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OVERSIGHT OF THE NATIONAL NANOTECHNOLOGY INITIATIVE AND PRIORITIES FOR THE FUTURE

HEARING

BEFORE THE

SUBCOMMITTEE ON RESEARCH AND SCIENCE EDUCATION

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED TWELFTH CONGRESS

FIRST SESSION

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Thursday, April 14, 2011

OVERSIGHT OF THE NATIONAL NANOTECHNOLOGY INITIATIVE AND PRIORITIES FOR THE FUTURE

THURSDAY, APRIL 14, 2011

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON RESEARCH AND SCIENCE EDUCATION,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, DC.

The Subcommittee met, pursuant to call, at 2:02 p.m., in Room 2318 of the Rayburn House Office Building, Hon. Mo Brooks [Chairman of the Subcommittee] presiding.

RALPH M. HALL, TEXAS
CHAIRMAN

EDDIE BERNICE JOHNSON, TEXAS
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U.S. HOUSE OF REPRESENTATIVES

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

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Subcommittee on Research and Science Education
Nanotechnology:
Oversight of the National Nanotechnology Initiative and Priorities for the Future
Thursday, April 14, 2011
2:00 p.m. - 4:00 p.m.
2318 Rayburn House Office Building

Witnesses

Dr. Clayton Teague
Director, National Nanotechnology Coordination Office (NNCO)

Dr. Jeffrey Welser
Director, Nanoelectronics Research Initiative, Semiconductor Research Corporation and Semiconductor Industry Alliance

Dr. Seth Rudnick
Chairman, Board of Directors, Liquidia Technologies

Dr. James Tour
Professor of Chemistry, Computer Science and Mechanical Engineering and Materials Science, Rice University

Mr. William Moffitt
President and Chief Executive Officer, Nanosphere, Inc.

HEARING CHARTER

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON RESEARCH AND SCIENCE EDUCATION
U.S. HOUSE OF REPRESENTATIVES

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

THURSDAY, APRIL 14, 2011
2:00 P.M.–4:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

Purpose

On Thursday, April 14, 2011, the Subcommittee on Research and Science Education will hold a hearing to examine the National Nanotechnology Initiative (NNI) and address the Nation's research and development priorities for the future. Witnesses include a representative from the NNI, as well as researchers and other nanotechnology experts. The hearing will provide background on the science and applications of nanotechnology.

Witnesses

Dr. Clayton Teague, Director, National Nanotechnology Coordination Office (NNCO)
Dr. Jeffrey Welser, Director, Nanoelectronics Research Initiative, Semiconductor Research Corporation and Semiconductor Industry Alliance
Dr. Seth Rudnick, Chairman, Board of Directors, Liquidia Technologies
Dr. James Tour, Professor of Chemistry, Computer Science and Mechanical Engineering and Materials Science, Rice University
Mr. William Moffitt, President and Chief Executive Officer, Nanosphere, Inc.

Brief Overview

- Nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications. (A nanometer is one-billionth of a meter. A sheet of paper is about 100,000 nanometers thick.) Unusual physical, chemical, and biological properties can emerge in materials at the nanoscale. These properties may differ in important ways from the properties of bulk materials and single atoms or molecules. [1]
- In December 2003, the President signed the *21st Century National Nanotechnology Research and Development Act* (P.L. 108–153). This Act provided a statutory framework for the interagency National Nanotechnology Initiative (NNI), authorized appropriations for nanotechnology research and development (R&D) activities through fiscal year 2008 (FY08), and enhanced the coordination and oversight of the program. The U.S. House of Representatives passed bills in both the 110th (H.R. 5940) and 111th (H.R. 554 and H.R. 5116) Congresses to amend and reauthorize the Act; however, the Senate did not act in either Congress.
- Funding for the NNI has grown from $464 million in fiscal year 2001 (FY01) to $1.9 billion in FY 10; 15 agencies currently have nanotechnology R&D pro-

[1] The National Nanotechnology Initiative Supplement to the President's FY 2012 Budget, p. 3

grams. Through FY 11, Congress has appropriated approximately $14.2 billion in nanoscale science, engineering, and technology, through the NNI. [2]

- The President's FY 12 budget request proposes a total of $2.1 billion for the NNI, more than a $200 million or 11.3 percent increase over the FY 10 enacted levels [3].
- It is estimated that in the U.S. the private sector investment in the research and development of nanotechnology is twice that of the public investment. [4]
- Globally, the U.S. is the leader in this field but foreign investments in nanotechnology continue to increase. In 2009, the U.S. continued to lead global public investments in nanotechnology at over $2.5 billion (Federal, state and local contributions). While Japan, France, China, South Korea, and Taiwan grew their support, no other investment reached $1 billion. [5]
- The very structure of materials can be improved through nanotechnology, by developing nanomaterials that are stronger, lighter, more durable or better conductors, among other traits adding nanoparticles to plastics can make them stronger, lighter and more durable. Nanoparticles are currently used in baseball bats and tennis rackets, but someday may also be used in bulletproof vests and light, fuel efficient vehicles.Nanotechnology also holds the potential to exponentially increase information storage capacity; soon [a] computer's entire memory will be able to be stored on a single tiny chip. [6]
- Varying estimates project nanotechnology product revenues will reach between $2.95 billion and $3.1 trillion by 2015. [7]

Background

As described by the NNI:

Nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale. A nanometer is one-billionth of a meter. A sheet of paper is about 100,000 nanometers thick; a single gold atom is about a third of a nanometer in diameter. Dimensions between approximately 1 and 100 nanometers are known as the nanoscale. Unusual physical, chemical, and biological properties can emerge in materials at the nanoscale. These properties may differ in important ways from the properties of bulk materials and single atoms or molecules. [8]

Nanotechnology is an enabling technology and, as such, its commercialization does not depend specifically on the creation of new products and new markets. Gains can come from incorporating nanotechnology into existing products, resulting in new and improved versions of these products. Examples could include faster computers, lighter materials for aircraft, less invasive ways to treat cancer, and more efficient ways to store and transport electricity. Some less-revolutionary nanotechnology-enabled products are already on the market, including stain-resistant, wrinkle-free pants, ultraviolet-light blocking sunscreens, and scratch-free coatings for eyeglasses and windows.

National Nanotechnology Initiative (NNI)

The National Nanotechnology Initiative (NNI) is a multi-agency research and development (R&D) program. The goals of the NNI, which was initiated in 2001, are to maintain a world-class research and development program; to facilitate technology transfer; to develop educational resources, a skilled workforce, and the infrastructure and tools to support the advancement of nanotechnology; and to support responsible development of nanotechnology.

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[2] Nanotechnology: A Policy Primer, CRS, p. 6: The Third Assessment of the NNI by PCAST denotes $12 billion spent on NNI since 2001; that report was published before the 2011 funding was in place.

[3] The National Nanotechnology Initiative Supplement to the President's FY 2012 Budget, p. 7 (Note: These amounts differ from the OSTP February 2011 Draft one-pager on the NNI used in previous budget hearings, as the Supplement had not yet been released.)

[4] Nanotechnology: A Policy Primer, CRS, p. 4

[5] Ranking the Nations on Nanotech: Hidden Havens and False Threats, LuxResearch August, 2010, p. 3–4

[6] Nano.gov, Applications and Products

[7] The National Nanotechnology Initiative: Overview, Reauthorization, and Appropriations Issues, CRS, p. 3

[8] Nano.gov, What is Nanotechnology

Currently, 15 Federal agencies have ongoing programs in nanotechnology R&D. Additionally, 10 other agencies, such as the Food and Drug Administration, the U.S. Patent and Trademark Office, and the Department of Transportation, participate in the coordination and planning work associated with the NNI (see Table 1).

TABLE 1: NNI PARTICIPATING AGENCIES[9]

Federal agencies with budgets dedicated to nanotechnology research and development
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)

(Table 1: NNI Participating Agencies) [9]

Other participating agencies
Bureau of Industry and Security (BIS, Department of Commerce)
Department of Education (DOEd)
Department of Labor (DOL, including the Occupational Safety and Health Administration, OSHA)
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)

[9] The National Nanotechnology Supplement to the President's FY 2012 Budget, p. 5

The potential contributions of nanoscale science and technology to future U.S. economic growth were first raised to the level of a Federal initiative, known as NNI, in the FY 01 budget request to Congress.

Legislatively, the NNI was originally authorized in 2003, through the 21st Century National Nanotechnology Research and Development Act (P.L. 108–153). The Act adds oversight mechanisms to provide for planning, management, and coordination of the program; encourages partnerships between academia and industry; encourages expanded nanotechnology research and education and training programs; and emphasizes the importance of research into societal concerns related to nanotechnology to understand the impact of new products on health and the environment.

The Act authorized appropriations for nanotechnology research and development (R&D) activities through FY 08. While the programs and funding in the Act were only authorized through 2008 they have continued to receive funding through the annual Appropriations process. As is the case with numerous Federal programs, in order to maintain program integrity the Federal government continues to provide funding while the reauthorization process takes place.

The U.S. House of Representatives attempted to reauthorize the NNI in both of the last two Congresses, passing H.R. 5940 in the 110th and H.R. 554 and H.R. 5116 in the 111th. The Senate did not act in either Congress.

The management structure for the NNI is as follows:

The National Nanotechnology Initiative 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) provides technical and administrative support to the NSET Subcommittee, serves as a central point of contact for Federal nanotechnology R&D activities, and engages in public outreach on behalf of the NNI. The NNCO also serves as a liaison to academia, industry, professional societies, foreign organizations, and others to exchange technical and programmatic information. Additionally, the NNCO coordinates preparation and publication of NNI interagency planning, budget, and assessment documents.[10]

The NNI has also established eight program component areas (PCAs) that provide an organizational framework for categorizing NNI activities (see Table 2).

[10] Report to the President and Congress on the Third Assessment of the National Nanotechnology Initiative, PCAST, p. vii

TABLE 2: PROGRAM COMPONENT AREAS[11]		
No.	**PCA Title**	**Description**
1	Fundamental Nanoscale Phenomena and Processes	Discovery and development of fundamental knowledge pertaining to new phenomena in the physical, biological, and engineering sciences that occur at the nanoscale. Elucidation of scientific and engineering principles related to nanoscale structures, processes, and mechanisms.
2	Nanomaterials	Research aimed at the discovery of novel nanoscale and nanostructured materials and at a comprehensive understanding of the properties of nanomaterials (ranging across length scales, and including interface interactions). R&D leading to the ability to design and synthesize, in a controlled manner, nanostructured materials with targeted properties.
3	Nanoscale Devices and Systems	R&D that applies the principles of nanoscale science and engineering to create novel, or to improve existing, devices and systems. Includes the incorporation of nanoscale or nanostructured materials to achieve improved performance or new functionality. To meet this definition, the enabling science and technology must be at the nanoscale, but the systems and devices themselves are not restricted to that size.
4	Instrumentation, Research, Metrology, and Standards for Nanotechnology	R&D pertaining to the tools needed to advance nanotechnology research and commercialization, including next-generation instrumentation for characterization, measurement, synthesis, and design of materials, structures, devices, and systems. Also includes R&D and other activities related to development of standards for nomenclature, materials characterizations and testing, and manufacture.
5	Nanomanufacturing	R&D aimed at enabling scaled-up, reliable, and cost-effective manufacturing of nanoscale materials, structures, devices, and systems. Includes R&D and integration of ultra-miniaturized top-down processes and increasingly complex bottom-up or self-assembly processes.
6	Major Research Facilities and Instrumentation Acquisition	Establishment of user facilities, acquisition of major instrumentation, and other activities that develop, support, or enhance the nation's scientific infrastructure for the conduct of nanoscale science, engineering, and technology R&D. Includes ongoing operation of user facilities and networks.
7	Environment, Health and Safety	Research primarily directed at understanding the environmental, health, and safety impacts of nanotechnology development and corresponding risk assessment, risk management, and methods for risk mitigation.
8	Education and Societal Dimensions	Education-related activities such as development of materials for schools, undergraduate programs, technical training, and public communication, including outreach and engagement. Research directed at identifying and quantifying the broad implications of nanotechnology for society, including social, economic, workforce, educational, ethical, and legal implications.

(Table 2: Program Component Areas) [11]

NNI FY 12 Budget Request

In February 2011, the NNI released a supplement to the President's FY 12 budget request. This supplement identifies the total amount of nanotechnology-related funding requested by each NNI participating agency.

The FY 12 budget request for NNI is $2.1 billion, an increase of $216 million or 11.3 percent over the FY 10 actual levels. The Administration's budget request includes funding for three signature initiatives: Nanoelectronics for 2020 and Beyond; Sustainable Manufacturing: Creating the Industries of the Future; and Nanotechnology for Solar Energy Collection and Conversion. The DOE contribution will increase to $611 million, a $237 million or 63 percent increase. Likewise, NASA sees a 64 percent increase, EPA an 11.9 percent increase, NSF a 6.3 percent increase, HHS a five percent increase, and NIST a one percent increase. All other agency funding is reduced by a total of $88 million. (See Appendix A for more detail.)

Each of the 25 participating agencies creates its own annual budget request, including its request for nanotechnology-related funding. "The NNI is an interagency budget crosscut in which participating agencies work closely with each other to create an integrated program." [12] Of the 25 participating agencies, only 15 have funding dedicated to nanotechnology-related fields (see Table 3).

[11] National Nanotechnology Initiative Strategic Plan, p. 5

[12] The National Nanotechnology Initiative Supplement to the President's FY 2012 Budget, p. 4

Table 3: NNI Budget, by Agency, 2010-2012[13] (dollars in millions)			
Agency	**FY10 Actual**	**FY11 CR***	**FY12 Proposed**
DOE**	373.8	380.8	610.6
HHS/NIH	456.8	456.8	464.8
NSF	428.7	412.1	455.9
DOD***	439.6	415.4	368.2
DOC/NIST	114.7	95.9	115.7
NASA	19.7	20.1	32.3
EPA	17.7	17.6	19.8
HHS/NIOSH	8.5	9.5	16.5
HHS/FDA	7.3	7.3	15
USDA/NIFA	13.2	13.2	11.6
DHS	21.9	12.3	10.2
USDA/FS	7.1	5	5
CPSC	0.5	2.2	2
DOT/FHWA	3.2	2	2
DOJ	0.2	0	0
TOTAL:	1912.8	1850.3	2129.6

* 2011 levels reflect the annualized amounts provided by the continuing resolution (CR) that extended through March 4, 2011.
** Funding levels for DOE include the combined budgets of the Office of Science, the Office of Energy Efficiency and Renewable Energy (EERE), the Office of Fossil Energy, and the Advanced Research Projects Agency for Energy (ARPA-E).
*** The 2010 DOD figures include $75 million in Congressionally directed funding that is outside the NNI plans.

(Table 3: NNI Budget, by Agency, 2010–2012) [13]

The FY 12 budget request states the NNI's continued support for the Federal role in basic research, infrastructure development, and technology transfer, while renewing an emphasis on accelerating the transition from basic R&D into innovations that support sustainable energy technologies, healthcare and environmental protection. To achieve this, Advanced Research Projects Agency for Energy (ARPA–E) at the Department of Energy, the Environmental Protection Agency, and the National Institutes of Health each receive significant funding increases through the request. [14] Further, environmental, health and safety (EHS) research remains a priority as identified by funding increases in the FY 12 budget request. NNI EHS funding for the Food and Drug Administration is increased over 100 percent, and the Consumer Product Safety Administration requests a 300 percent increase. Additionally, agencies like the Occupational Safety and Health Administration are strengthening their role in the NNI and EHS research. [15] (See Appendix B, C, and D for FY 10—FY12 Agency investments by PCA.)

PCAST Third Assessment of the NNI

The 21st Century National Nanotechnology Research and Development Act required that a National Nanotechnology Advisory Panel (NNAP) biennially report to Congress on trends and developments in nanotechnology science and engineering and on recommendations for improving the NNI. The President's Council of Advisors on Science and Technology (PCAST) acts as the NNAP, and as such conducts the biennial assessments. The latest assessment by PCAST was released in March 2010.

The third assessment of the NNI utilized three overarching categories for its evaluation and recommendations. [16]

(1) Program Management-An appraisal of how well NNI leadership has performed with respect to the roles it has been tasked to carry out. Recommendations include:

- NNCO broadened impact and efficacy and improved ability to coordinate and develop NNI programs and policies related to those programs;

[13] The National Nanotechnology Initiative Supplement to the President's FY 2012 Budget, p. 8
[14] The National Nanotechnology Initiative Supplement to the President's FY 2012 Budget, p. 7
[15] Ibid.
[16] PCAST's Third Assessment of the NNI, p. viii-xiii

- Focus on commercialization;
- Develop coordinated milestones, promote strong educational components, and create public-private partnerships to leverage the outcomes of the Signature Initiatives;
- Continue investments in innovative and effective education
- NNCO consideration of the commission of a comprehensive evaluation of the outcomes of the overall investment in NNI education; and
- Develop a clear expectation and strategy for programs in the societal dimensions of nanotechnology.

(2) Nanotechnology Outcomes-An analysis of what the Federal nanotechnology investment has delivered and recommendations to enhance the outcomes, especially economic outcomes, as follows:

- Include a greater emphasis on manufacturing and commercialization while maintaining or expanding the level of basic research funding in nanotechnology;
- Launch at least five government-industry university partnerships across the Federal government;
- Advise the NNI on how to ensure that its programs create new jobs in the United States (Department of Commerce and Small Business Administration);
- Take steps to retain scientific and engineering talent trained in the United States; and
- Clarify the development pathway and increase emphasis on transitioning nanotechnology to commercialization.

(3) Environment, Health, and Safety (EHS)-An assessment of NNI's performance in helping to orchestrate the identification and management of potential risks associated with nanotechnology, with particular attention paid to reviewing progress the NNI has made in following through on recommendations made in the 2008 NNAP review of the NNI. New recommendations include:

- Develop clear principles to support the identification of plausible risks associated with the products of nanotechnology;
- Further develop and implement a crossagency strategic plan that links EHS research activities with knowledge gaps and decision-making needs within government and industry;
- Develop information resources on crosscutting nanotechnology EHS issues that are relevant to businesses, health and safety professionals, researchers, and consumers; and
- Foster administrative changes and communications mechanisms that will enable the NNI to better embrace the EHS issues associated with nanotechnology research, development, and commercialization.

NNI Strategic Plan

The National Nanotechnology Initiative Strategic Plan is the framework that underpins the nanotechnology work of the NNI member agencies.Its purpose is to facilitate the achievement of the NNI vision by laying out guidance for agency leaders, program managers, and the research community regarding planning and implementation of nanotechnology R&D investments and activities. [17]

Released in February 2011, the NNI strategic plan is used by participating agencies to guide coordination of nanotechnology-related research, training programs and resources. The strategic plan builds on the four NNI goals by creating objectives to support each goal. (See Table 4.)

[17] National Nanotechnology Initiative Strategic Plan, p. 2

Table 4: NNI Strategic Plan Goals and Objectives [18]

Goals		Objectives
1	Advance a world-class nanotechnology research and development program	1.1 Continue to support R&D at the frontiers and intersections of scientific disciplines in the form of intramural and extramural programs targeting single investigators, multi-investigator and multidisciplinary research teams, and centers for focused research. 1.2 Develop at least five broad interdisciplinary nanotechnology initiatives that are each supported by three or more NNI member agencies and support significant national priorities. 1.3 Identify and support goal-oriented nanoscale science and technology research aimed at national priorities informed by active engagement with academia, industry, and other stakeholders. 1.4 Develop quantitative measures to assess the performance of the U.S. nanotechnology R&D program relative to that of other major economies, in coordination with broader efforts to develop metrics for innovation.
2	Foster the transfer of new technologies into products for commercial and public benefit	2.1 Develop robust, scalable nanomanufacturing methods necessary to facilitate commercialization by doubling the share of the NNI investment in nanomanufacturing research over the next five years. 2.2 Increase focus on nanotechnology-based commercialization and related support for public-private partnerships. 2.3 Establish and/or sustain national user facilities, cooperative research centers, and regional initiatives with the goal of accelerating the transfer of nanoscale science from discovery to commercial products. 2.4 Assist the nanotechnology-based business community, including small- and medium-sized enterprises, in understanding the Federal Government's R&D funding and regulatory environment. 2.5 Increase international engagement to facilitate the responsible and sustainable commercialization, technology transfer, innovation, and trade related to nanotechnology-enabled products and processes.
3	Develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology	3.1 Initiate, develop, support, and sustain programs for educating, training, and maintaining a skilled nanotechnology workforce. 3.2 Initiate outreach and informal education programs and publish related information to foster a student population, workforce, and public that are well informed about the opportunities in nanotechnology-related industries and the potential impacts of environmental, health, and safety (EHS) and ethical, legal, and societal implications (ELSI) of nanotechnology. 3.3 Provide, facilitate that sharing of, and sustain the physical R&D infrastructure for nanoscale fabrication, synthesis, characterization, modeling, design, computation, and hands-on training for use by industry, academia, nonprofit organizations, and state and Federal agencies.
4	Support responsible development of nanotechnology	4.1 Incorporate safety evaluation of nanomaterials into the product life cycle, foster responsible development, and where appropriate, sustainability across the nanotechnology pipeline. 4.2 Develop tools and procedures for domestic and international outreach and engagement to assist stakeholders in developing best practices for communicating and managing risk. 4.3 Identify and manage the ethical, legal, and societal implications (ELSI) of research leading to nanotechnology-enabled products and processes. 4.4 Employ nanotechnology and sustainable best practices to protect and improve human health and the environment.

