springer (in press); available electronically now at: http://wtec.org/nano2/Nanotechnology_Research_Directions_to_2020/. See Chapter 2.

- Working with the National Science Foundation and the Department of Education to develop innovative nanotechnology education approaches to disseminate this curriculum widely across the United States, for local schools systems to consider using in their classrooms.
- Conducting public outreach and education activities that generate excitement about science and technology, from the exciting advances in S&T that are currently being enabled by nanoscale science and technology to advances in S&T in general, thus encouraging students to take up careers in science and technology. NSF will support "Nanoscale Informal Science Education" and "Nanotechnology in Society" networks to reach public and professional communities in the U.S.
- Working with the NSF, Department of Education, and Department of Labor to create new approaches and disseminate information about career opportunities specifically in nanotechnology research and manufacturing, to attract students to pursue these opportunities.
- Working with NSF and other agencies to support the National Nanomanufacturing Network for nanomanufacturing research and education; developing new nanoscale materials and processes, and nanoinformatics.
- Expediting the issuance of visas to foreign students and guest workers with specialized experience in nanotechnology. (Industry representatives have cited this as among their biggest issues in maintaining successful nanotechnology R&D and manufacturing operations in the United States.)
- Establishing clear guidelines for safe handling of nanomaterials by both research and manufacturing workers. The United States is a leader in this respect currently, especially with the groundbreaking work of NIOSH in publishing voluntary guidelines. It is vital that the United States continue to lead in this area, as it does in many other areas of industrial hygiene.

I thank this Committee for its strong leadership, commitment, and support of Federal investments in nanoscale science and engineering. And I will be pleased to answer any questions you may have.