(Table 3: NNI Strategic Plan Goals and Objectives) [18]

The NNI strategic plan looks forward over the next ten years for areas to induce greater agency collaboration, such as the nanotechnology Signature Initiatives: Nanotechnology for Solar Energy Conversion; Sustainable Nanomanufacturing; and Nanoelectronics for 2020 and Beyond. The strategic plan also calls for leveraging collaborative interagency opportunities and building an internet-based "one-stop shop" access point for nanotechnology information. "Moving into the next decade, meaningful engagement with stakeholders and ongoing external assessments will strengthen the efforts of the NNI as the participating agencies move toward realizing the four NNI goals." [19]

[18] National Nanotechnology Initiative Strategic Plan, pp. 23–32
[19] National Nanotechnology Initiative Strategic Plan, p. 39

APPENDICES

A. Agency Investment in Signature Initiatives

(dollars in millions)

Nanotechnology for Solar Energy Collection and Conversion		
Agency	**FY11 CR**	**FY12 Proposed**
DOE	65.0	79.2
NSF	0.0	32.0
NIST	3.8	11.5
NASA	0.0	2.0
USDA/NIFA	0.0	1.0
Total:	**68.8**	**125.7**

*Funding levels for the DOE include the combined budgets of the Office of Science, the Office of Energy Efficiency and Renewable Energy, and the Advanced Research Projects Agency for Energy.

Sustainable Nanomanufacturing		
Agency	**FY11 CR**	**FY12 Proposed**
DOE*	7.6	35.3
NSF	0.0	35.4
NIST	0.5	7.4
NASA	0.0	5.0
USDA/FS	0.2	0.9
Total:	**8.3**	**84.0**

*Funding levels for the DOE include the combined budgets of the Office of Energy Efficiency and Renewable Energy, and the Advanced Research Projects Agency for Energy.

Nanoelectronics for 2020 and Beyond		
Agency	**FY11 CR**	**FY12 Proposed**
NSF	0.0	50.0
DOE*	0.0	33.8
NIST	11.7	11.7
NASA	0.0	3.0
Total:	**11.7**	**98.5**

*Funding levels for the DOE include the combined budgets of the Office of Science and Renewable Energy, and the Advanced Research Projects Agency for Energy.

B. Actual FY10 Agency Investments by PCA

(dollars in millions)

	1. Fundamental Phenomena & Processes	2. Nanomaterials	3. Nanoscale Devices & Systems	4. Instrument Research, Metrology, & Standards	5. Nano-manufacturing	6. Major Research Facilities & Instr.Acquisition	7. Environment, Health, and Safety	8. Education & Societal Dimensions	NNI Total
DOE	97.6	115.8	25.4	20.2	6.5	105.2	2.6	0.5	373.8
HHS/NIH	60.0	76.0	244.0	22.0	0.8	8.0	20.0	26.0	456.8
NSF	168.1	74.9	55.6	17.9	21.4	29.3	27.1	34.5	428.7
DOD	138.0	59.1	168.5	6.6	26.4	35.6	0.0	5.4	439.6
DOC/NIST	22.3	8.2	24.3	17.3	27.2	12.1	3.4	0.0	114.7
NASA	0.0	7.6	10.0	0.0	2.1	0.0	0.0	0.0	19.7
EPA	0.2	0.2	0.2	0.0	0.0	0.0	17.1	0.0	17.7
HHS/NIOSH	0.0	0.0	0.0	0.0	0.0	0.0	8.5	0.0	8.5
HHS/FDA	0.0	0.0	0.0	0.0	0.0	0.0	7.3	0.0	7.3
USDA/NIFA	1.0	2.0	5.5	0.3	0.2	0.0	3.7	0.5	13.2
DHS	1.4	11.5	5.0	4.0	0.0	0.0	0.0	0.0	21.9
USDA/FS	2.0	1.4	2.4	1.1	0.2	0.0	0.0	0.0	7.1
CPSC	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.5
DOT/FHWA	0.0	2.0	1.2	0.0	0.0	0.0	0.0	0.0	3.2
DOJ	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Total:	**490.5**	**358.9**	**542.1**	**89.4**	**84.8**	**190.2**	**90.2**	**66.9**	**1912.80**

C. Estimated FY11 CR Agency Investments by PCA

(dollars in millions)

	1. Fundamental Phenomena &Processes	2. Nanomaterials	3. Nanoscale Devices & Systems	4. Instrument Research, Metrology, & Standards	5. Nano-manufacturing	6. Major Research Facilities & Instr.Acquisition	7. Environment, Health, and Safety	8. Education &Societal Dimensions	NNI Total
DOE	103.2	120.5	33.0	15.7	2.6	105.8	0.0	0.0	380.8
HHS/NIH	60.0	76.0	244.0	22.0	0.8	8.0	20.0	26.0	456.8
NSF	152.6	78.7	43.7	18.3	22.4	37.8	24.3	34.3	412.1
DOD	180.1	31.5	145.3	2.4	27.7	25.7	0.0	2.8	415.4
DOC/NIST	21.7	7.3	20.8	16.9	14.6	11.4	3.2	0.0	95.9
NASA	0.0	7.8	10.0	0.0	1.9	0.0	0.0	0.4	20.1
EPA	0.2	0.2	0.2	0.0	0.0	0.0	17.0	0.0	17.6
HHS/NIOSH	0.0	0.0	0.0	0.0	0.0	0.0	9.5	0.0	9.5
HHS/FDA	0.0	0.0	0.0	0.0	0.0	0.0	7.3	0.0	7.3
USDA/NIFA	1.2	3.0	6.0	0.3	0.2	0.0	2.0	0.5	13.2
DHS	0.8	1.5	3.0	7.0	0.0	0.0	0.0	0.0	12.3
USDA/FS	1.9	1.3	0.6	1.0	0.2	0.0	0.0	0.0	5.0
CPSC	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	2.2
DOT/FHWA	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	2.0
DOJ	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total :	**521.6**	**328.8**	**507.5**	**83.6**	**70.3**	**188.7**	**85.6**	**64.0**	**1850.30**

D. Proposed FY12 Agency Investments by PCA

(dollars in millions)

	1. Fundamental Phenomena & Processes	2. Nanomaterials	3. Nanoscale Devices & Systems	4. Instrument Research, Metrology, & Standards	5. Nano-manufacturing	6. Major Research Facilities & Instr.Acquisition	7. Environment, Health, and Safety	8. Education & Societal Dimensions	NNI Total
DOE	121.3	246.3	86.8	18.4	18.3	119.5	0.0	0.0	610.6
HHS/NIH	61.0	77.0	249.0	23.0	0.8	8.0	20.0	26.0	464.8
NSF	151.6	76.3	59.2	16.6	57.2	31.5	34.5	29.0	455.9
DOD	162.8	24.1	132.6	2.1	20.3	16.4	0.0	10.0	368.2
DOC/NIST	21.1	8.9	20.0	20.0	17.5	16.6	11.6	0.0	115.7
NASA	0.0	9.3	11.7	0.0	7.3	0.0	2.0	2.0	32.3
EPA	0.0	0.0	0.0	0.0	0.0	0.0	19.8	0.0	19.8
HHS/NIOSH	0.0	0.0	0.0	0.0	0.0	0.0	16.5	0.0	16.5
HHS/FDA	0.0	0.0	0.0	0.0	0.0	0.0	15.0	0.0	15.0
USDA/NIFA	1.0	2.0	5.5	0.3	0.3	0.0	2.0	0.5	11.6
DHS	0.7	1.5	1.0	7.0	0.0	0.0	0.0	0.0	10.2
USDA/FS	1.4	1.5	0.1	1.0	0.9	0.0	0.1	0.0	5.0
CPSC	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	2.0
DOT/FHWA	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	2.0
DOJ	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total:	**520.8**	**447.9**	**566.9**	**88.4**	**122.5**	**192.0**	**123.5**	**67.5**	**2129.60**

Chairman BROOKS. The Subcommittee will come to order. Good afternoon, everyone. Thank you. This is, as you can tell, this is my first time to chair a Subcommittee. I am a freshman from the state of Alabama, Mo Brooks. I am going to be needing some assistance from staff and also Mr. Lipinski from the state of Illinois.

Welcome to today's hearing entitled Nanotechnology: Oversight of the National Nanotechnology Initiative and Priorities for the Future. In front of you are packets containing the written testimony, biographies, and truth in testimony disclosures for today's witness panel.

Before we get started not only is this the first meeting of the Research and Science Education Subcommittee for the 112th Congress, but it is also, as I stated earlier, my first hearing as Chairman. It is an honor and a pleasure for me to Chair the Research and Science Education Subcommittee for this Congress and is a position I do not take lightly.

As such, I look forward to working with you, Mr. Lipinski. I want you to know that I will endeavor to serve all Members fairly and impartially, and I will work to ensure that the Subcommittee on behalf of the American people performs its legislative oversight and investigative duties with due diligence with regards to matters within its jurisdiction throughout the 112th Congress.

It is imperative that we take seriously our charge to make sure that the agencies and programs under our jurisdiction are worthy of the public support.

I now recognize myself for an opening statement. First, let me thank each of our witnesses for joining us today, and in particular, I would like to give a special thank you to Dr. Clayton Teague. From what I understand tomorrow not only marks your eighth anniversary as Director of the National Nanotechnology Coordination Office, but it will also be your last day in that role. I am sorry I will not have the opportunity to work with you in this capacity but would certainly like to thank you on behalf of the Subcommittee for your dedication and service to this Nation. Thank you.

Then into my statement. Nanotechnology represents a great deal of promise for the future of the U.S. economy, both in terms of leaps and bounds in the scientific knowledge base and in terms of potential products and employment opportunities as the technology continues to mature. Many believe it has the potential to be the next industrial revolution leading to significant social and economic impact. Nanotechnology is already prevalent in our lives. It is in sunscreens and cosmetics, batteries, stain-resistant clothing, eyeglasses, windshields, and sporting equipment. The development of nanomaterials that are stronger, lighter, and more durable may lead to better technology for items such as bulletproof vests and fuel efficient vehicles. Advances in nanomedicine to diagnose and treat diseases, as well as deliver drugs with fewer side effects, are literally just over the horizon. Many are already in clinical trials.

The National Nanotechnology Initiative or NNI is the United States government's effort to coordinate the nanotechnology research and development activities of the Federal agencies. While nanotechnology is not a new scientific field, it remains an emerging technology. It is my understanding that neither this Subcommittee, nor the full Committee for that matter, has held a hearing focused on the NNI since early 2008, primarily because the House passed an NNI Reauthorization Bill in both the 110th and 111th Congresses, only to see them die in the United States Senate. Regardless, much has happened in the past three years, including a new PCAST Assessment and the issuance of a strategic plan. This hearing today provides us with an opportunity to get feedback on those documents and have a discussion about national priorities for this technology.

In addition, we will also examine the President's fiscal year 2012 NNI Budget Supplement, which represents funding requests from the 15 federal agencies investing in nanotechnology. The request includes a more than an $11 million, excuse me. More than a $200 million increase or 11 percent from fiscal year 2010 enacted levels, including significant increases for environmental, health and safety areas, and nano-manufacturing. In these difficult budget times, Congress needs to be sure that all federal investments will work to strengthen the economy, including our investments in nanotechnology.

I look forward to hearing the testimony to be presented today and to the beginning of what I hope is a fruitful discussion on U.S. nanotechnology investments and priorities.

And, again, thank you for joining us today.

[The prepared statement of Mr. Brooks follows:]

PREPARED STATEMENT OF CHAIRMAN MO BROOKS

Good afternoon and welcome. Again, let me thank each of our witnesses for joining us today.

Nanotechnology represents a great deal of promise for the future of the U.S. economy, both in terms of leaps and bounds in the scientific knowledge base and in terms of potential products and employment opportunities as the technology continues to mature. Many believe it has the potential to be the next industrial revolution leading to significant social and economic impact. Nanotechnology is already prevalent in our lives; it is in sunscreens and cosmetics, batteries, stain-resistant clothing, eyeglasses, windshields, and sporting equipment. The development of nanomaterials that are stronger, lighter, and more durable may lead to better technology for items such as bulletproof vests and fuel efficient vehicles. (With gas prices soaring isn't that a welcome thought?) Advances in nanomedicine to diagnose and treat diseases as well as deliver drugs with fewer side effects are literally just over the horizon; many are already in clinical trials (as we will hear today).

The National Nanotechnology Initiative (NNI) is the U.S. government's effort to coordinate the nanotechnology research and development activities of the Federal agencies. While nanotechnology is not a new scientific field, it remains an emerging technology. It is my understanding that neither this Subcommittee, nor the full Committee for that matter, has held a hearing focused on the NNI since early 2008, primarily because the House passed an NNI reauthorization bill in both the 110th and 111th Congresses, only to see it die in the Senate. Regardless, much has happened in the past three years, including a new PCAST Assessment and the issuance of a Strategic Plan. This hearing today provides us with an opportunity to get feedback on those documents and have a discussion about national priorities for this technology.

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I look forward to hearing the testimony to be presented today and to the beginning of what I hope is a fruitful discussion on U.S. nanotechnology investments and priorities.Again, thank you for joining us today.

Chairman BROOKS. And now the Chair recognizes Mr. Lipinski for an opening statement.

Mr. LIPINSKI. Thank you, Chairman Brooks, and I want to congratulate you on being made the Chair of this Subcommittee. I served as Chair of the Subcommittee last year. It is a very—we do a lot of important work here. I really think that research is critical, our scientific research is critical to the future of our country, and science education clearly also is critical to our future. So I am looking forward to working with you on the committee, and I think that we can get a lot of good things done, starting today with one of my favorite subjects of nanotechnology.

Not only are nanotech products and science fascinating in their own right, but investments in this area have already resulted in job creation in my state and across the Nation. I firmly believe the potential for return on a relatively modest federal investment is many times what we have already witnessed.

I am fond of saying and have said this countless times here in this committee, that at one point I drank the nanotech Kool-Aid to believe that it really is the next industrial revolution as the Chairman had mentioned. And it may have been when I visited Chad Mirkin's lab at Northwestern University about five years ago. Mr. Moffitt knows it very well. I was amazed by what could be done on the scale of a single atom. In nanotechnology there is now a branch of engineering that simply did not exist 23 years ago when I was getting my degree in mechanical engineering at Northwestern.

By controlling individual atoms we are creating new materials, products, companies, and jobs. It is not just material sciences or semiconductors. Companies like Mr. Moffitt's Nanosphere, which emerged from Dr. Mirkin's lab ten years ago, are succeeding because nanotechnology is helping us understand biology at the cellular level. We are now seeing applications that were not even imagined 11 years ago when the National Nanotechnology Initiative was first created.

The range of potential applications is broad. It will have enormous consequences for electronics, energy transformation and storage, materials, and medicine and health to name just a few.

The Science Committee recognized the problems of nanotechnology early on, holding our first hearing more than a decade ago to review federal activities in the field. The committee was subsequently instrumental in the development and enactment of a statute in 2003 that authorized the interagency National Nanotechnology Initiative, the NNI. As the Chairman said, we have passed three times since the House in 2008 a reauthorization of NNI, and we passed it in a bipartisan manner. Unfortunately, all three times they died in the Senate. Not the only things that did.

But I hope that working together, Chairman Brooks, we will have the opportunity to take up a reauthorization once again this Congress and maybe the fourth time will be the charm.

I do not think that the NNI requires major revisions, but I do think there are opportunities to formalize some of the recommendations we have received in the last few years from PCAST and the

National Academies on how to strengthen the program even further without any additional costs.

Our bill has been about making smarter use of the money we are already spending, not necessarily about spending more. I welcome recommendations from our witnesses today on how we can continue to improve upon the existing program.

I am particularly excited about the Administration's Signature Initiative in sustainable nano-manufacturing, and I look forward to hearing how the agencies are responding to PCAST's recommendations to ensure that this initiative is successful, such as by developing coordinated milestones, promoting strong educational components, and creating public, private partnerships in nano-manufacturing.

I would like to spend my last couple minutes talking about something else. In our invitations to the witnesses we did not ask you to submit testimony specifically on environmental, health and safety, or EHS research. That must be part of any comprehensive nanotechnology research strategy, but hopefully we can engage in some discussion on this topic during the Q&A.

It is important for the successful development of nanotechnology that potential downsides can be addressed from the beginning in a straightforward and open way. We know too well that negative public perceptions about the safety of technology can have serious consequences for its acceptance and use.

I hope to hear from our industry witnesses about their thoughts on this issue, and it is certainly not the purpose of fear mongering. It is for purposes of really clearing up any misconceptions that are out there and making sure that nothing new that we are doing here in nanotechnology is going to have a negative impact on the environment, health, or safety.

The NNI has always included activities for increasing the understanding of these aspects of nanotechnology, but I believe that EHS research did not receive sufficient attention or funding for many years. I am concerned about the lack of a well-designed and executed EHS research program.

I look forward to hearing from Dr. Teague about the strategy that is, I understand is scheduled to be released in the coming days on EHS, and I am looking forward to hearing how it incorporates the comments of experts from both academia and industry.

And on that note I wanted to echo Chairman Brooks in thanking Dr. Teague for his work. He has been with NNI almost since the beginning, and I know that your expertise is going to be missed.

Once again, I am very happy we are having this hearing today, and I look forward to all the witness testimony and the Q&A, and I think you all for being here today and thank you for the extra time here this week.

Mr. Chairman, I yield back.

[The prepared statement of Mr. Lipinski follows:]

PREPARED STATEMENT OF RANKING MEMBER DAN LIPINSKI

Thank you Chairman Brooks, for yielding, but more importantly, thank you for holding this hearing today. It's been exactly three years since the committee last held a hearing on nanotechnology, so I'm happy we're returning to one of my favorite topics. Federal investments in nanotechnology research have already led to job creation in my state and across the nation, and I believe the potential for return on our relative modest federal investment is many times what we've already witnessed.

I'm fond of saying that I "drank the nanotech kool-aid" the first time I visited Chad Merkin's lab at Northwestern. I was amazed by what he could do at the scale of a single atom. In nanotechnology there is now a branch of engineering that simply did not exist 23 years ago when I was getting my degree in mechanical engineering. By controlling individual atoms we can create new materials, products, companies, and jobs.

And it's not just materials science or semiconductors. Companies like Mr. Moffitt's Nanosphere, which emerged from Dr. Merkin's lab 10 years ago, are succeeding because nanotechnology is helping us understand biology at the cellular level. We are now seeing applications that were not even imagined 11 years ago when the National Nanotechnology Initiative was first created. The range of potential applications is broad and will have enormous consequences for electronics, energy transformation and storage, materials, and medicine and health, to name just a few examples.

The Science Committee recognized the promise of nanotechnology early on, holding our first hearing more than a decade ago to review Federal activities in the field. The Committee was subsequently instrumental in the development and enactment of a statute in 2003 that authorized the interagency National Nanotechnology Initiative - the NNI.

We have passed a widely supported, bipartisan update to the NNI bill in the House three times since 2008. Unfortunately, all three times the bill died in the Senate. But I hope, Chairman Brooks, that we will have an opportunity to take up an NNI Reauthorization bill once again in this Congress. Maybe 4th time is a charm?

I don't think the NNI requires major revisions. It seems to be working pretty well. But I do think there are opportunities to formalize some of the recommendations we have received in the last few years from PCAST and the National Academies on how to strengthen the program even further, without any additional costs. Our bill has been about making smarter use of the money we are already spending, not necessarily about spending more. I welcome recommendations from our witnesses today on how we can continue to improve upon the existing program.

Today's hearing is a broad overview of the NNI program and its benefits to our economy and society. I am particularly excited about the Administration's signature initiative in sustainable nanomanufacturing, and I look forward to hearing how the agencies are responding to PCAST recommendations to ensure that this initiative is successful, such as by developing coordinated milestones, promoting strong educational components, and creating public-private partnerships in nanomanufacturing.

But I would like to spend my last couple of minutes talking about something else. In our invitations to the witnesses, we did not ask you to submit testimony specifically on environmental, health, and safety - or EHS - research that must be part of any comprehensive nanotechnology research strategy. But hopefully we can engage in some discussion on this topic during the Q&A.

It is important for the successful development of nanotechnology that potential downsides be addressed from the beginning in a straightforward and open way. We know too well that negative public perceptions about the safety of a technology can have serious consequences for its acceptance and use. I hope to hear from our industry witnesses about their thoughts on this issue. However, this is about more than just perception.

The simple fact is the science base is not now available to pin down what types of engineered nanomaterials may be harmful. We don't yet know what characteristics of these materials determine their effects on living things or on the environment. Nor do we even have standards and measurement tools for the full range of relevant or potentially relevant characteristics.

The NNI has always included activities for increasing understanding of the environmental and safety aspects of nanotechnology. But I believe that EHS research did not receive sufficient attention or funding for many years. While I applaud the current Administration's increased emphasis on EHS, I remain concerned about the lack of a well designed and effectively executed EHS research program. I understand that a new EHS strategy is days away from being released. I look forward to hearing from Dr. Teague about that strategy and how it incorporates the comments of experts from both academia and industry.

Finally, before I yield back, I'd like to express my gratitude to Dr. Teague for his 8 years of service to the NNI and to our country. I learned yesterday that he will be retiring. Tomorrow, I believe. Dr. Teague has been with the NNI almost since its beginning, and I know his expertise will be missed.

Once again, I am very happy we are having this hearing today. I look forward to all of the witness testimony and the Q&A, and I thank you all for being here today. I yield back.

Chairman BROOKS. Thank you, Mr. Lipinski. If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

Now, before I introduce the witnesses, I would like to yield a few minutes to the distinguished Chairman of the Science, Space, and Technology Committee, Mr. Hall of Texas.

Chairman HALL. Thank you very much, Mr. Chairman. I appreciate your good work and your hard work and your long hours of work and your subcommittee, and also I thank you for telling us about Clayton Teague and his history and the long service he has rendered. About 41 years ago I started in public service as a state senator and then 31 years ago I started up here, so we started out about the same time. You look a lot younger than I do, but we thank you.

And this is a very important committee, and this is, I think, nanotechnology and the priorities and the initiatives and everything for the future is very important. It is much more important than these empty chairs here indicate, but we are at an urgent time in this Congress now when we are trying to decide whether to pass a budget or CRs to put the government off and keep them from shutting down. A lot of people just want to let them shut down and forget about it, but I think with the leadership of this Chairman and this Committee you are onto the subject and issue that is very vital to us, and that offers a great, great service to us for the future.

Thank you, Mr. Chairman, for what you do, and thank you all for giving your time it takes to get here and to prepare for a hearing and to get back to your work. God bless you. Thank you.

Chairman BROOKS. Thank you, Mr. Chairman.

At this time I would like to introduce our witness panel. Dr. Clayton Teague is Director of the National Nanotechnology Coordination Office for the National Nanotechnology Initiative.

Dr. Jeffrey Welser is the Director of the Semiconductor Research Corporation's (SRC) Nanoelectronics Research Initiative, or NRI. The SRC conducts research on behalf of the semiconductor industry and the Semiconductor Industry Association or SA—SIA. Dr. Welser is on loan to the NRI from IBM.

Dr. Seth Rudnick is a medical doctor and Chairman of the Board of Directors for Liquidia Technologies, a nanotechnology company located in Research Triangle Park, North Carolina—I might have to ask you about whether you are for NC State, North Carolina, or Duke, I am a Duke guy, so be ready—that develops highly-precise particle-based vaccines and therapeutics for the prevention and treatment of human disease.

Dr. James Tour is a Professor of Chemistry, Computer Science, and Mechanical Engineering and Material Science at the Smalley Institute of Nanotechnology at Rice University.

Mr. William Moffitt is the President and Chief Executive Officer of Nanosphere, Inc., a nanotechnology-based healthcare company offering diagnostic testing technologies housed in Northbrook, Illinois.

As our witnesses should know, spoken testimony is limited to five minutes each, after which the Members of the Committee will have five minutes each to ask questions.

At this point we recognize our first witness, Dr. Clayton Teague, the Director of National Nanotechnology Coordination Office. As I do so, please, everyone should be aware that we are scheduled to have votes before long, and at some point we will have to recess for those votes to be taken, at which point we will resume thereafter.

So, Dr. Teague, the floor is yours.

STATEMENT OF CLAYTON TEAGUE, DIRECTOR, NATIONAL NANOTECHNOLOGY COORDINATION OFFICE (NNCO)

Dr. TEAGUE. Chairman Hall and Chairman Brooks, Ranking Member Lipinski, first of all, thank you for your kind words about my service. It is very much appreciated. It has been my distinct privilege and honor to serve as the NNCO Director.

It is also my distinct privilege to be here with you today to discuss the NNI and the contributions of Federal agencies to sustaining U.S. leadership in nanoscale science, engineering and technology.

For more than a decade, the 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 this field, the NNI has catalyzed remarkable advances in electronics, medicine, energy, manufacturing, and many other areas. 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.

Starting in 2001, the NNI has developed into an engine of innovation that has drawn 25 federal agencies into fruitful collaboration resulting in their investing a cumulative total of over $14 billion in this fast-moving area. The NNI Strategic Plan, which was delivered to you in February, provides a description of how the NNI adds value to all participating agencies.

I want to note at least two things about the plan's inclusion of two new subjects. First, specific objectives for each of the plan's four goals, a first for this strategic plan, and second, three important signature initiatives for interagency focus and alignment of resources.

Agencies are proposing about $300 million in the 2012 budget drawn from their agency budgets for these signature initiatives in order to accelerate progress in areas of national importance.

The President's 2012 budget provides $2.1 billion for the NNI. These investments will advance our understanding of phenomena and nanoscale and enhance many of the things that Chairman Brooks just laid out for us; our ability to engineer nanoscale devices and systems to address areas such as renewable energy, next generation electronics, and sustainable manufacturing.

Let me briefly show you a few examples, and if the slide would come up, of how nanotechnology is revolutionary. One is carbon nanotubes. You can think of them as super-thin sheets of carbon, just one atom thick, rolled into microscopic tubes or straws. They are extremely strong and lightweight and are showing great potential in important structural and electronic applications.

Shown here is an application of carbon nanotube-based materials, the second—go back to the first one, please, to build a large, lightweight, 52-foot long boat that can travel 2.5 miles per gallon. Comparably-sized conventional boats can travel only one-fifth of that distance per gallon of fuel.

In the next slide and in the sample being passed among the committee, you can see a test sample using similar nanomaterials for potential use in bullet-proof vests that have a high resistance to penetration, yet are far lighter than any other currently-available material. Note that in this case a test shot of a high-speed, nine millimeter metal jacketed bullet did not penetrate this sample that is only 1 millimeter thick.

A third example comes from the medical domain where nanotechnology is showing great promise for disease diagnosis, cancer treatment, and drug delivery. This slide shows a novel nanotechnology-based method for revealing the amount of artery-choking plaque inside a blood vessel. Red and yellow represent higher levels of plaque. Low levels are represented in blue and green.

The before and after images illustrate the efficacy of not only the medical treatment but also the imaging tool. Such imaging tools can enable faster and cheaper development of life-saving drugs.

Multiple sources have now 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 with major ramifications for jobs. 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.

The United States is, however, not the only country to recognize the potential of nanotechnology. At least 60 countries now have national nanotechnology strategies with the European Union 27 countries outspending the United States. Perhaps more important the spending increases in some countries such as Russia, China, and South Korea are considerably greater than here in the United States.

A recent analysis of the number of nanotechnology patents, publications, and citations show that our leadership is being strongly challenged. This could put our national security at risk since technological superiority is a foundation of our national security strategy.

I see us now at a crossroads. With 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 United States could fall behind in this extremely important race.

So while the U.S. is currently a global leader in this area of technology, it is crucial that our place—pace of investment be maintained.

I would like to conclude on a personal note. I have interacted with this Committee since 2003, throw five Congresses and two different Administrations. As I leave this post I want to sincerely thank this Committee for all its strong leadership, commitment, and support of federal investments in nanotechnology that you have provided throughout this period.

I will be pleased to answer any questions you may have, and thank you.

[The prepared statement of Mr. Teague follows:]

PREPARED STATEMENT BY DR. E. CLAYTON TEAGUE, DIRECTOR, NATIONAL NANOTECHNOLOGY COORDINATION OFFICE (NNCO)

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)

[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 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)
- 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 . 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 . 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 two-year degrees. In fact, many nanotechnology companies report that they are hiring Ph.D.s 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. , 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 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)
- 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 . 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 . This compares to 2008 U.S. Government spending of $1.55 billion , 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).

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 . 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:

- TFunding basic research in nanoscale science and technology, to keep the pipeline flowing with new innovations for consideration by industry.
- TWorking 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.
- TFunding research on the health and safety aspects of nanomaterials and working with industry to facilitate safety in the workplace.
- TProviding 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.
- TPromoting fair international trade in nanotechnology-enabled products and processes.
- TSupporting the protection of intellectual property both domestically and internationally, i.e., through the U.S. Patent and Trademark Office (USPTO).
- TProviding 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.
- TServing 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.
- TFunding 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.
- TWorking 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.
- TEstablishing 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.

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.

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.
- 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.

Chairman BROOKS. Thank you, Dr. Teague.

Our next witness is Dr. Jeffrey Welser.

STATEMENT OF JEFFREY WELSER, DIRECTOR, NANOELECTRONICS RESEARCH INITIATIVE, SEMICONDUCTOR RESEARCH CORPORATION AND SEMICONDUCTOR INDUSTRY ALLIANCE

Dr. WELSER. Good afternoon. Thank you for inviting me today and for your continued commitment to advancing science and technology, especially as we struggle with difficult fiscal challenges.

Semiconductor chips are in everything from computers and smart phones to medical devices and LED lights. They are making the world around us smarter and more efficient. They are also economically vital to the Nation. In 2010, U.S. semiconductor companies generated over $140 billion in sales, representing nearly half the worldwide market and making semiconductors the Nation's largest export industry.

Our industry directly employs over 180,000 workers in the U.S. and another six million American jobs are made possibly semiconductors. Studies show that semiconductors and the information technologies they enable represent three percent of the economy but drive 25 percent of the economic growth.

Remarkable success in the semiconductor industry is due to continuously technological advances built upon robust research and development. U.S. semiconductor companies invest on average 17 percent of revenues in product-related research and development, among the highest of any industry.

Just as critical, however, is long-term fundamental science research, which is largely performed at universities funded by the Federal Government. The university research supplies the knowledge from which all companies benefit and which no one company can afford alone. Publicly-funded long-term research and privately-funded product-related research are different, yet complimentary.

We are now in the cusp of an exciting new era enabled by nanotechnology. NNI has played a key role over the past decade in accelerating progress in many scientific disciplines. In the coming decade the NNI should be called upon and authorized to maintain U.S. leadership by continuing the broad discovery work while coordinating federal efforts in areas of promise both for scientific breakthroughs and large economic impact. One of these areas, nanoelectronics, is key to the future of the semiconductor industry.

We are quickly approaching the fundamental limits of current semiconductor technology. We need to find entirely new devices to continue advancing technology, and this will require new discoveries in the fundamental science that NNI supports.

Hence, maintaining funding in nanoelectronics research has never been more important for the economy, for high-paying jobs, and for the Nation's ability to innovate and compete globally. The nation that is first to discover and develop the necessary nanotechnologies, that is the next switch, will lead the nanoelectronics era just as the U.S. has led the microelectronics era for the past 50 years. Countries around the world recognize this and are investing accordingly. Continued U.S. leadership is far from assured.

To attack this challenge the SIA and SRC form the Nanotechnology Research Initiative (NRI), a public-private program that funds research at universities in partnership with federal and state agencies. NRI supports goal-oriented, fundamental research across many scientific fields and strives to harvest the results quickly. Two federal agencies, NIST and NSF, are key partners in NRI. Robust budgets of these agencies and other research agencies that support nanoelectronics are critical.

Beyond the research breakthroughs, funding university scientific research educates our technology workforce. A pipeline of science and engineering graduates is critical to keeping and growing the businesses that will rebuild the economy. Indeed, several states are supporting NRI as nanoelectronics offers an opportunity to grow a new industry around their university base.

I have a few recommendations for strengthening the NNI and ensuring U.S. leadership in nanoelectronics. First, Congress should reauthorize the NNI and in particular support the Signature Initiative on Nanoelectronics for 2020 and beyond. Congress should adequately fund the participating agencies and ensure they prioritize nanotechnology research when facing difficult budget choices.

Second, NNI agencies should coordinate and leverage investments of industry consortia and states to get the most out of every dollar spent.

Third, in other areas of nanotechnology research topics with broad, long-term economic potential should have priority. We also encourage NNI agencies to form additional public-private initiatives like the NRI.

I want to close with this point. NNI funding of nanoelectronic research produces the new ideas, as well as the talented scientists and engineers critical for driving America's innovation economy and for solving society's biggest challenge in medicine, security, and energy. The nanoelectronics industry will be in the U.S. only if we choose to support the research necessary to discover these new technologies first.

Success will only come from the combination of the best science from the universities, the mission focus of the industrial and government labs, and consistent funding from the government for the fundamental science and from industry for translating these breakthroughs into new products.

In the five minutes I have been talking to you the semiconductor industry made over 600 trillion transistors. Silicon Valley grew from innovation built on federal research. What companies will populate the new Nanoelectronics Valley? The question is not whether this place will exist but where it will be.

I thank you and look forward to answering your questions.

[The prepared statement of Mr. Welser follows:]

PREPARED STATEMENT BY DR. JEFFREY WELSER, DIRECTOR, NANOELECTRONICS RESEARCH INITIATIVE

Introduction

My name is Jeffrey Welser and today I'm testifying on behalf of the Nanoelectronics Research Initiative (NRI), Semiconductor Research Corporation (SRC), and Semiconductor Industry Association (SIA). I'd like to thank Chairman Brooks, Ranking Member Lipinski, and other members of the Subcommittee on Research and Science Education for inviting me to testify before you. Thank you for your commitment to science and technology and nanotechnology advancement. Your Committee's role in providing a vision that ensures the technological leadership needed to drive economic growth to build America's future has never been more important than it is today, when we are faced with an unprecedented fiscal challenge which will require difficult decisions in every area of Federal spending.

Your Committee fostered the ecosystem that enabled innovation-driven economic growth and high tech job creation in the past. By insuring we are spending limited Federal resources wisely to maintain that ecosystem, you will also enable entire new industries for the 21st Century. The subject of today's hearing, nanotechnology research, is a foundation for those future industries.

In a time of limited resources, it is crucial to insure adequate support for those areas of research that have proven to be drivers of the economy and job growth broadly and long-term. I come here today representing major organizations in the area that has arguably been the most important driver of the U.S. economy over the past half-century, built on America's world-leading research and university capability: semiconductor electronics—or as they are commonly referred to, chips.

The Nanoelectronics Research Initiative (NRI), which I direct, is a consortium that supports university research in novel computing devices with the goal of enabling technology advances that will carry the semiconductor industry beyond the approaching limits of the current silicon-based technology. NRI leverages industry, university, and government funds (local, State, and Federal) to support research at U.S. universities, driven by industry needs, to ensure that the United States will be the world leader in the nanoelectronics revolution, reaping the economic and security benefits that leadership provides.

Semiconductor Research Corporation (SRC) is the premier industry consortium that invests in university research to solve the technical challenges facing the semiconductor industry and to develop technical talent for its member companies. SRC and its subsidiaries manage several semiconductor research programs, including NRI. Since its founding nearly three decades ago, SRC has managed in excess of $1.2 billion in research funds, supporting nearly 9,000 students and 2,000 faculty at 257 universities, resulting in more than 50,000 technical documents and 373 patents. In 2007, SRC was awarded the National Medal of Technology with a citation recognizing the unique value of this organization: "For building the world's largest and most successful university research force to support the rapid growth and 10,000-fold advances of the semiconductor industry; for proving the concept of collaborative research as the first high-tech research consortium; and for creating the concept and methodology that evolved into the International Technology Roadmap for Semiconductors."

The Semiconductor Industry Association (SIA) is the voice of the U.S. semiconductor industry, America's largest export industry over the last five years and a bellwether of the U.S. economy. Semiconductor innovations form the foundation for America's $1.1 trillion dollar technology industry affecting a U.S. workforce of nearly 6 million. Founded in 1977 by five microelectronics pioneers, SIA unites more than 60 companies that account for 80 percent of the Nation's semiconductor production. SIA seeks to strengthen U.S. leadership in semiconductor design and manufacture by working with Congress, the Administration and other industry groups. SIA works to encourage policies and regulations that fuel innovation, propel business and drive international competition in order to maintain a thriving semiconductor industry in the United States.

Executive Overview

The U.S. technology-based economy in general, and the semiconductor industry in particular, relies heavily on the pipeline of new scientific ideas, breakthroughs, and highly-trained students that can only come from the broad research enabled by consistent Federal funding of the U.S. university system. Within that spectrum of research, the National Nanotechnology Initiative (NNI) has played a key role in accelerating progress at the leading edge of nanoscale science and engineering-an area that is critical to the future of the semiconductor industry. As you consider the NNI and its future, the main points that I want to leave you with are as follows.

1. Nanoelectronics is a priority for the economy, for high paying jobs, and for the nation's ability to innovate and compete in the future. As Congress works to reduce the Federal deficit, it must give priority to those expenditures that create the long term economic growth and jobs that will expand our tax base and raise our standard of living.
2. Strong university research correlates geographically with leading edge technology development and flourishing technology businesses. If the United States is to lead in nanoelectronics, it needs a robust university research effort in nanoelectronics. Government and private sector funded university research should be done in a coordinated or, better yet, collaborative manner.

3.The electronics industry is facing a challenge similar to the 1940s, when vacuum tubes were replaced by semiconductor chips. The nation that is first to discover and develop the key nanotechnologies-i.e., the next logic "switch"-will lead the nanoelectronics era, much like the United States has led the microelectronics era for the past half century. This fact is recognized by countries around the world and U.S. leadership is far from guaranteed.

4.NRI is an industry-driven consortium that funds a coordinated program of university research in partnership with Federal and State government agencies. Thanks in large part to NRI, the United States is the current leader in nanoelectronics at this early stage. But the challenges are great and the global competition is growing.

5.Funding university scientific research educates our technology workforce. A pipeline of science and engineering graduates is critical to growing and keeping the very businesses that will help to rebuild the economy. Funding for the NNI and other scientific research ensures the pipeline is adequately filled. NRI-funded students also have meaningful interactions with industry mentors, which enhance their education, expose them to career opportunities, and allow them to contribute productively once they graduate.

Recommendations for strengthening the NNI and ensuring the United States' leadership in nanoelectronics:

1.The Federal government should continue its support for the National Nanotechnology Initiative, especially in the "Signature Initiative" on long-term nanoelectronics research.

2.Congress should reauthorize the NNI and the participating agencies, to make clear its desire to see nanotechnology research remain a priority by the agencies that fund science and engineering research today.

3.The NNI agencies that are part of the nanoelectronics Signature Initiative should leverage each other's investments and those of NRI, to get the most out of every dollar spent.

4.The participating agencies should develop interdisciplinary nanotechnology initiatives that are supported by multiple NNI agencies and that support significant national priorities (as outlined in the NNI Supplement to the President's Budget for 2012, the 2011 NNI Strategic Plan and as called for by PCAST in its 2010 assessment of the NNI).

5.In choosing research priorities, NNI agencies and the interagency coordinating bodies should give strong consideration to the potential long-term economic impact of the research area, with key positive indicators being:

(a) Support of a broad research agenda that will create enabling breakthroughs for a large market segment, rather than choosing to focus on just one or two specific technologies

(b) SEarly engagement of industry to facilitate rapid transfer of knowledge and ideas from university scientific research into the hands of those who can use them in commercial applications.

Federal investment in Nanoelectronics research is priority for continued U.S. economic growth

Nanotechnology is the understanding and control of matter on the scale of atoms and molecules. Nanotechnology is making it possible to build machines on the scale of human cells and create materials and structures from the bottom up, building in desired properties.

Nanotechnology and research supported by the NNI is impacting many industries, but I would like to highlight the enormous impact the investment in nanoelectronics in particular could have on the future of the semiconductor industry and the potential scale of that impact on the U.S. economy.

Semiconductor industry of today

From its beginnings in the 1940s, the semiconductor industry has grown to become the largest U.S. exporter over the last five years (see Appendix 1a). In 1980, worldwide semiconductor revenues were under $20 billion. This year that figure will exceed $300 billion. American semiconductor companies alone generated $144 billion in sales—representing nearly half the worldwide market in 2010. In the United States, there are 182,200 jobs directly associated with the domestic semiconductor industry and the average annual salary is $99,622.

The remarkable growth in semiconductor jobs and revenues through the years has been made possible by continuous technological advances based on the semiconductor transistor; it is the "switch" that creates the ones and zeros in our digital world and is the fundamental building block in electronics. Transistors are in the "chips" that permeate modern life, enabling computers, smart phones, the internet, national defense applications such as night vision goggles and unmanned aircraft, video entertainment, automobile systems such as antilock brakes and traction control, medical imaging devices, factory robotics, and countless other uses (see Appendix 2b). Advances over the last 60 years have led to smaller and smaller transistors, which in turn have enabled dramatic increases in performance and function, and decreases in cost. The increase in the number of transistors per computer chip (or decrease in the size of an individual transistor) by a factor of two approximately every 18 months is known as "Moore's Law".

The ability to make chips smaller, better, and cheaper has had enormous economic impact beyond the semiconductor industry itself. For example, semiconductors enable 6 million jobs in the U.S. including software engineers, network administrators, home entertainment system installers, medical imaging technicians, ATM service personnel, and desktop publishers. This figure does not include all of the jobs that are made more productive by IT-pharmacists who check drug interactions, real estate agents who use computer listings and virtual tours, and on-line retailers, to name just a few. Harvard economist Dale Jorgenson has noted, "The economics of Information Technology (IT) begin with the precipitous and continuing fall in semiconductor prices." Professor Jorgenson attributed the rapid adoption of IT in the United States to driving substantial economic growth in the nation's gross domestic product since 1995, concluding, "*from 1995–2005], Information Technology industries have accounted for 25 percent of overall economic growth, while making up only three percent of the GDP (see Appendix 3b). As a group, these [IT] industries contribute more to economy-wide productivity growth than all other industries combined." [1]

The phenomenal advances in semiconductor technology and the ability of the U.S. industry to remain the world leader flows from the unique U.S. "innovation ecosystem", comprising university, industry, and government scientists and engineers performing a range of complementary research and development activities. On the industry side, U.S. semiconductor companies invest an average of 17% of revenues in product-related R&D, which totaled about $25 billion in 2010. This is one of the highest percentages for any industry. Coupled with capital expenditures of 11% of sales, our industry invests nearly 30% of its revenues to drive future growth. Even in the midst of decreasing revenues in the recession, SIA member companies sustained their R&D investments.

Whereas industry carries out primarily near-term research and development, the long-term fundamental science research that underpins new technologies is largely performed at universities that are funded principally by the Federal government. University or "basic" research adds to the body of knowledge from which all companies benefit and which no one company can afford alone. In addition, university research is the means by which scientists and engineers are educated and trained for careers in technology. University research and education are inextricably linked; one would not exist without the other.

The Federal government also funds scientific research to meet its own needs, for example in the area of national security, often paying a premium to be the first customer. But in multiple instances, such investments have led to whole new industries. As noted by the President's Information Technology Advisory Council, "Since World War II, the Federal government has funded advanced information technology research to meet its own requirements, which have ranged from critical national-defense applications to weather forecasting and medical sciences. Federal funding has seeded high-risk research and yielded an impressive list of billion-dollar industries (the Internet, high performance computers, RAID disks, multiprocessors, local area networks, graphic displays, etc.)." [2] The Federal government played a similar role in the area of semiconductors, funding the development of early integrated circuits for missile and other space applications where the weight of the current electronic technology was prohibitive.

Unique among all industries, the semiconductor industry has taken steps to connect its internal science and engineering research to the academic sector by forming and funding the Semiconductor Research Corporation (SRC). Through SRC, the industry supports university research that is pre-competitive; totaling $240 million from 2005 to 2010. SRC includes several research initiatives that address different

[1] Dale W. Jorgenson. "Moore's Law and the Emergence of the New Economy" in "2020 is Closer than You Think"; 2005 SIA annual report.

[2] Information Technology Research: Investing in Our Future, President's Information Technology Advisory Committee Report to the President, February 24, 1999.

aspects of the industry's long term research needs. SRC brings together industry and academic experts thereby insuring feedback during the course of the research and technology transfer. In the process, SRC supports 1500 students annually.

Nanoelectronics industry of tomorrow

The semiconductor industry by any measure has been hugely successful. But today's transistor technology is approaching fundamental physical limits that will prevent further improvements; and technological and economic advancement that has been fueled by Moore's Law for the last fifty years could slow to a trickle. You might ask, "Why do we need even more capable technology?" Imagine a future in which a child with diabetes no longer has to prick her finger to check her glucose or get insulin shots thanks to an implanted artificial pancreas; when smart tools and sensors enable a highly efficient electric grid that saves billions of dollars in wasted energy costs and avoids the need for new power plants based on non-renewable energy; or powerful systems to design and manufacture new materials for radically lighter, yet safer, cars and planes. Each of these is a grand challenge for science and engineering, but underlying them all are nanoelectronics-the devices that will make our future world smart and efficient, and without which many solutions will remain out of reach.

In addition to commercial applications, there are countless benefits to U.S. national security. "Taking nanotechnology seriously could single-handedly change the future for the better," wrote Dr. James Carafano of the Heritage Foundation in a recent op-ed. "Washington can build a military with cutting-edge capabilities at affordable cost, while laying the groundwork for a U.S. nanotechnology industry."

Many of today's IT products and infrastructure were enabled by early-stage research at the Department of Defense (DoD) decades ago. "Today's iPads and iPods are descendents of the chips created for the Minuteman," concludes Carafano.3 3 James Jay Carafano: U.S. must gird for war in very small places. Washington Examiner. December 12, 2010.

In fact, we are in a race to find a replacement technology for the transistor-to address technological needs and challenges, and to do so first. U.S. researchers made the discoveries that led to the microelectronics industry, thanks to early support for research and development by the Federal government. The United States continues to dominate the development of new technology, due in large part to continued Federal support for scientific research. But today, many other countries have made it a goal to attract and build semiconductor businesses. When faced with generous financial incentives to locate not only manufacturing but also research facilities overseas, one factor that is in favor of locating operations in the United States is access to the best university faculty and student researchers.

Cutting funding for agencies that participate in the NNI neutralizes one of the main reasons why companies that will rely on nanotechnology advances stay in the United States. It cuts funding for current students and discourages future ones. And it threatens American leadership in an industry that seemingly every nation is doing its best to see take root within their own borders.

Nanoelectronics will create future jobs, contribute to budget deficit reduction

As Congress works to create high-paying jobs and reduce the Federal budget deficit it must give priority to expenditures such as nanoelectronics research that create long term economic growth and greater productivity. As mentioned above, today's semiconductor technology enables 6 million U.S. jobs directly and many more indirectly. Semiconductor technology has made computing and communications faster and less expensive, and nanoelectronics will continue these trends. Leadership in nanoelectronics research will allow U.S. companies to be first to market, creating entirely new industries and categories of jobs throughout the manufacturing and service economy. If the past is an indication of the future, nanoelectronics will contribute significantly to GDP, thereby expanding the tax base and helping to reduce Federal deficits.

While it may be tempting to cut Federal nanotechnology research budgets as part of an overall reduction in the Federal deficit, such across-the-board, arbitrary reductions would be shortsighted. Continued support for nanoelectronics research should instead be seen as an important element in any long-term Congressional Federal budget deficit reduction strategy.

NRI is leading the way in collaborative research in nanoelectronics

The Nanoelectronics Research Initiative (NRI) is a consortium within the SRC that leverages contributions from industry, universities, and governments (local, State and Federal) to fund collaborative research at thirty-five U.S. universities (see Appendix 4d). NRI is focused on the key challenge for continuing the progress in semiconductor electronics which has fueled the world economy for the past 50 years: finding the next "switch" and thereby keeping the United States at the forefront of the nanoelectronics revolution.

NRI funds multi-disciplinary research in physics, chemistry, materials science, and engineering that addresses fundamental problems standing in the way of progress toward "real world" applications. The consortium is open to any U.S.-based company and potentially useful technologies that emerge are efficiently shared with all team members. NRI not only funds the university research, it coordinates among the universities and between industry and academia, avoiding duplication and encouraging collaboration.

NRI research is extremely early stage, and like most scientific research, it is unlikely to become part of a commercial product for ten years or more. Such long-term, high-risk research is typically funded by the Federal government. Yet NRI industry members (GLOBALFOUNDRIES, IBM, Intel, Texas Instruments, and Micron Technology) contribute millions of dollars each year because of the importance of the research to their long-term future. They also dedicate company researchers to work alongside the university researchers, helping to accelerate progress even at the beginning stages of the research and to insure strong technology transfer paths are in place for the future.

NRI is partnering with the Federal government

In addition to having members from industry, NRI partners with Federal agencies whose missions align with NRI's. The National Institute of Standards and Technology (NIST), which has a mission to promote U.S. innovation and industrial advancements, co-funds the university research and contributes in-house resources (staff and facilities). The National Science Foundation (NSF) is the primary funding agency of physical science and engineering university research and funds a number of Nanoscale Science and Engineering Centers related to nanoelectronics. NRI provides additional support and engages Center researchers in annual reviews and web-based workshops and seminars. In 2011, NSF and NRI will jointly fund about 10 nanoelectronics research teams that meet the selection criteria of both organizations. All of these partnerships have been enabled by the strong support and focus the NNI has brought on to nanoelectronics.

The NRI partnerships with NIST and NSF make sense. Without Federal funding for scientific research, there would be devastating consequences for the NRI mission. And bringing together industry, university, and government scientists and engineers benefits all parties. University researchers are more aware of the diverse, longer-term challenges faced by industry. Industry stays abreast of academic research and develops relationships with top-notch faculty. Government scientists and program managers understand future industry needs and can thereby enhance the value of their own research missions.

In addition to jointly funding research with NRI, the Federal government has built and maintained the world's best university system through the NNI and its broader research initiatives. American research universities produce graduates with advanced degrees who lead the world in innovation-creating new products, new businesses, and even new industries. NRI's modest and targeted investments are effective-and in fact are only possible-because of the ongoing Federal support for university research broadly. Sustained Federal support for science and engineering research is absolutely vital if government-university-industry initiatives like NRI are to succeed.

Technology transfer is built into NRI

A benefit of NRI is the seamless transition of research results from the university researchers to NRI member companies. Because industry has "skin in the game", industry representatives are more engaged-providing feedback during the course of the research and taking results back to others in the company. In addition, as students graduate and are hired, they bring with them detailed understanding of the research. This approach has worked well. NRI is hopeful that agencies that support nanoelectronics research in addition to NIST and NSF will also elect to join.

Supporting research supports education and workforce development

In fact, NRI has two primary outputs, both of which are valuable to member companies and to the greater science and technology enterprise. One output is the research results, which researchers are allowed to make public and disseminate broadly. The other is the students who perform the research as part of their studies and who are highly sought after as employees upon graduation. Graduates are well prepared and are able to contribute to nanoelectronics research and development once hired.

NRI-funded students are not obligated to take a position with a member company, although many do. NRI graduates also take positions as university or government researchers, or in other parts of the private sector. Through its publications, presentations, and graduates, NRI is benefiting a much larger segment of the U.S. economy than just its members.

NRI and NNI leading edge science and engineering research produces new ideas and people that are critical to American innovation in the critical area of nanoelectronics.

SRC and SIA applaud the NNI Signature Initiative on "Nanoelectronics for 2020 and Beyond"

NNI has taken steps to focus some of its investments in areas of potentially high impact. The 2011 NNI Strategic Plan includes a goal to, "develop at least five broad interdisciplinary nanotechnology initiatives that are each supported by three or more NNI member agencies and support significant national priorities." In addition, NNI identified nanoelectronics as one of its Signature Initiatives in the 2011 and 2012 budget requests.

We are pleased that the NNI agencies recognize that the field of nanoelectronics has the potential for significant economic contributions. As the leading nanoelectronics research entity, we look forward to working with other "target agencies", in addition to NSF and NIST, to coordinate and collaborate on research that will provide the greatest value and lead to the greatest progress.

Finally, we appreciate the recommendation by the President's Council of Advisors on Science and Technology (PCAST) in its 2010 assessment of the NNI that the, "Federal Government should launch at least five government-industry-university partnerships, using the Nanoelectronics Research Initiative as a model." We trust that this is also a recommendation for continued participation in NRI.

Other factors influencing the U.S. semiconductor industry's ability to compete internationally

While providing Federal funding for pre-competitive nanoelectronics research will enable the industry to compete tomorrow, there are a number of additional immediate challenges to maintaining U.S. leadership in semiconductors today. The industry depends on a highly skilled workforce and therefore improvements to the STEM education system are necessary in the long-term. In the short-term, we must reform our immigration system to allow bright foreign nationals that graduate from U.S. universities in STEM fields to stay here after they graduate. These innovators create jobs for Americans as they develop small businesses or create entire new product lines. Tax and regulatory policies are equally important factors that businesses consider when deciding to expand operations and add jobs.

Throughout the world, governments have identified the semiconductor industry as a strategic industry because of its implications on economic growth, societal welfare, and national security (see Appendix 5e). These same governments have implemented policies and structured investment incentives with the aim of significantly growing semiconductor manufacturing and R&D in their countries.

Conclusion

Our nation faces a challenge that can be compared with the transitions that occurred from vacuum tubes to the transistor and on to integrated circuits and to large scale semiconductor systems. The United States led the semiconductor industry through these challenging transitions. We led because of our public and private research strengths and our formidable university research infrastructure. It required substantial investment of Federal funds to create the first semiconductor diode, initially for military use. Those investments launched the entire IT industry, which has driven the economy ever since. We led because entrepreneurs incorporated this research into products that created new industry segments. And the Federal government played a critical role all along the way.

Today, the U.S. semiconductor industry has nearly fifty percent of the $298 billion worldwide market share. Sustained research funding, along with sensible tax, trade, workforce, education, and regulatory policies are all factors that influence the semiconductor industry's ability to compete internationally.

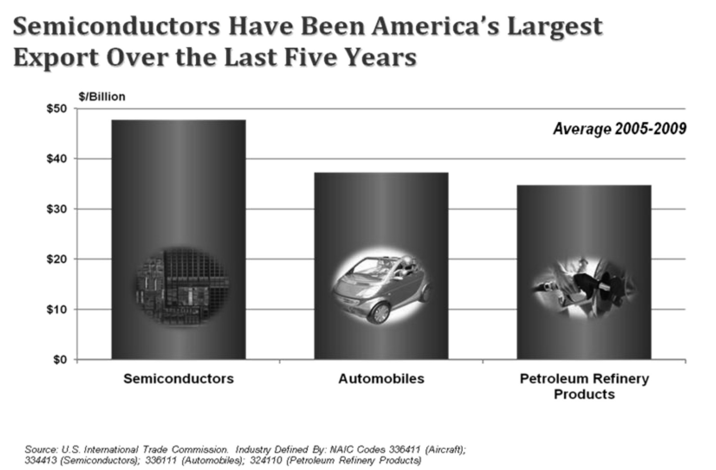
In a globalized economy, research must begin far in advance of the technological transitions we will encounter. Luckily, we know the broad outline of some of these challenges, and by funding research in nanoelectronics, Congress will lay the bedrock for new U.S. jobs and industries of the future, much like those that were enabled by the transistor age. We are creating something wholly new with untold potential, and this research is taking place here in this country through the NRI and other SRC programs, our public-private partnerships, and nanoelectronics focused programs at NSF, NIST, DoD and the Department of Energy.

Future nanoelectronics-enabled products will be designed and manufactured in the United States if we choose to be the region that discovers and markets these new technologies first. The latter is largely dependent upon making strategic choices today and acknowledging that nanoelectronics infrastructure and scientific research provide our nation the best return on its tactical and strategic economic investments.

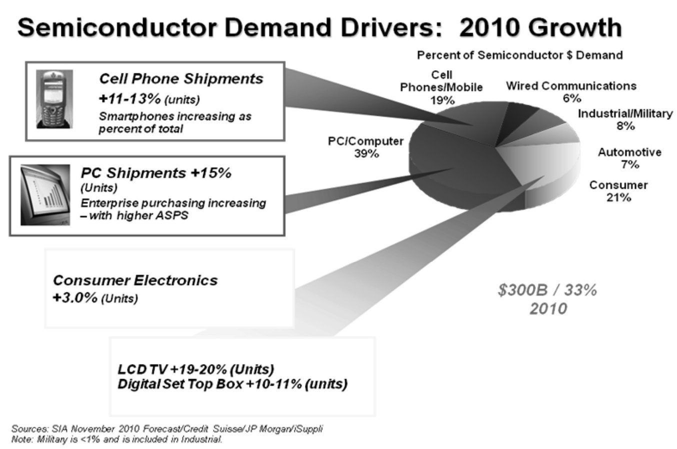
In the middle of the last century, Silicon Valley grew from innovation built on Federal research. What are the names of the companies that will dot the horizon of the new "Nanoelectronics Valley?" The question is not whether this place will exist, but rather where will it be.

Appendix

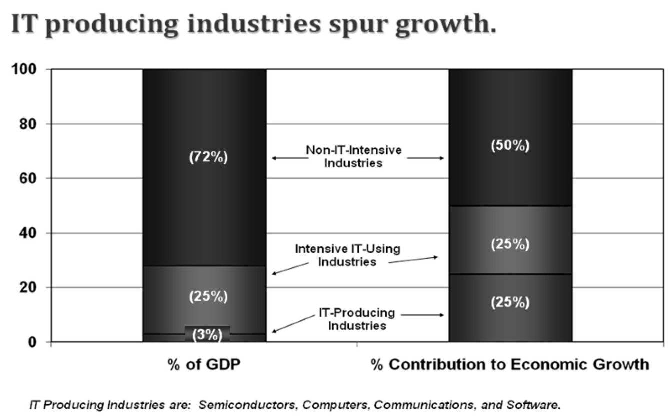
1a)



2b)

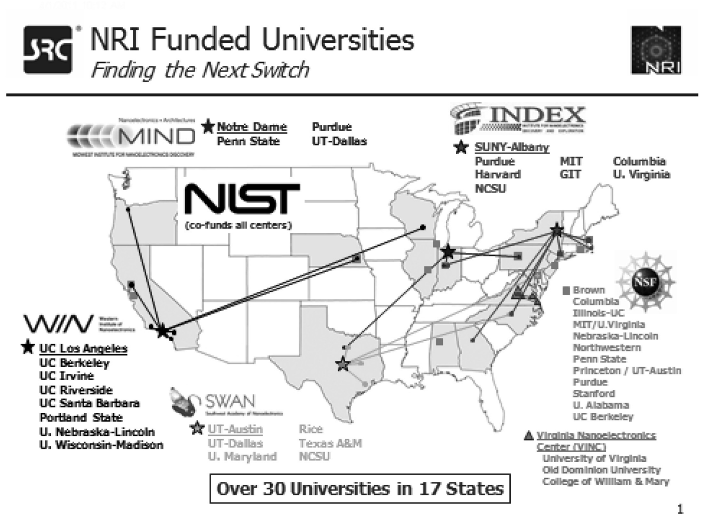


3c)



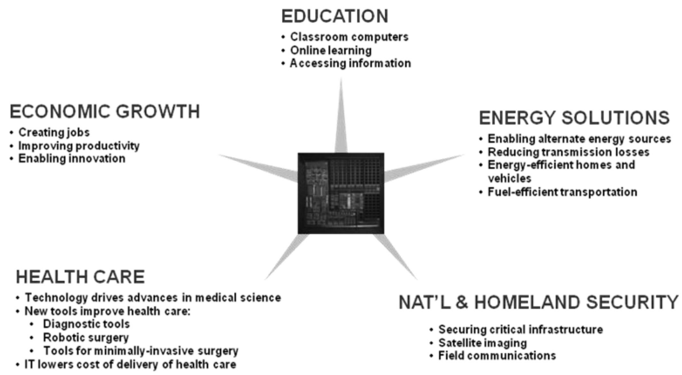
Source: Based upon Dale W. Jorgenson (Harvard University). "Moore's Law and the Emergence of the New Economy" in "2020 is Closer than You Think"; 2005 SIA annual report.

4d)



5e)

Semiconductors - Driving Innovation, Shaping The Future



Chairman BROOKS. Thank you, Dr. Welser.
Next we have Dr. Seth Rudnick.

STATEMENT OF SETH RUDNICK, CHAIRMAN, BOARD OF DIRECTORS, LIQUIDIA TECHNOLOGIES

Dr. RUDNICK. Mr. Brooks, Mr. Lipinski, thank you very much for allowing me the opportunity to address the committee and talk about nanotechnology and as you can guess as a physician I am going to direct most of my discussion to medicine.

You have heard that substantial funds have been addressed to many different agencies which have, in turn, affected many different companies and products around the United States and the world. It is a huge and growing part of our economy, and I am going to talk about that little red corner that is medicine.

In nanotechnology medicine has transformational impact, and by that I mean the ability to change the way we address disease, the way we treat disease, the way we diagnose it, and the way we prevent it. Therapeutics that ran from targeted delivery of drugs, to cancer, to avoiding particular toxicities of drugs by changing the way they traffic through the body, all of that has been already proven by new nanotechnology drugs, some of which are actually on the market today. Ultimately our goal is always to increase safety in efficacy, and nanotechnology is a lever, a very important lever in doing that.

There are other areas, including the prevention of disease, that I think are equally well addressed, vaccines being a primary example of that. Nanoparticles are synthetic carriers. They allow particular areas of the body to be inoculated with antigens and adjuvants, potent ways of getting the body to recognize a particular viral or bacterial disease and treat it. This is a next generation of biotechnology. It is, again, already in the clinic and, in fact, my company, Liquidia, has had its first safe clinical trial completed late last year.

We believe that not only will we be able to be safer and more effective, but the ease of manufacturing using technologies that, in fact, derived from microelectronics are an important part of driving the costs down such that vaccines will be far more useful to the third world and not just the first world.

You will hear more about diagnostics and imaging from one of the other speakers, but the ability to rapidly detect new disease, to multiplex, to look at large numbers of population markers, and to identify the risk of disease early is something that is critical to medicine and is being transformed by nanotechnology.

The reason that nanotechnology has become so useful in medicine is because the scale of nanotechnology is now addressing biologically-relevant sizes. In the 1970s nanotechnology, which is microelectronics at that point, was addressing scale at the red blood cell size. Today we are already down to the molecular size, and we have passed through bacterial and viral sizes during this last two decades.

By being able to address and traffic those areas we now understand mechanisms of disease that were heretofore untouchable. But not only did we need to address these, we needed to be able to manufacture something that could address these at the proper scale, and that ability to take the etching off a semiconductor plate, put it onto a film, and manufacture at the scale that a newspaper press operates at or a photo film press operates at, which is many thousands of feet per hour, has led to Liquidia's manufacturing. And again, I was going to use the hundreds of trillions analogy, but that one piece of film that is in the lower right corner actually represents hundreds of trillions of vaccine particles that can be used that are treating disease.

I would like to tell you that we, in fact, now have the ability to address almost every size and shape based on the microelectronics etching of particles down to 30 nanometers, 40 nanometers, right at the edge of what microelectronics can etch. This is a representation of a series of shapes that we use in research, or in treatment, or in diagnostics. You can see that many of these shapes actually incorporate multiple colors, and those represent different drugs, different adjuvants, or different antigens that are being administered for a particular disease.

We can change the softness or hardness, the modulus or the porosity. We can change how particles actually float into the lung. You can see over in the right-hand side of that slide particles that look just like pollen. All of this is enabled by technology that has actually originated out of the NNI.

There is one regulatory agency that is quite used to handling nanotechnology. You may be aware that the Food and Drug Administration (FDA) has approved drugs in this field, has looked at diagnostics in this field, and has had an incredibly-positive interaction with not only our company but many companies in trying to move this technology forward, and as an example, the recent clinical trial that we completed was done in a year and a half from concept to first therapeutic intervention. I think the FDA has shown its ability to handle the technologic challenges of nanotechnology and done so in a very positive fashion with industry.

I would like to thank all of the agencies out of NNI that have contributed to the University of North Carolina. To answer your question I am a heel, but we appreciate greatly the opportunity to speak here today and to have—answer questions as they arise.

[The prepared statement of Dr. Rudnick follows:]

PREPARED STATEMENT BY SETH RUDNICK, M.D., CHAIRMAN, BOARD OF DIRECTORS, LSIQUIDIA TECHNOLOGIES

Key Points of Testimony

Commercialization of Nanotechnology

- The investment in nanotechnology by the NNI and private industry has confirmed that nano-enabled products are a means to solving some of humanity's most vexing challenges and a critical driver of future economic growth.
- To translate this investment into viable products and new industries, manufacturing R&D must go hand-in-hand with scientific discovery to ensure that U.S. manufacturers can quickly transform innovations into processes and products.
- Due to the historic emphasis on funding and commercialization of inorganic nanomaterials, there is an even larger gap to commercialization for nanotechnology in life science applications.
- Nanomedicine technologies have tremendous potential for transformational results—disruptive changes over and above current methods and strategies

for healthcare, with wide-ranging implications on how we detect, prevent and treat disease. To maintain the dominant position of the U.S. in healthcare innovation and quality of life, we must close the gap from proof-of-concept to commercial viability for nanomedicine platforms.

- Nanotechnologies must be brought to market responsibly; meaningful nanoparticle standards to assess physio-chemical properties of nanomaterials for environmental and health implications are necessary for sustainable product development.

Recommendations

- Increase the support of nanomanufacturing initiatives. We are in strong agreement with the PCAST recommendation to increase the focus on nanomanufacturing to accelerate technology transfer to the marketplace.
- Ensure that nanomedicine platforms are included within the Signature Initiatives of the NNI.
- Support the development of reference materials, test methods, and other standards that provide broad support for industry production of safe nanotechnology-based products. We strongly support the establishment of a "particle foundry" to meet these needs.
- Strengthen the NNCO to ensure the breadth of investments and advancements in nanotechnology R&D are translated into viable commercial products.

Liquidia's PRINTr nanotechnology platform

- The proprietary PRINT nanofabrication technology was pioneered at the University of North Carolina and is being commercialized by Liquidia Technologies, a small venture-backed company in Research Triangle Park, North Carolina.
- The PRINT technology offers unprecedented control of particle size, shape and chemistry in a highly consistent and scalable roll-to-roll manufacturing process.
- Liquidia is currently focused on commercializing applications in vaccines, inhaled therapeutics and oncology. The company's first product was successfully introduced into Phase 1 clinical trials in Q4 2010.

Written Statement

We are in strong agreement with the general recommendations by PCAST focused on Program Management, Outcomes and EH&S. In particular, strong leadership through the National Nanotechnology Coordination Office (NNCO) is needed now more than ever to coordinate the broad investments and outcomes and to ensure the investments in nanotechnology innovation can be successfully transformed into commercial products. Liquidia's current efforts towards commercial implementation of our nanotechnology platform is the direct result of the strong support that the NNI has received to date.

Let us summarize what we have been able to accomplish as a direct result of our previous support from various agencies through the NNI as well as provide some thoughts and refinements regarding specific aspects of the PCAST recommendations.

Introduction to Liquidia's PRINT Nanotechnology Platform

Many innovations have emerged from the NNI to date, especially at the interfaces between disciplines. Indeed our particular nanofabrication innovation has been to co-opt the lithographic manufacturing technologies from the microelectronics industry and apply them to making new vaccines and medicines. This work was pioneered in the Department of Chemistry at the University of North Carolina at Chapel Hill (UNC) and Liquidia Technologies, Inc., a start-up company spun out of UNC (www.liquidia.com). The technology trademarked as PRINT (Particle Replication in Non-wetting Templates) marries the slow, yet highly precise batch based process used to make integrated circuits with the volume production of the film and printing industry. This creates a proprietary, US-based roll-to-roll manufacturing process useful for making vaccines and therapeutics that are in nanoparticle form. The PRINT manufacturing platform offers unprecedented control of particle size, shape and chemistry in a highly consistent and scalable roll-to-roll manufacturing process. The UNC team is funded by NIH, NCI, NSF, DOE, DARPA and ONR and the Liquidia Team has been largely venture financed (Canaan, NEA, and others) with a few significant grants awarded from NIST ATP and TIP programs. Just recently, Liquidia received the first ever equity investment by the Bill and Melinda Gates Foundation in a for-profit biotech company. Liquidia has a focus in vaccines (influenza, malaria, cancer, etc), respiratory diseases (COPD, PHT, CF, Asthma) and oncology, and successfully introduced its first product into Phase 1 clinical trials in Q4 2010. As such, we believe PRINT is the first nanotechnology platform that is now cGMP compliant.

Specifically for nanomedicine, the ability to manipulate size, shape, chemistry and modulus of nanomaterials can have wide-ranging impact on how we diagnose and treat disease. New abilities to tune these features can provide researchers with a more thorough understanding of "how" and "why" cellular and organ systems react, allowing scientists to build highly efficient tools that can safely operate inside the body. New technologies that have the power to control size, shape, and other functionalities are currently being developed and have shown remarkable promise, but significant investment in scaling-up and producing engineered nano-structures in a cGMP environment is necessary to bring innovations to commercial reality. What the latest advances in the field brings is the precision necessary to improve safety and to engineer new products with enhanced capabilities. This is exactly what the regulatory agencies have asked for: Increased reproducibility and precision, which is readily accomplished via Liquidia's PRINT technology.

Recommendations and Refinements to the PCAST Report

With this perspective and background, we have the following comments that we would like to make:

Unmet needs to advance the field of nanoscience and technology

- Nanotechnologies must be brought to market responsibly; meaningful nanoparticle standards to assess physio-chemical properties of nanomaterials for environmental and health implications are necessary for sustainable product development.
- There is a need for "qualified" nano- and micro-materials with control in particle size, shape and chemical composition and that are available at a scale useful for a broad range of scientific studies. The need for such "qualified" materials is different than the need being fulfilled by the nano-standards being developed by NIST which are mainly useful for very high-end technology needs, like the calibration of measurement instrumentation. Rather, "qualified" materials are materials that are almost of the same quality as the standards being developed by NIST but meet additional specifications to allow for utility across differentiated industries, including larger quantities at lower costs than that associated with NIST calibration standards.
- Additionally, a set of well characterized materials (environmental and health studies) that accurately represent the types of nanomaterials that are incorporated into products is needed to address many of the concerns voiced by the public. While EH&S research has always been a focal point for the NNI, we need to ensure that the nanomaterials used for this research are the same classes of materials used for consumer products and are tested in a relevant context.
- Liquidia's PRINT technology is one example of a breakthrough in particle manufacturing (40 nm in size and greater) that allows complete control in particle size, shape and chemical composition. The PRINT technology is particularly useful for generating a host of organic nanomaterials, a unique capability that is crucial for evaluating life science applications. Because of the roll-to-roll nature of the PRINT manufacturing process, one can allow researchers to have access to materials in meaningful volumes useful for many real world studies that NIST calibration standards are not suitable for. For example, important studies are needed and could be accomplished if "qualified nano-standards" were available such as aerosol standards (for inhalation studies, particulate distribution studies in cities and buildings, etc); environmental standards (for ground water fate studies, etc) and organic materials for in vivo biodistribution studies.
- It is recommended that the NNCO consider the establishment of a Nanoparticle Foundry much in the way that the Department of Energy through Lawrence Berkeley National Laboratory established the Molecular Foundry. The establishment of the Nanoparticle Foundry would address a key

bottle neck for the generation of ideas and would play an important role in establishing our Nation's preeminence in nanomanufacturing which is crucial to establishing and growing jobs in the U.S.

Unmet needs for commercialization of nanoscience and technology

- Nanomanufacturing is the means through which the Nation will realize the benefits of nanotechnology. A major opportunity exists to leverage the past ten years of NNI research platforms and establish programs to translate this knowledge into viable products through the advancement of nanotechnologies. Nanomanu-facturing R&D must go hand-in-hand with scientific discovery to ensure that U.S. manufacturers can quickly transform innovations into processes and products and that the investments made to date can be realized in the form of revenue and job creation
- Currently, private investment in nanotechnology is hesitant, weighing the risks of this relatively new field where considerable investment has already taken place in academia, which has yet to fully validate and deliver cost-effective and commercially viable platforms. Government funding in Nanomanufacturing is needed to realize the investments that have already been made. Bridging the gap from proof-of-concept to commercial viability will provide the risk mitigation needed to encourage the private sector to support and further develop nanomedicine platforms.
- Nanomanufacturing developments need to strongly focus on manufacturing issues unique for the applications in the life sciences. Based on the current recommendations and NNI strategic plan, the nano manufacturing foci are largely devoid of materials and processes destined for use in life sciences.
- Targeted, government-driven funding can make a crucial difference in the scale, breadth, and time horizon of industry-driven R&D for nanomanufacturing. In the US, the largest funding opportunities that seed commercialization activity are the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs. These programs are extremely limited in the terms of time and budget needed to support innovation in technology infrastructure. Transitioning a prototype process to a viable commercial scale is an effort that requires capital expenditure and timelines well beyond that of the SBIR and STTR programs, which in most cases offer a $100K phase I effort for a 6-month to one year effort. In addition, many nanotechnology based businesses are venture backed, requiring significant capital for pre-clinical or proof-of-concept studies prior to revenue. These companies are often not eligible for SBIR and STTR programs due to ownership requirements.
- The regulatory pathways for nanomaterials should be made explicit; the pathways should be scientifically based and it should be made clear which of the current regulatory pathways are already adequate for commercial approval. The issue is particularly applicable to therapeutics by the FDA but are inclusive of other agencies as tools become available
- One of the more important non-nano specific issues that need to be addressed to facilitate the development of such industries of the future is the U.S. Patent Office. The USPTO is bogged down, with timelines to patent issuance being longer than ever in history. Such delays cause uncertainties and uncertainties inhibit private and corporate investments in new companies. This inefficiency is in stark contrast to recent announcements in China and other foreign competitors who are massively increasing the funding of their patent offices for rapid turnaround and issuance.

In conclusion, nanotechnology has the undeniable potential to create entirely new industries and products that will positively impact our environment as well improve the quality of life and prevent disease. But we cannot just innovate, we need to scale our inventions to realize this potential, creating jobs and economic prosperity. Perhaps no one has stated this more clearly than Andy Grove recently in an op-ed in Bloomberg News:

Startups are a wonderful thing, but they cannot by themselves increase tech employment. Equally important is what comes after that mythical moment of creation in the garage, as technology goes from prototype to mass production. This is the phase where companies scale up. They work out design details, figure out how to make things affordably, build factories, and hire people by the thousands. Scaling is hard work but necessary to make innovation matter. Andy Grove, July 1, 2010

Thank you for considering our comments.

Chairman BROOKS. Thank you, Dr. Rudnick. Better luck to both of us next year.

Up next we have Dr. James Tour. Dr. Tour.

STATEMENT OF JAMES TOUR, PROFESSOR OF CHEMISTRY, COMPUTER SCIENCE AND MECHANICAL ENGINEERING AND MATERIALS SCIENCE, RICE UNIVERSITY

Dr. TOUR. Thank you. I have the good fortune of being able to teach in the Departments of Chemistry, the Department of Mechanical Engineering and Material Science, and also Computer Science because nanotechnology bridges across all of those areas. I have over 400 research publications and 50 patents on diverse nanotechnology products, ranging from high performance materials to ultra small electronic devices, targeted chemotherapy delivery agents, and nanomachines.

Today I will underscore the threat of foreign competition, the need for continued support to basic nanotechnology, and continued support for transitions into nano-manufacturing to ensure U.S. jobs and preeminent global competitiveness.

Nanotechnology is about the study of the very small, a range between the molecular size and the cellular size. Some examples from my own lab are on the slide. A light-powered nano-car is in the lower left box. Thirty thousand of these cars can fit on the diameter of a human hair. They are for manufacturing in the future, 50 years from now, where we will do bottom-up manufacturing.

For example, if we want to make the table, we go down, we find a big tree, we cut it down, and we make a table. That is not the way we will be manufacturing 50 years from now, but we will be able to build bottom up, just like nature's enzymes do it. Machines bringing in molecules for direct construction of the table.

We need to work now to be the leaders in 2060, but nanotechnology is also upon us today. The top middle box shows an oil well blowout preventor that are eight times tougher than the typical ones because they have carbon nanotubes in them. I founded a company in Houston that now makes these toughened rubber materials so that nano-manufacturing is with us today.

I am the son of immigrants who came to the U.S. right after World War II. My parents instilled in their children a love for this country. My father used to tell us that the U.S. was the greatest country in the world, and I still believe he is correct.

I say to tell you what is now at risk. With governing bodies rightly seeking to trim budgets, there is consideration of deep cuts in basic research for nanotechnology. Some are unaware that nano-manufacturing is about to spawn entirely new segments that will rise from the current 150,000 American jobs to 800,000 jobs by 2015. The U.S. has benefited from the best brains in the world coming to our shores for the past many years. People's intellects are our best asset, and by God's grace we have been the recipients of the world's top brains. Those brains have caused us to win the nuclear race, the space race, and the Cold War. U.S. higher education and research is the apple of America's eye and the envy of the world.

Alarmingly, however, foreign competition is now on our shores, successfully wooing the best and brightest away with assurances of funding for basic research and support for transitions to manufacturing. In the past 14 months I have been invited to Singapore with a second trip planned this summer, and I have had more than a dozen visits from Singaporean representatives interested, including twice from the Economic Development Board of Singapore, interested in building me a lab in Singapore, funding my lab there, and having some of the new nanotechnology companies founded there with their capital backing and a much lower tax burden than offered in the U.S.

I have also been approached by Russian, Chinese, and Japanese officials. Welcome to my world of global competition.

American researchers are industrious and self-driven. We have been trained that way. If we cannot get our science funding and transition into the—in the U.S., we will go abroad, and top researchers will not wait for a decade for recovery. The brain drain has already begun, and it will continue at an alarming pace within the next 1 to three years if access to research and development funds become sparse.

If American researchers start going abroad, the impact of the brain drain would be devastating to near and long-term economic development in the U.S. Federal funding for nanotechnology beyond the discovery phase is also needed to spawn the transitions from the laboratory to the manufacturing stage. This can be done using a competitive grants process that keeps the government from choosing its favorites and permits competition through grants applications analogous to the competitive SBIR and STTR Programs.

In closing, let me underscore we are not finished with basic research and translational development in nanotechnology. The programs must continue. Foreign competition is at our doorsteps to capitalize upon and divert the country's lead in nanotechnology that will underpin the manufacturing of this century.

And I want to thank you for your service to this country, and I would be honored to answer any questions.

[The prepared statement of Mr. Tour follows:]

PREPARED STATEMENT BY JAMES M. TOUR, PH.D. RICHARD E. SMALLEY INSTITUTE FOR NANOSCALE SCIENCE AND TECHNOLOGY RICE UNIVERSITY

Chairman Brooks, Ranking Member Lipinski and Members of the Subcommittee on Research and Science Education; I appreciate the opportunity to testify before you today on three aspects of nanotechnology of great importance to the nation, Rice University and myself. My name is James Tour. I am the T.T and W.F. Chao Professor of Chemistry, Professor of Computer Science and Professor of Mechanical Engineering and Materials Science in the Richard E. Smalley Institute for Nanoscale Science and Technology at Rice University in Houston, Texas. I have over 400 research publications and 50 patents on nanotechnology topics ranging from high performance materials, ultra-small electronic devices, targeted cancer delivery agents, and nanomachines.

I come before you today to address three critical concerns:

1. Foreign competition,
2. Federal funding beyond the discovery phase, and
3. Paths to commercialization.

Overview of the Smalley Institute

Rice University is the location where C60, known as Buckminsterfullerene, was discovered in 1985 by Richard Smalley, Robert Curl and Harold Kroto and their team of students. That discovery, more than any other single discovery, is credited with the genesis of nanotechnology, and that single discovery led to three Nobel

Prizes in Chemistry. The Smalley Institute at Rice University is now one of the premier research facilities in the world that supports and promotes researchers who use nanotechnology to tackle civilization's grand challenges—energy, water, environment, disease, education—by providing experienced and knowledgeable leadership, a solid administrative framework, world-class scientific infrastructure, and productive community, industry, and government relations. Rice University owns more licensed nanotechnology patents than any other university in the world.

The Smalley Institute interacts with the private sector at several levels. We interact with major corporations (such as Lockheed Martin Co.) directly at a high level by forming centers (such as the Lockheed Advanced Nanotechnology Center of Excellence at Rice, or LANCER) to perform basic research in multiple projects which address significant technical challenges faced by the corporate scientists and engineers. LANCER, now in its fourth year, has funded six initial projects, at an overall level of funding of about $1.5 million per year. The Rice/Lockheed partnership has resulted in over 200 Lockheed engineers and scientists being trained at Rice during week-long courses on nanotechnology. The Smalley Institute is currently working on two or three additional corporate relationships that have the potential to reach the same funding and partnership level as LANCER.

The Advanced Energy Consortium (AEC) is a second example of corporate funding that the Smalley Institute helps to foster, independent of any government support. The Smalley Institute and the University of Texas at Austin started the AEC, joining ten major oil and gas companies together at a level of funding of $10 million per year, starting in January 2008. Rice has benefited from AEC funding at about $2 million year for direct research projects to explore the use of nanotechnology down hole in characterizing oil and gas formations and increasing production from those fields. In addition to the above examples, the Smalley Institute assists in connecting individual companies with individual Rice researchers to perform sponsored research projects .These projects range from a few thousand to $500,000, and cover a wide range of nanotechnology fields.

In the area of philanthropic funding, the Smalley Institute also serves as the advocate for fund-raising from both individuals and foundations to support Rice's infrastructure of research as well as direct funding of research, especially in terms of undergraduate, graduate student, and postdoctoral fellow funding, both immediate use and endowed funds. We have raised funds to build buildings (Dell Butcher Hall, the first dedicated nanotechnology building in the world that was completed in 1997), help hire and endow talented new faculty members, buy research equipment, support meetings and workshops and seminars, and encourage nanotechnology education. We also provide local, national and international outreach activities to advance nanotechnology through lectures, short courses, and even classes in our continuing studies department.

Key Nanotechnology Issues

As our country struggles to emerge from the recession, the most important issue to the public is jobs. Nanotechnology is an enabling technology that, if supported and developed adequately, will usher in the next industrial revolution and create hundreds of thousands of new jobs and make products that are more competitive globally. According to a presentation by Clayton Teague, Director of the federal National Nanotechnology Initiative, the nanotechnology industry currently employees over 150,000 Americans and that number is expected to grow significantly. It is estimated that there could be as many as 800,000 direct jobs in nanotechnology by 2015. That is less than four years from today. These are highly skilled, highly paid jobs that result in long-term sustainable economic development for the countries that support them. As the Internet revolution propelled our economy in the early 90s, nanotechnology can be the major driver of economic growth over the next two decades. The U.S. needs to make important decisions now to ensure that this growth occurs in the United States where it can be of greatest benefit to U.S. citizens who provided the resources to fund this technology.

When we talk about nanotechnology, we are not talking about something in the future, but something that exists today. Nanotechnology is used now in electronics, energy, medicine, cosmetics and materials. At Rice University, we incorporate carbon nanomaterials into high-strength composites that produce lighter and more conductive materials that can be used as lightweight body armor for our troops or in electrical wiring. We inject gold nanoparticles directly into the bloodstream of patients to target and kill cancer cells. Carbon nanoparticles are also being used to make printable radio frequency tags that will displace barcodes and permit real-time inventory in warehouses. Nanofilament-based silicon will also usher in the post-flash electronic memories that will drive handheld communication and entertainment devices used today. Graphene, single-atom-thick sheets of carbon grown from table sugar and a nanotechnology application can be used for touch-screen displays on, for example, cell phones. This would allow the entire phone to be rolled up like a pencil to insert in your pocket. These are not technologies expected in the future. These technologies are being used today and U.S. workers, the same ones whose taxes paid for the technology development, can manufacture and produce these products if the U.S. government continues to support and fund nanotechnology research and commercialization at an adequate level. My personal life story testifies to the positive impact of federal funding for education, research and commercialization of technology. I am the child of immigrants who came to the U.S. seeking a better life and, as we worked for it, we found it. My Ph.D. and laboratory research was subsidized by federal research grants. While I am thankful for a government that has created opportunity for me and many others to make world-changing and life-saving discoveries, I am gratified that these discoveries also create a demand for high quality education, produce high-paying jobs, attract global talent, revolutionize manufacturing and solve difficult problems. All of these benefits to the U.S. will be lost if we fail to address the following three issues:

1. Foreign competition,
2. Federal funding beyond the discovery phase, and
3. Paths to commercialization.

Foreign Competition

Foreign governments compete for nanotechnology human talent, research and manufacturing because these things are the key to global competitiveness. The primary areas of competition are:

- Basic research discoveries that lead to scientific papers and then to Intellectual Property, such as patents,
- Hiring and funding of nanotechnology researchers, and
- Commercializing and investing in nanotechnology enterprises.

The U.S. leadership role in each of these areas is threatened because other countries are aggressively implementing national strategies to acquire this technological advantage and then compete against us.

The U.S. is currently the intellectual leader for nanotechnology—representing close to 30 percent of all patents held and 23 percent of all scientific papers published internationally. In addition, the U.S. government is also the largest investor in nanotechnology, investing close to $5.7 billion in 2008. However, other nations are beginning to close the gap. According to the March 2010 P–CAST report, from 2003 to 2008, U.S. public and private investments in nanotechnology grew at 18 percent annually, while global investment grew at 27 percent annually. In addition, U.S. government investments in nanotechnology R&D were overtaken by European Union in 2005 and by Asia in 2008 (primarily Japan, China and South Korea). In fact, the executive summary of the P–CAST warns:

> "..the United States stands to surrender its global lead in nanotechnology if it does not address some pressing needs. Key among those is a need to increase investments in product commercialization and technology transfer to help ensure that new nanotech methods and products make it to the marketplace, and the need to strengthen [National Nanotechnology Initiative] commitments to explore in a more orderly fashion environmental, health, and safety issues."

Foreign interests will continue to invest in both the basic science and application of nanotechnology. Now is not the time for the U.S. to surrender its leadership position just as the results of our research investments are moving to commercialization.

Federal Funding Beyond the Discovery Phase

In order to preserve our leadership role, we must support federal nanotechnology funding beyond the discovery phase. Federal funding of basic research must continue because many companies are no longer conducting basic research. In order to continue this basic research, we must pay students because we have to pay them-they do not line up outside science and engineering departments as they do for medical and law schools. This federal support for scientists and engineers has a successful track record over the past 50 years as evidenced by the U.S. superiority in the Cold War, agricultural advances, energy development in the ultra deepwater and in shales and the space program to name just a few achievements.

It is an exciting time for nanotechnology because we are now moving from the initial discovery stage to corporate development labs, nanomanufacturing and emerging markets. This is the stage in technology development when the U.S. can begin to realize a return on our nanotechnology investment if we continue to support and fund nanotechnology research and commercialization at an adequate level. The Federal Government has a specific role in two major areas of nanotechnology: nano-manufacturing and the environment.

The key to a successful shift to commercialization of nanotechnology is through nano-manufacturing. Nano-manufacturing takes the basic science of nanotechnology and uses it in the production of nanoscaled materials. If we do not adopt and deploy an aggressive strategy to encourage the growth of nano-manufacturing immediately, we will find ourselves losers to China, India, Russia, Singapore and other places where government funds and supports the use nano-manufacturing to create jobs and wealth. As the U.S. manufacturing sector continue to shed jobs and as these jobs move abroad, nano-manufacturing is one bright spot of opportunity where the U.S. has the potential to be a world class global competitor.

In the past 18 months, I have been invited to Singapore once with a second trip planned this summer (both business class flights). I have had more than a dozen visits from Singaporean representatives, including two visits from their Economic Development Board. The purpose of these visits was to encourage me to do my work in Singapore. I have been promised a lab and funding to do my work there. In addition, I have been promised capital backing and a lower tax burden than the U.S. if I launch new nanotechnology companies there. I have also been approached by Russian, Chinese and Japanese representatives. In the past two weeks alone, officers from both Toshiba and Mitsubishi have been in my office. This is global competition and it is the realm in which we nanotechnology researchers work. I do not say this to add a threatening tone to this testimony. Rather, I share this information to provide some context in which to view my recommendations. American researchers are industrious and self-driven. If they cannot get our science funded and transitioned here, they will go abroad. And top researchers will not wait a decade for recovery. The brain-drain has already begun, and it will continue at an enormous pace within the next 1–3 years if access to research and development funds are reduced. Progress will continue, and it is my hope that the U.S. will be the beneficiary of that progress. If American researchers start going abroad, the impact of the brain-drain would be devastating to near and long-term economic development in the US.

Environmental stewardship is also an area where the Federal Government needs to play a role in the post-discovery phase of nanotechnology development. Uniform and transparent environmental regulations are critical to the future growth of this industry. The government needs to encourage commercialization with sound science-based environmental stewardship, without creating unnecessary regulatory hurdles that are not supported by sound science. Nothing can stifle economic growth faster than regulatory uncertainty. Universities and companies need a framework to address this uncertainty. Without it, , we will struggle through this next stage. The NNI helps to provide this guidance across the 25 different agencies that touch nanotechnology. As nano-manufacturing develops rapidly worldwide, there is a need for a reasonable regulatory framework that protects human health and the environment.

The Federal Government has been a crucial partner in the discovery of nanotechnology. We must now use the nanotechnology tools funded by U.S. citizens to provide U.S. jobs and make U.S. products more competitive in the global market. This can be done through federal support for the commercialization of nanotechnology through support to universities and the private sector to move these technologies to the market and to the consumer.

Paths to Commercialization

Federal funding for nanotechnology beyond the discovery phase is needed to spawn the transitions from the laboratory to the manufacturing stage. This can be done through Private-Public partnerships where a competitive grants process keeps the government from choosing its favorites, and permits competition through grants applications analogous to the competitive Small Business Innovation Research (SBIR) and the Small Business Technology Transfer (STTR) programs that merge universities with small companies for the transition from research to development and manufacturing.

We only need to look at Texas for a few examples of some successful efforts in business -government nanotechnology partnerships. One company that I founded is NanoComposites Inc. NanoComposites make tougher elastomeric materials using carbon nanotube composites for items such as oil-well blowout preventors that are eight times tougher than existing systems. The development was funded, in part, through the Emerging Technologies Fund (ETF) of the State of Texas. That funding saw the Company though a period of transitional research where the application of the basic science to real systems was too risky to be considered for private sponsorship. Now, a major oil service support company has seen the efficacy of the process and invested heavily in NanoComposites. This is an example of a Private-Public partnership. Outside of the ETF, the State of Texas also helps fund cutting edge research through the Cancer Prevention and Research Institute (CPRIT). CPRIT began with $3 billion in bonds to fund groundbreaking cancer research and prevention programs and services in Texas. CPRIT's goal is to expedite innovation and commercialization in the area of cancer research and to enhance access to evidence-based prevention programs and services throughout the State. This is a model that is working successfully in Texas and something the Federal Government should review to build upon its success.

Federal and state competitive funding for nanotechnology research has been wildly successful. We attract the best researchers in the world to our universities and these researchers, their institutions, and U.S. companies hold the largest number of nano patents in the world. We are now equipped as a country to deploy these technologies to make our businesses more competitive globally. However, continued federal funding in the post discovery phase is necessary to capture the value of what we have achieved thus far. If we reduce funding and commitment to nanotechnology during this critical juncture, this decision would be the equivalent of dropping out of a race voluntarily when you are in first place.

The Way Forward

In order to achieve these goals, the National Nanotechnology Initiative (NNI) should be reauthorized to help guide the industry through transition. Currently, the NNI budget supports nanoscale science, engineering, and technology research and development (R&D) at 15 agencies with 10 additional participating agencies. NNI helps to align these agencies so that they can work in a coordinated way to move this technology from discovery to commercialization. A new reauthorization will allow the Federal Government, universities, and the private sector to work to find creative ways to bring these promising technologies to the market more quickly and economically. In the absence of reauthorization, these agencies will be focused in different directions and the industry will struggle to transition into the next stage while other countries continue to close the existing gap.

Conclusion

As Congress and the country wrestles with ways to encourage job growth in a global economy, nanotechnology is moving from basic discovery to commercialization. It is in this transition that we can begin to realize significant economic development and job creation. Our country is no longer the manufacturing leader in the world—we now outsource most of our manufacturing jobs overseas -but this does not have to be the case with nanotechnology. The U.S. is currently the intellectual leader in this promising field of discovery, but if we fail to make the investments needed today, then other countries will and we will begin to see the outsourcing of nano-manufacturing jobs overseas. Our government has made significant investments into this promising technology and now is not the time to walk away or diminish our financial commitment. I know that during these times of tight budget priorities must be made with funding. We have the opportunity to reclaim our manufacturing base that helped to build this great country. There is too much at stake to do nothing and other countries are already closing the gap. The issue before you is about economic development and a commitment to ensure that the United States remains the intellectual leader, driver and recipient of the economic benefits of this growing technology I close with the three priorities I urge the Subcommittee to address:

1. Foreign competition,
2. Federal funding beyond the discovery phase, and
3. Paths to Commercialization.

Thank you for your time. I would be honored to answer your questions.

Chairman BROOKS. Thank you, Dr. Tour.

We have received a notice of votes, and this is our game plan. Mr. Moffitt, if you are comfortable that you can make your remarks in five minutes, I have been informed that we have got a series of two votes, and as soon as your remarks conclude, we will go into a recess. We will vote, and then we will resume the hearing 10 minutes after the beginning of the last vote.

STATEMENT OF WILLIAM MOFFITT, PRESIDENT AND CHIEF EXECUTIVE OFFICER, NANOSPHERE, INC.

Mr. MOFFITT. Thank you, Mr. Chairman. I am comfortable that I can do that in five minutes or less. So thank you, Chairman Brooks, Ranking Member Lipinski, and distinguished Members of the committee.

I am here today to speak with you about your health. Your health, the public health, and the health of our economy, all underwritten by nanotechnology.

I appreciate the opportunity to testify before this committee and to stress upon you the importance of NNI and how crucial that has been to the success and the commercial success of my company. I am the President and Chief Executive Officer of Nanosphere, Incorporated. I am also a member of the NanoBusiness Commercialization Association on whose behalf I testify as well. In full disclosure, I am a former science teacher and a Duke Blue Devil.

Nanosphere is an 11-year-old company formed about the same time as the origination of NNI. We are a company that manufactures, develops, and markets an advanced molecular diagnostics platform for testing both in human health or infectious diseases, pharmacogenetics or personalized medicine, if you will, and in the area of ultra-sensitive protein testing for the earliest detection of advanced diseases such as cardiovascular disease and cancer. We also manufacture a bio-security system that detects the slightest trace of bio-terrorist threat agents in water and is field deployable around the globe, anywhere that it is needed, on a moment's notice.

It is the extraordinary properties of nano-particle technology that enable us to achieve these breakthroughs in human genetic testing, pharmacogenetics, and ultra-sensitive protein testing. We created life-saving tests for tens of dollars. It could be sold for tens of dollars as opposed to the hundreds and thousands of dollars we hear today about genetic tests. All of this is in the format of a system that can be moved right to the patient's side, can be installed in the average community hospital or any medical setting, and be used when and where the physician needs results to these crucial tests.

I want to spend a second and acquaint you with a couple of these. One of these is a test that is based on an established bio-marker. A bio-marker is the fingerprint of a disease. It is the earliest telltale sign of heart disease. It has been used to diagnose heart attacks in emergency rooms for 25 or 30 years. Through nanotechnology we have found two new uses for this tried and true marker.

One is the earliest detection of early-onset cardiovascular disease, and the other just discovered in the last 6 months is the use of this same marker to be able to monitor the progress of chronic heart failure patients and adjust their therapy more appropriately, therefore, improving their health and also reducing re-hospitalization, re-hospital admissions for them. So all of these lifesaving technologies can be brought right to the bedside in the hospital, if you will, by virtue of nanotechnology.

We also has the ability to test for septic shock, the bacteria and the organisms that cause sepsis, not in three days as would take today, but in two hours, therefore, moving a critical diagnosis farther much faster so that the appropriate therapy can be started earlier. This also have implications for exposure of antibiotics to the rest of the organisms in the world and resistant strains that are continuing to be a problem for public health.

I could go on and on with the things that we have done, but let me tell you this would not exist if it had not been for NNI. The efforts that have funded those agencies and the coordination there have helped tremendously in funding our company. The leverage in our company has been tremendous. Five or $6 million in federal grant aid was put into Nanosphere, which has augmented that with another $200 million plus in private and public equity financing. A 40 to one leverage ratio for the government dollar invested.

This has been a success story so far, and we believe it will continue to be one. We would not have crossed that Valley of Death, if you will, had it not been for the NNI and government funding, which supports the transition of core science into commercializable technologies.

This company has created jobs. We are small but growing. We are 115 strong today, but in years to come we will be hundreds, and we will be thousands in size, and these are high-tech jobs. Eighty-five percent of our employees have college degrees or advanced degrees. The average salary in our company is over $85,000, and that is if you take the top level off.

So we are creating the kinds of jobs that underwrite the economy in this country. Our greatest challenge is employees, workers. I think we all are aware of the crisis we face in STEM education, the crisis in this country, and we cannot underscore that enough.

Let me by— let me close, I know I am going over here, by simply saying that we also realize and recognize that the competition we get from foreign investments and nanotechnology, they are closing the gap on us rapidly. We cannot stress that enough.

Thank you, again, for the opportunity to speak, and I look forward to answering your questions.

[The prepared statement of Mr. Moffitt follows:]

PREPARED STATEMENT OF WILLIAM MOFFITT, PRESIDENT & CHIEF EXECUTIVE OFFICER, NANOSPHERE, INC.

SUMMARY

- The National Nanotechnology Initiative provides crucial funding to revolutionary ideas and enables private enterprise to find and invest in promising technologies and companies.
- These technologies can represent important breakthroughs in crucial industries such as healthcare and defense.
- The market is efficient at funding and commercializing viable technology into useful products, so long as those technologies have sufficient funding to make it through the “valley of death.”
- The National Nanotechnology Initiative is the primary tool that Congress has available to make sure that promising technologies like these make it through the “valley of death” and into the marketplace.
- The National Nanotechnology Initiative is also a direct investment in high-paying, highly-skilled American jobs.
- Companies like Nanosphere can bring their technology to the marketplace relatively quickly—in our case, we went from research laboratory to marketplace in only ten years.
- The U.S. nanotechnology industry faces challenges in the U.S. labor pool as well as other countries’ aggressive investments in nanotechnology, particularly healthbased research.

- Nanosphere is committed to the responsible development of nanotechnology, particularly with regard to any environmental, health and safety issues related to the development of this new technology, and will leverage nanotechnology research to solve potential challenges.

Chairman Brooks, Ranking Member Lipinski, and distinguished Members of the committee, thank you for allowing me the opportunity to testify before the House Science, Space and Technology Committee's Subcommittee on Research and Science Education, regarding how the National Nanotechnology Initiative has been crucial to my company's success.

I am the President and CEO of Nanosphere, Inc., which is a member of the NanoBusiness Commercialization Association, on whose behalf I am also testifying. Nanosphere is an eleven yearold company based in Northbrook, Illinois, that is revolutionizing the way diseases are diagnosed and bio-security risks are discovered using nanotechnology. Nanosphere develops, manufactures and markets an advanced molecular diagnostics platform, the Verigene System, for ultra-sensitive protein, human genetic and infectious disease detection. This easy-to-use and cost-effective platform enables simple, low cost, highly sensitive testing on a single platform available to any medical setting anywhere in the world. Nanosphere has also developed mobile bio-security systems that can detect biological agents—such as anthrax, plague and other pathogens—in a local water supply. This system is field-deployable to any potentially threatening hotspot or U.S. embassy anywhere in the world.

Both of these systems rely on nanotechnology to make these breakthroughs possible. For instance, one of the greatest benefits nanotechnology has delivered to the market is speed to diagnose a patient. Our technology, which enables tests to be performed right at the site of patient care as requested by the patient's physician, generates critical diagnostic information when and where it is required. We have eliminated the high cost and complexity of genetic tests for human inherited disease, pharmacogenetics (or personalized medicine) and infectious diseases through the use of breakthroughs in nanotechnology. Nanotechnology has enabled us to develop a molecular diagnostics platform that operates in a very simple format that eliminates the need for highly specialized labor. Moreover, the underlying cost of the consumable test cartridge is very inexpensive, which allows for pricing that is in line with any number of other routine diagnostic tests. This means that a life-saving test can now cost a patient tens of dollars as opposed to hundreds or even thousands of dollars and these new, more sophisticated molecular diagnostic tests can be easily integrated into mainstream medical care without additional financial burden on our health care system.

Nanotechnology also allows for earlier detection of life-threatening diseases. Harnessingnanotechnology, we have developed a diagnostic procedure that provides advanced detection for human protein biomarkers—or the "fingerprints" of disease—that is simply not possible using other technologies. For example, we have in development a test for cardiovascular disease which has already proven to be far more sensitive in detecting heart attacks and acute coronary syndromes than traditional technology. Recent data also suggest that this assay has great value in monitoring patients with chronic heart failure, allowing doctors to more accurately adjust a patient's therapy for this life threatening condition. Nanosphere has also developed the ability to detect recurrent prostate cancer following treatment years earlier than tests available without using nanotechnology. Today, the best weapon to fight cancer is early detection. Our products using nanotechnology make early detection possible and affordable.

The National Nanotechnology Initiative is the primary tool that Congress has available tomake sure that promising technologies like these make it to the marketplace. This Initiativeprovides crucial funding to revolutionary ideas and enables private enterprise to find and investin promising technologies and companies.

Simply stated, without the National Nanotechnology Initiative, Nanosphere might not exist. Nanosphere is a product of university-based research funded by NSF, NIH, and DARPA, among others. Since its inception the company has received approximately $5–6 million in government grant funding, which has been leveraged to an additional $200 million in private and public equity financing, a 40 to 1 investment ratio. Early government funding was critical to the long-term future and success of Nanosphere and the realization of significant advances in medical diagnostics.

The market is efficient at funding and commercializing viable technology into useful products. However, in order for forward-thinking companies with promising technologies such as ours to succeed, the basic technology must be nurtured until it reaches a market-sustainable level. And once federal funds support a technology to the point where it is ready to commercialize, the marketplace provides venture capital to the best products. Our company has raised about forty dollars of private venture capital and public institutional equity investment for every one dollar of public funding to commercialize our molecular diagnostics platform. That one public dollar, though, was provided at a crucial time for any product trying to make it past the so-called "valley of death" for new technology. Venture capitalists are ready to invest in technologies that can get across the "valley of death" and be commercial successes. But economies built on basic research, such as the U.S. technology economy, cannot be sustained without robust government support for promising new technologies.

The National Nanotechnology Initiative is also a direct investment in American jobs. NNI-supported technologies are often commercialized by small businesses that excel at making those technologies useful in the marketplace. These companies employ highly-paid researchers, scientists and technology experts in order to develop their new products. As these companies grow, their workforces expand to include sales professionals and administrative personnel.

We have brought our technology from the university research bench to commercial reality in less than ten years. As our company continues to grow, we generate incremental jobs. Today we employ over 115 people and expectations are that we will grow to several hundred over the coming years. These are high tech jobs with more than 85% of our employees holding college and advanced degrees. Our average salary exceeds $85,000. Companies like Nanosphere are a key growth factor in the nation's economy. These high-paying jobs employing professionals here in the U.S. simply would not exist without basic support for nanotechnology being developed in laboratories across America.

In this regard, one of our greatest challenges is the available labor pool. This Committee is well-aware that we face a STEM education crisis. The NNI provides a strategy to help address that crisis and generate the highly skilled workforce that companies like Nanosphere need in order to compete in the global marketplace.

The U.S. nanotechnology industry also faces the challenge of foreign competitors making significant progress in nanotechnology research. Large foreign companies as well as start-up enterprises are capitalizing on major advances in nanotechnology to create new products and new economic growth opportunities for their respective countries in the health-care arena. We face stiff competition from China, Germany, Korea, and Japan. Competitors in those countries are patenting at a furious rate, and the investments of these four countries in nanotechnology, especially as it applies to human health, exceeds total investment by the U.S. The governments are proactively investing in key areas like nanomaterial-enabled diagnostics and therapeutics because they know these advances have a chance to define their economy for decades to come.

In addition, these countries are strategically finding ways to decrease the gap between invention and commercialization. Indeed, they are generating central arteries of development and commercialization by establishing institutes and centers of excellence in key subareas of nanotechnology, including energy, materials, electronics, bio-nanotechnology, and many subareas of medicine. Learning from the best practices of these competing countries could prove valuable to further refining the NNI.

Like the other members of the Nanobusiness Commercialization Association, Nanosphere is committed to the responsible development of nanotechnology, particularly with regard to any environmental, health and safety issues related to the development of this new technology. One of the key components of the National Nanotechnology Initiative is learning how nanoparticles interact with the environment around us. As our company's success with developing new health technologies demonstrates, nanotechnology more often than not provides the solution to environmental, health and safety problems. However, as we make these new discoveries, we can learn more about the impact of nanoscience, identify any risks that may develop, and determine solutions accordingly.

Thank you again for the opportunity to address the committee today. I look forward to responding to any questions you may have.

Chairman BROOKS. Thank you, Mr. Moffitt. Based on our conversations with Mr. Lipinski, the Ranking Member, and myself, we are going to recess. I would anticipate we will be back somewhere in the neighborhood of 15 to 25 minutes. It is a series of two votes. The Members should be back 10 minutes after the last vote starts to be cast.

We are in recess.

[Recess.]

Chairman BROOKS. My wife is a math teacher. She would have loved to have had that kind of response using a gavel.

Well, I thank the panel for their testimony, reminding Members that committee rules limit questioning to five minutes. The Chair will at this point open the round of questions, and the Chair recognizes himself for five minutes.

Before I begin my five minutes, though, I have the consent of the minority to go ahead and resume. From what I understand Congressman Lipinski is on the way back and should be with us shortly.

The first question for Dr. Welser, in your testimony you state that nanoelectronics can contribute to deficit reduction in three ways; increasing jobs, wages, and expanding the tax base, lowering the cost of computing to the government, and increasing economic productivity, and as you can imagine in the context of the battle that we are now in Washington, we have unsustainable budget deficits, we have basically three approaches or a combination of those three that we can use. One is to cut spending dramatically, one is to increase taxes dramatically, or a third way is to grow the economy, which naturally will generate additional revenue.

So if you would, can you please expand on these ideas? How can Congress build on these concepts?

Dr. WELSER. Yeah. Thank you very much for the question. I think that obviously the most important factor that the nanoelectronics provides is the ability to grow the economy, and it is not just the chip industry but everything else that gets enabled around it.

One of the reasons the exponential increase in revenues has occurred at the semiconductor chip level is because when something gets smaller, it doesn't just get faster. We can make whole new products, so you have smart phones or GPS or embedded sensors or drug delivery systems in the body, all enabled, new markets and industries enabled by increasing the scale of nanoelectronics.

So I think that is the number one thing that happens, and then the jobs, of course, that go with that continue to then grow the economy as well.

On the other side, for productivity and efficiency, if you look at the cost of computing over time, the iPad that we have today has the computing power of basically a super computer from the late '90s, so if you would try to do the kind of calculations and things that we want to do with the super computer then, you can now do it by buying an iPad.

So there is a huge increase in productivity that you get for your dollars and computation. I think these two are probably the main ways that we can contribute, but obviously, I think just having more electronic capability also ends up assisting people in their jobs in all sorts of fields.

Chairman BROOKS. And on the chance that any of the other witnesses would also like to address that question, you are free to.

Seeing none, Dr. Tour, your testimony discusses the importance of federal investments in nano-manufacturing and public-private partnerships. In addition, you state that the continued federal commitment to basic research at universities and companies helps to mitigate the investment risk for those looking to enter the marketplace.

Certainly you are aware of the budget and deficit decisions facing Congress. In looking at the fiscal year 2012 budget and what is already a finite pot for federal investment and will likely be even smaller the next year, which area do you believe is more important for federal investment; basic research or nano-manufacturing, and if your answer is both, which it may very well be, then where in this field do you recommend we find the savings that we absolutely must find in order to enhance our expenditures in other areas?

Dr. TOUR. Well, if the number is X number of dollars would be committee, a portion of that X should go to both. So there should be a portion of X in the transition in nano-manufacturing, but we have got to have the basic research, because basic research is not done, but we have got to be able to have the funds also to transition them. And there are mechanisms to do that, SBIR, STTR grants, which are already in place, these sort of mechanisms to do that. But if we just take X and we take a portion and we put it into both.

Chairman BROOKS. And this question is for, first for Dr. Teague, but if anyone else wants to chime in afterwards, feel free.

Dr. Teague, I believe it was your testimony that related to us what other nations were spending on nanotechnology research and development, basic research, things of that nature. In your judgment how much does the United States need to commit to this field in order to remain competitive?

Dr. TEAGUE. I wish I had an immediate answer to that. I can tell you that we have looked at the amount of funding that is going into nanotechnology R&D by other countries. Probably the one that currently is in the lead is the overall European Union and the member states of the European Union. Rough estimates are that in 2010, they will be investing something like $2.6 billion in nanotechnology R&D. This is one year of their new framework that they are investing.

So I think that they are certainly the leaders in the world as of major economy in investing in nanotechnology R&D. The other countries are coming up very strong. It is really quite difficult to estimate how much funding is really in place in places like Korea, Japan, and China because one of the biggest reasons it is difficult to estimate how much they are investing is typically they don't publish a lot of numbers in terms of the labor costs of what—when you see estimates of funding. You will see mainly what they invest in equipment, new research, and things of that nature. So the numbers that you often see for China, Korea, and Japan, they often do not reflect labor, because that is assumed that it is just there.

So if we wanted to keep competitive with the European Union, which I think is frankly one of the fastest-moving economies in the world, our estimate this year with the request for 2012 is 2.1 billion. European Union already had in 2010, 2.6 billion. That would be the comparison that I would look at, and I think, my judgment is when you start looking at publications, publication citations, and things of that nature the fastest-growing countries there are probably—is probably China. If you look at the graphs of our publications and our publication citations, and you look at those of China, ours is leveling off some, and theirs are growing exponentially.

So those are the two countries that I would really look at as very, very competitive if I were trying to make an estimate. I would hesitate to give you a hard number, but I would look at those two comparisons very carefully.

Chairman BROOKS. Does anyone else wish to share an opinion or a judgment concerning how much you believe we should be investing in nanotechnology in order to be competitive?

Dr. TOUR. I think in light of the current budget and where we are, we certainly don't want to decrease what we have been coming in at. I think that that would be devastating to the progress of nanotechnology to suffer with any decrease.

Chairman BROOKS. Thank you. Now I recognize Ranking Member, Mr. Lipinski.

Mr. LIPINSKI. Thank you, Mr. Chairman. Mr. Moffitt, I want to commend you on the remarkable success of Nanosphere in just 11 years, and I noted in your testimony you talked about receiving $5 to $6 million in government grant funding, I believe, in those 11 years, which was a leverage of an additional $200 million in private and public equity financing, giving a 40 to one investment ratio.

I just wanted to ask all of our panelists, throw this out there, the—what type of—what has been your experience with leveraging grant money in order to have further—getting private investment into business?

Anyone want to—Dr. Rudnick.

Dr. RUDNICK. So I think it is of great interest from the perspective of international health that the Gates Foundation invested $10 million in Liquidia this past month, and they did so because of the drive to be able to supply populations of the world that can't have vaccines today with new and more importantly improved vaccines.

I think the ability to get that Gates money to be stemmed directly back to the initiative and the funding that came through NIST and other agencies to Liquidia over this last five years, I think it is imperative to have that kind of leverage and to continue to have that kind of leverage, at least in healthcare.

Mr. LIPINSKI. Anyone else? Dr. Tour.

Dr. TOUR. What I have seen with the companies that I have started, it is, for example, with Nano Composites, it has been around seven years, the company. The company was just, a large part of it was bought by a major party now, and it has been about eight to one ratio, but, again, this is seven years. I heard you mention with Mr. Moffitt 11 years, and this is part of the problem with nanotechnology. It doesn't come immediately. This transition takes time, and without the government standing behind us to bear this, it is very hard to get the investment that will ultimately come, and for us it was seven years before a major player come in. Seven or eight years.

Mr. LIPINSKI. Mr. Moffitt.

Mr. MOFFITT. Thank you for the kind comments. I think I would remiss if I didn't point out to the committee while there is a 40 to one leverage in the money that has been invested into Nanosphere, the ultimate return on investment here is the cost savings that we get in our public health system and the costs that we eliminate or reduce in our—in the healthcare system in this country, and indeed, ultimately, others will benefit around the world.

But I can even point already to some examples of where our products are sitting in a position to be able to cut hospital readmissions simply by better treatment of the patient when they are in the first place, or pharmacogenetics, the term we use in this industry, personalize medicine, the ability to ensure that the drug that is being given to the patient is, in fact, the right drug, one that is not going to be harmful to them or one that is going to be effective for them.

And there are already examples there of where a simple genetic test before somebody goes on the drug Coumadin, a blood thinner, Warfarin-based material, if you will, and there were about six million people in this country that are on it, and it has a significant adverse side effect in the first few days on a certain percentage of that population. A study that was done two years ago by a Mayo Clinic in Medco, showed that you could reduce hospital admissions by 30 percent after taking that drug if you simply performed this simple, little, inexpensive genetic test before dosing it.

So I think the long-term payback here is much, much greater than 40 to one.

Mr. LIPINSKI. Thank you, and I want to throw out one more quick question here.

Mr. Moffitt, you stated we face stiff competition from China, Germany, Korea, Japan, and others who have strategically found ways to decrease the gap from invention to commercialization, and that is a big issue that we face, not just in nanotechnology but in other technologies and other research that we are conducting here.

What are some of the best practices, just whoever wants to comment, some best practices we can take from other countries to refine our NNI?

Mr. MOFFITT. I think one of the best practices I have seen has been the formation of, I guess our term in this country would be centers of excellence, but I would call it more like arteries or pipelines, centers that are charged not only with the basic research but moving it onto translational development of products that are focused on specific industries, such as healthcare and perhaps even more focused on specific niches in healthcare.

For example, the nano-cancer centers that have been funded in this country. I think more of that kind of effort where we not only just fund the basic research, but we fund the ultimate development and application of it, focused on core problems in our country.

Mr. LIPINSKI. Anyone else want to comment on that?

Dr. WELSER. Just make a brief comment from the nanoelectronics side. When we were setting up the NRI, one of the things that determined where we were putting some of these centers was the willingness of the states to putting in money, not just for the research and infrastructure of the universities but your neighboring innovation parks, incubator labs, that could then take results that come out and rapidly try to put them into products, which is particularly important when you are doing basic research because it doesn't always impact the industry or the area you thought it was going to. So certainly our companies are very rapidly picking up the results that come out that can affect us on the nanoelectronics side, but you can have other collateral results in sensors or communication areas that perhaps startups would want to go after instead.

So I think having that kind of environment around universities makes a big difference.

Mr. LIPINSKI. Thank you. Anyone else? Okay.

Thank you very much. I yield back, Mr. Chairman.

Chairman BROOKS. Thank you, Mr. Lipinski.

Next we have Congressman Harris from Maryland.

Mr. HARRIS. Thank you very much, Mr. Chairman, and thanks to all the Members of the panel for being patient with us to go and make those votes and come back and let me just—and this is a fascinating topic because obviously a lot has changed in medicine since I went to medical school, Dr. Rudnick and Mr. Moffitt. The—but I have to ask, the first question is at some point you have to move the basic science. At some point industry will be ready to pick this up, and for instance, in the electronics industry, I mean I know the balance sheet of some of the large semiconductor companies. I mean, why aren't they—there are so many benefits to them of doing this, why does the government have to fund any of that anymore?

I mean, at some point you have to push—you cut the umbilical cord, and you know, industry should do this, and maybe Dr. Welser and Dr. Rudnick, I mean, at what point do we—can we cut the umbilical cord on these things?

Dr. WELSER. Well, we certainly do pick up the research in the R&D. As you heard, we put about 17 percent of our revenue into product-related R&D, and if you look back over time, certain areas that we used to rely on university research and breakthroughs to go through we no longer rely on that. We do it ourselves.

My area of research and my Ph.D. in the early '90s was strain silicon, and that was a lot of very fundamental research on materials. We didn't understand how to use it, and now it is in our production lines, and we are constantly making improvements on it, and we don't fund research in that back in the universities for a large extent or ask the government to do it either, because it is an area that we can now handle on our own.

I think the reason that the government needs to be involved still at the basic level for even something like nanoelectronics is we constantly need to move to the next device, the next material, and that requires screening huge number of potential materials and ideas and structures that maybe aren't even in the materials that we use today.

So that requires an investment that no company on its own can afford to do, and although we ourselves in industry put about $60 million a year into industrial, into university research on this, that is not enough to go after all the different materials that are possible. We have to focus those dollars on those things that we think can have the most promise going forward.

Dr. RUDNICK. On the medical front I think it is interesting to look at what happened at Liquidia. About five years ago the company was started. It was started with an idea that a little piece of film could have these nano-sized pores etched into it, and literally you could rub another piece of film over it, fill those pores, get drug substance out that was appropriately sized and shaped.

To take that from that concept that started the company and developed manufacturing that now can literally produce hundreds of thousands of feet of film per month filled with particles was about $25 million and about four years.

If the government hadn't stepped in and supplied some of the money through NIST to get that manufacturing ramped up, I doubt that venture capital would have been attracted to it. It would have been too early, too difficult, and there was no other place to go and get that level of resource to move it along except for that NIST funding for nano-manufacturing.

Mr. HARRIS. I have just a follow up on that but now that industry I think is going to realize the value of this, again, at some point, and I don't know. I mean, it could be a broad enough field that we should just always spend the same amount of money and look into different areas, but with regards to screening products the pharmaceutical industry which also has a pretty good balance sheet, I mean, they do the screening of their drugs on their own. I mean, they do the same thing. They screen hundreds and hundreds of chemical compounds to find the one that is the next blockbuster drug.

So,that is the only question I have, and very briefly, because Mr. Moffitt, you actually suggested that, I think in one of your answers that we should go actually beyond basic science and actually fund some of these things and get it further out, but I would say that— is that correct? Is that kind of what you had suggested, because to me the appropriate role of the government is to do something that no private individual would do, and to be honest with you, I had a little reticence. You know, the trouble with academic research, I love it, I did it, is that it is public domain. I mean, the Chinese have the access to the academic research that we fund, to be honest with you, which is different when industry does it, and it becomes something that is intellectual property that stays here in the United States.

So, Mr. Moffitt, if you could just follow up on that?

Mr. MOFFITT. It is a comment about crossing what I think everyone refers to as the Valley of Death. Once the basic core academic research is done, how do you translate that into something? If the folks doing the basic research don't have a vision and idea for what this could become, then there needs to be a vehicle for making that happen.

I think the venture capital community in this country is very efficient at picking the winners from the losers, and they are ready to put the significant, at-risk capital to work in the earliest stages, but there is a gap between those two. And what I refer to there, and I think it is a best practice that is occurring in some of our competitors around the world, competitive countries around the world, is they are finding a way to close that gap up, and they are doing it with either partnerships, private and public, or additional funding from government resources.

Again, targeted to very specific problems that are there. But—so it is all about getting the technology to the point where industry, the venture capital community can recognize the pathway forward from there. And then I think at those points they are happy to take it forward.

Mr. HARRIS. And if I could just, Mr. Chairman, just briefly follow up, just very briefly, observation is that some of the states, Maryland included, have said that is fine, but we could provide some of that venture capital to do that bridging to conventional venture capital, the difference being is when it becomes successful Maryland is making back some money, because we are actually bridging the venture capital.

Mr. MOFFITT. And there are good examples of that. Maryland is one state. There are other states where there are programs in place to help connect that link, if you will, and the payback is in the economies of those states.

Mr. HARRIS. Well, not only payback in the economy but also a true physical dollar payback.

Mr. MOFFITT. Sure. Return on investment.

Mr. HARRIS. Thank you, and I don't know, Chairman, Dr. Tour I think wants to follow up a little, and then I will yield back the balance.

Dr. TOUR. Could I make one comment?

Mr. HARRIS. Please.

Dr. TOUR. The reason why we need to pay students to do research is because we have to pay them. Students line up at medical schools and law schools to pay their way through. They don't do that with science. They haven't done that with science for 50 years. We do that as a Nation because we feel it is valuable to train students in science and engineering. We pay them because we have to.

I will give you an example. We were doing pure basic science, didn't know where it was going, graphene oxide. As soon as we saw the way it plugged filters, then we talked with our friends in the oil industry in Houston and starts going down hole to make cleaner drilling holes so that we get less infiltration.

So it is the basic science that has to be done to spawn the new ideas that are then going to be transitioned, and it is not all in the public domain. I have 50 patents all through the university. So that—because of the Bi Dole Act is given to the university. The university then has the power to license that out, and I agree with you. We first file the patent, then, boom, we publish the paper. So we do both.

Chairman BROOKS. Thank you. The Chair next recognizes Congressman Clarke from Michigan.

Mr. CLARKE. Thank you, Mr. Chair. I want to pick up on the line of questioning especially those issues raised by the good gentleman from Maryland, but I just want to preface my questions that I do not have an ideological agenda or position I am trying to push right now through this questioning.

I am going to ask you the questions for one reason. I would like to know the answers, and anyone can respond, but I am from metro Detroit. I am acutely aware of the fact that we need to create more jobs, and we got to do it faster. So how can we accelerate the commercialization of nanotechnology, and what do you think would be the most, not necessarily proper role but effective role for us to invest our tax dollars in this process?

And the reason why I ask this, especially in light of Dr. Tour's written testimony and verbal here, that outlined the strong global competition for U.S. researchers, that truly concerns me, on top of the fact that you have a lot of foreign students who are graduating from our great research universities, one of which is in the area that I represent, Wayne State University, yes, I am plugging them. And then those graduates end up going back home and not staying in the U.S. We want to try to keep them here, but that is a matter of immigration policy.

But still also for the same objective so that we can be truly competitive, and I want us to be number one in this area of commercialization, creating jobs in nanotechnology.

That is the end of my speech in essence. My question is genuine, though. How do we best leverage federal tax dollars to create more jobs in nanotechnology and create them quicker?

Dr. RUDNICK. May I start to answer that question? I don't know that I can fully answer it.

Chairman BROOKS. I think he left it up to any of the five who want to jump at the mic first.

Dr. RUDNICK. One thing that I think can be extremely helpful is for the government to recognize that there are positive and negative influences that they exert, and the setting of standards for the development of nanotechnology I think is a critical area, and whether you call them environmental and health standards or you call them manufacturing standards or whatever you choose to put behind them, the government can through NNI help to set positive standards to frame the types of examination that nanotechnology particles, for example, will have to make sure that there are standards available to people if they need to test and investigate.

And that is something that if it doesn't happen, if the national standards are not set and enforced in a reasonable and functional, the way the FDA practically does it for drug products, I think there is always the risk that things will slow down, and I would hate to see that happen, and so that is just one perspective and one small corner.

The idea of having foundries that can manufacture these particles for anyone to use and test and know that they are getting the same thing time after time, I think is a very useful NNI response.

Dr. WELSER. I would also like to add I think there is value to having these for the public-private partnerships. The NRI in particular when we started it was sort of an experiment for the industry in that this was research that was really quite far out for us, something that we normally didn't get involved with, but we saw the urgent need with this transition coming up in the industry to start doing some funding on it, and we found that even though we were funding chemists, physicists, material scientists doing very basic work, having the industrial assignees working with them, we could identify ideas much more quickly that looked that they might actually solve a problem we would have or look like it could actually go do something different.

So rather than having that be just a pure science result, we could more rapidly say, well, let's take the science, learn the science, and also think about how you would apply it.

Mr. CLARKE. This is at the basic research level?

Dr. WELSER. Very basic research level.

Mr. CLARKE. Okay.

Dr. WELSER. So, for example, graphing material, there was a physicist down at U.T. Austin who had come up with an idea for making room temperature excitons, I am sorry, made excitons, great idea, didn't mean a whole lot. We asked him, well, could it ever be done at room temperature, he never even though of that, went and looked at it and said, actually, it could. It could be one of the first room temperature excitons. It is a great science result. If it is true, it actually could make a device that would be a thousand times less energy than our current CMOS transistors. So obviously of clear interest to us.

So we are hoping that that kind of interaction, even at the early stages, can identify things that we could move more rapidly.

Dr. TOUR. I think that money is always a great incentive, and if we want to push these out faster, one of the things that we could do is to say, when I am speaking to an industrial entity to say, look what I have got, if you start to invest in this to do this transition of this nano-material into your business, there are certain laws that would give you different tax structure during this phase that are particularly enhancive to, would particularly enhance this system, this particular type of research.

And whether it be 15 cents that the U.S. Government would put in on the dollar that the company would put in or if it would be some other type of incentive in this way.

Mr. CLARKE. Dr. Tour, I know my time is up, this is very important. Is there a way that you could get me some bullet points of these types of proposed incentives that could work at different stages of the process?

Dr. TOUR. Absolutely.

Mr. CLARKE. I really appreciate it, and I am Hansen Clarke from Detroit.

Dr. TOUR. Okay.

Mr. CLARKE. Thank you.

Dr. TEAGUE. May I add a few comments from the federal program, please? Yes. All right. I just wanted to point out that within the new NNI Strategic Plan that there are two aspects of it that I think move in the direction that several of the Congressmen has spoken about.

One is the three signature initiatives that I talked about. These signature initiatives are really aimed at moving maybe towards slightly the next stage but still being in basic research, but they are really aimed to focus upon a number of common areas that are seen as being of high economic importance and national importance, and trying to align the resources of all the 25 federal agencies, at least those that have interest in those signature initiatives, to move towards the direction of maybe not, certainly not commercialization, but certainly to try to make the next stage, moving towards the application areas and to some degree trying to move the technology that came out of exploratory research into some of the next stages that Dr. Welser and some of the other ones have spoken about.

That is their principle aim is to align the resources of those interested federal agencies toward common thrust areas and toward common targets that identified and all the agencies that are working, agencies working on it have agreed.

The second thing that I would point out is that within the EHS Research Strategy the principle goal of that EHS Research Strategy is to both look at simultaneously the safety as far as human health is concerned and as far as the environment is concerned, but also to make sure that the commercialization of things are not limited and are actually boosted by this trying to focus on environmental health and safety aspects of nanomaterials.

Many people have said that one of the potential greatest barriers to commercialization of nanotechnology products is concern about the environmental health and safety. So I think that this focus by the agencies, particularly those in the regulatory community, to focus on both the safety aspects of it as well as the advancement of the technology and the commercialization of the technology, it is really quite an important move by the agencies to assist and to aid commercialization and technology advancement.

So I would encourage you to really take some look hard at all three of the signature initiatives and to the new EHS Research Strategy once you have it in your hands.

Chairman BROOKS. Before we get to our next member, Congressman Tonko, I am going to add that we have a little bit of time for additional questions, so should any member want to ask some more, just let me know, and we will have a second round.

With that we have Congressman Tonko of New York.

Mr. TONKO. Thank you, Chairman, and thank you and our ranker for what I think is a very important discussion. Let me thank our panel for the guidance that you are providing.

I represent the capital region of New York, which is the third fastest growing hub of science and tech jobs, high-tech jobs, a lot of it driven by the investment we have made in nanoscience. So I totally respect the impact that it can have favorably on our economy.

Dr. Welser, in your testimony you mentioned that the NRI research is extremely in early stage, and like most scientific researches it is unlikely to become part of a commercial product for ten years or more. Is there any concern that that ten-year delay in a commercial product will have a negative impact on the semiconductor industry?

Dr. WELSER. Yes, certainly. I think that we are after this right now because we know in about ten years we will have no other alternatives, but there is a long way to go in the next ten years. Just making the current technology we are constantly struggling to make things smaller and smaller, and that is really, of course, what scaling has all been about.

And particularly in the patterning side of things, this is—there are some huge roadblocks ahead. We have been using what they call 193 nanometer light for quite awhile. We really need to move to smaller wavelengths. We are making features now in the order of 30 nanometer, so EUV, extended UV is a major focus right now of work within industry consortia and with government partners. Semi Tech in your area, of course, is a leader on this as well, and that—the solutions are not there yet. It is not only just making it work, but there is still materials work that needs to be done, understanding how to get light sources that can work, and on top of that we also think ultimately we need to think about patterning with other methods and combining that with things like directed self-assembly or other mechanisms.

So there is a long way to go just to make sure our current technology continues forward.

Mr. TONKO. And what role, I mean, what can we best do to move the EUV concepts along? I mean, it seems as though it is going to be a very pricy investment, but there obviously should be a partnership with the government I would hope.

Dr. WELSER. I absolutely agree. I think that, particularly if you consider the competition out there, the other countries already, of course, are striving to get more and more of the FABs over there. Very fortunately, of course, Global Foundries has recently chosen to put a FAB in the U.S., which is, I think points to the fact that all of our companies really would like to have FABs in the U.S. if the business environment is right and if we can be close to hubs where the R&D is going on.

So having a partnership with the government for this incredibly expensive development that needs to go on and research on the basic materials that are there is the only way we will remain competitive with the other countries that are putting that money in.

Mr. TONKO. It frightens me that whoever gets that investment as a nation will be controlling the job count out there, and while everyone is bulking up with investment, we are talking about defunding, which is a frightening thought.

Dr. Teague, do you agree with those recommendations made by Dr. Welser, and could you also incorporate your comments on the signature initiative in terms of how it could help us pull us into the right direction here toward that effort?

Dr. TEAGUE. I definitely agree with Dr. Welser's comments on the need for that, and I think that if you look at, particularly the signature initiative on nanoelectronics for 2020 and beyond, these are, I think, quite well aligned with some of the directions and the emphasis and the needs that are needed for advancing these next electronics.

I might just point out that we have four thrust areas within the Nanoelectronics Signature Initiative, and I think that they are quite well aligned with a lot of the directions that the Nanoelectronics Research Initiative by the SRC and the electronics industry is taking.

If I may just read those, and he might, Dr. Welser might comment on them, the first one of the thrust areas is exploring new and alternative state variables, architectures, and modes of operation for computing. I know this—I am quite confident this is very parallel to what the NRI is doing.

Merging nanoelectronics with nanophotonics and exploring carbon-based nanoelectronics, exploring nanoscale processes and phenomena for quantum information systems, and national nanoelectronics research and manufacturing infrastructure network that is university based in their overall infrastructure.

We currently are trying to, as I say, align the activities of the main agencies which are concerned with this, the National Science Foundation, the National—NIST, DOE, and DOD in these areas.

The next step that I think will be taken with the signature initiatives is to start interacting more with private industry for a possible public-private partnerships but mainly to try to make sure that what the agencies are doing, what they are funding is aligned with, to some degree, what is happening out in industry.

Mr. TONKO. I note that I am running out of time, but if you could get back to me personally or to the committee about how to grow the public drive, the general public, to push nanoscience. So many times that is what is needed in our culture. You have other cultures that are pushing investment in science and technology. We seem to be concentrated on entertainment and sports cultures and are lulled, we are somewhat lethargic about investing in science and technology. If any of you as panelists here could advise us on how we can engage the public to drive the advocacy for investment in this area, I would love to hear that.

Dr. TEAGUE. I couldn't agree with you more on that. After working with it, as I indicate, for the past period that I have been, the engagement of the public and mounting their interest in the nanotechnology, both in terms of its potential and in terms of the knowledge of it, efforts are being made to make it be a safe technology right from the start is something that I think we truly need to make sure the public fully understands and hopefully accepts rather than being potentially afraid of it.

Mr. TONKO. Uh-huh. Well, as a kid I saw that general passion of the Nation to be the first to land a person on the moon. I would love to see that sort of passion again for nanoscience.

Thank you, Mr. Chair.

Chairman BROOKS. Thank you, Mr. Tonko.

I have got three questions. The first one is to Dr. Teague, the second one would be all witnesses, and the third one would be for you all to digest and get back to us on.

Dr. Teague, what continues to be the primary concerns about the environmental health and safety impacts of nanotechnology?

Dr. TEAGUE. I think in terms of the general concern, if you are talking about the general concern sometimes of the public or the particular genuine concerns that are held by the scientific community, people that are involved in toxicology and the health aspects of nanotechnology, as well as the potential hazards that might it be posing for the environment, much of it is still remaining lack of knowledge of how some of the nanomaterials may potentially cause harm to human health and to the environment.

The investments by the National Nanotechnology Initiative member agencies, and I am pleased to say that we have had joining this year the Food and Drug Administration, as well as the Consumer Product Safety Commission in investing some in R&D for nanotechnology.

Our focus and I would say they have been pretty measured, as well as targeted, and trying to answer these questions and to come up with increased knowledge about the potential hazards of nanomaterials is the greatest concern. There has been much growth, much effort in this direction. I think the NNI and the NNI member agencies are making great progress. Our investments in the United States are far beyond any other country in the world, including the entire European Union, in this area, trying to understand it.

We have for the entire period of the NNI led the world in trying to understand these potential hazards of nanomaterials.

The—and I think the EHS strategy lays out a wonderful path forward in terms of how we will try to address this. The—all the agencies that have worked on the EHS strategy has really been laying out a great program to achieve the goals of making it safe and also being able to advance the technology of nano.

They call it their risk management research framework, and this overall framework of trying to take account simultaneously of safety concerns as well as those that are needed for advancing the technology is, I think, an excellent path that they have laid out. It has been developed with huge inputs from the entire community. We have had four different workshops over the past year to get great input from the experts in the field of toxicologists to help especially the fields that might be concerned about environmentalists, to lay out this path.

And so I hope that we can address this particular concern.

Chairman BROOKS. This one is for all the witnesses. Are current federal and private research efforts adequate to address concerns about environmental health and safety impacts of nanotechnology, and why does the Federal Government need to increase spending of EHS activities in the White House budget fiscal year 2012 by 36 percent over fiscal year 2010 which was 44 percent over fiscal year 2011 continuing resolution?

And that is for whomever of you may wish to address that issue as to why the need is so great for increased funding on EHS activities.

Dr. TOUR. I don't agree that we need that increase. I would rather see that increase be put into the basic research because as basic researchers we are already doing a lot of the EHS. When we are studying nanoparticle toxicity in our animal models for therapeutics, we are already gathering a lot of that data. I have been in companies that are thinking about incorporating nano, and they already have a lot of the testing that they are doing as part of their normal regulatory work that they are doing.

So I am not sure that there needs to be that increase.

Chairman BROOKS. Anyone else have any judgment to share?

Mr. MOFFITT. I am not an expert. I can't speak to the increase itself and the detail of the budget, but I would say this. I do think it would be irresponsible of us in our—in this industry to continue to develop these products without understanding the long-term downstream implications of them and the impacts on these materials that we are making.

And I think if I think about Congressman Tonko's question about how to engage the public, I think this is an example of how we help engage the public, which is by reassuring them that these materials are not dangerous or, in fact, getting the answers if they are and how to handle them.

Chairman BROOKS. Any other insight?

Dr. TEAGUE. May I just add a few comments on that in response?

Certainly the percentage of increase is from the continuing resolution in 2011, and from the actual amounts expended in 2010. I think your—I wouldn't question your figures on that, but I would make sure that everybody is understanding that these increases still bring the total investment by all the NNI agencies and the environmental health and safety research still remains at something like five percent of the overall NNI investment.

This seems to be quite, as I say, that—and even that level has been very carefully looked at through a lot of consultation across the federal agencies, through all the input that I mentioned through workshops outside, through PCAST recommendations, through recommendations from the National Academy of Sciences.

So the current investments and these increases still by many people in the field think that that is too small, but I think because of the careful consideration of inputs from a broad range of stakeholders and from, as I say, PCAST and the Academy of Sciences, those increases are really quite justified in consideration of the hazards which many people think need to be addressed and better understood.

Chairman BROOKS. Dr. Welser, excuse me, Welser or Dr. Rudnick, do you all have an opinion you wish to share? If not, that is okay.

Dr. WELSER. I think I would like to reinforce the two opinions to the left in the following fashion. I think that I can't judge the overall amount and the value of that amount, but I can say that there is a great deal of work that is already going on in terms of safety of these particle-like products, and it is being done as part of the medical development of them, and not sharing that information across agencies would be a mistake.

And I think that has been one of the great strengths of NNI which is the sharing of information across agencies has been strong. I would hope that however the budget is constructed and however the workshops are constructed going forward that that continues to be the case.

Chairman BROOKS. Thank you. If we provide each of you with a copy of the text of House Resolution 554, the NNI Reauthorization Bill from the last Congress, would you please provide us with feedback for the record? Share with us your insight on the verbiage that is used and the scope of that legislation?

All right. We will do that.

Next, Mr. Lipinski, Ranking Member, do you have some follow-up questions?

Mr. LIPINSKI. Thank you, Mr. Chairman, and one area that I was going to go down, and you did a good job covering in the—in your questions there, and I certainly just want to echo the sentiments that we have heard from some of our witnesses about the importance of environmental, health, and safety research and the need to be investing in that.

The question I had about computer chips, our current chips are 32 nanometers. The next generation, maybe next year or maybe sooner, 22 nanometers. As we approach 10 nanometers, everything changes, quantum mechanics.

I want to ask Dr. Teague and Dr. Welser what is being done for research as to what we do next given the importance of rising computational power, and is there anything more that needs to be done, anything more that the—can be done by the Federal Government in helping industry deal with this issue?

Dr. WELSER. So I will start if you don't mind since this is exactly where the NRI is focused. I think we all realize that while we see a roadmap around 10 nanometers, and no one wants to predict exactly whether it is 10 or 8 or 5, but somewhere in along that line, but the current devices, we know that in the next ten years the reason the NRI is looking out beyond that is because we know it needs to be completely different at that point.

At that point it doesn't become about shrinking anymore but actually about finding a different device, which probably means different materials, certainly means different physics needs to be involved because we understand the limits that we are reaching with our current physics, and it is actually all about energy and power it turns out. The problem isn't necessarily that you couldn't go maybe slightly smaller, but the energy these things utilize, the power density on the chip is just too large at that point. So finding physics that can reduce that energy is huge.

So all the things I am listing there and you heard the five areas that the NNI has also targeted all are about finding basic new physics and materials to carry this forward, and I think that it is so critical to do it early because although we can take it eventually to industry and actually do something with it that makes it into a product, we have to have a firm basis that has already been done at the research lab level before we can really take that in.

Mr. LIPINSKI. Dr. Teague.

Dr. TEAGUE. I am not sure that I can add a lot to what Dr. Welser said. I am not an expert by any means on quantum information systems. What I do hear much and I read much about the great promise that people see in moving to quantum information, computing quantum information, communication systems, and overall quantum logic devices.

For many people these seem to be the long, long range of what people hope to do. As we run upon the barriers of quantum mechanic tunneling at the distances that we are talking about, 10 nanometers and below, much of the classical way that we have looked at building electronic devices, electronic computing systems, we will run into barriers that we cannot overcome because we have run into the ends as far as the basic physics of those kind of systems.

Even there as indicated by these five different ways in which the agencies have laid out their path forward on nanoelectronics for our 2020 and beyond, that is one of the paths that is to be followed and to try to pull together all of the—and align the efforts of the agencies along those directions.

The other one is the one that I think the NNR, NRI, and as well as the agencies are going to be pursuing is looking at other state variables other than electronic charge. This seems to be one of the paths that is looking at, looks a lot promising. For instance, spin systems, using spin as the state variable rather than the electronic charge is one option that people are looking at. I am not an expert in this field and would hesitate to say that that is one of the more promising ones. There are a lot of others. I think Dr. Welser could maybe speak much more knowledgably about that, so I would be interested in his thoughts on that.

Dr. WELSER. Well, I am not going to pick a winner here today. If we knew that, we would go after it, but I will say the spintronics in the area of carbon electronics clearly show huge advantage.

I realize one other part of your question was what—are we doing enough? What more could we be doing? I think one of the things that does concern me is because of the fact we have been very careful in terms of where we focus this, we are looking at just the main transistor switch right now, and that is, of course, the building block that the entire chip industry is built on, but going along with that, if we move to spin or if we move to something completely different, you need to figure out how you are going to interconnect that, how you are going to build memory devices that go with that, the architectures and circuits that go along.

One of the important things about the signature initiative is it pulls together people who think about circuits and architecture and memory devices with the people who do transistors and then the people who do physics and chemistry, and in getting those people altogether and a critical amass of funding to enable them to do their research in their areas is something that I think is crucial to actually finding a technology and rapidly moving it in rather than waiting until we find the perfect device and then suddenly say, wait, now we got to figure a circuit that is going to be used.

So I think that is a real value to these signature initiatives in these areas.

Mr. LIPINSKI. Thank you.

Dr. TEAGUE. Just one last comment on that. Dr. Welser mentioned the spin and also with new carbon-based electronics. The one thing that I think that is very, very much overlapping between what the government agencies are doing, hopefully there is great communication with industry, but all of them are looking at how do the architectures, the basic overall architecture of the computer change as you move into these new systems.

Much, much thought to be given to how do you completely restructure the electronics, reconstruct the entire way that logic is done in—as you do computing.

Another one that should be considered is the coupling between nanoelectronics and nanophotonics. Light-based aspects of the computing architectures are also beginning to play a major role in even current computing systems.

Mr. LIPINSKI. Very good. Thank you.

Chairman BROOKS. Well, there go those bells again.

I thank the witnesses for their valuable testimony and Members for their questions. The Members of the Subcommittee may have additional questions for the witnesses, and we will ask you to respond to those in writing. The record will remain open for two weeks for additional comments from the Members.

The witnesses are excused, and this hearing is now adjourned.

[Whereupon, at 4:09 p.m., the Subcommittee was adjourned.]

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Response by Dr. Clayton Teague, Director, National Nanotechnology Coordination Office (NNCO)

Questions Submitted by Chairman Mo Brooks

Q1. What impacts are environmental, health, and safety concerns having on the development and commercialization of nanotechnology-related products and what impact might these concerns have in the future.

A1. The introduction of new technologies and substances into commerce should be not only economically and socially beneficial, but also have minimal impact on humans and the environment. Our goal is to avoid problems that can arise when inadequate attention is given to environmental, health, and safety (EHS) concerns.

If we are slow to develop the information needed to ensure that we are producing nanomaterials with minimal adverse impact, there are two primary ways in which EHS concerns may affect the development and commercialization of nanotechnology-related products: uncertainty whether some nanotechnology-enabled products may harm human health and the environment, and perceptions that regulatory uncertainty is harming the business environment.

Uncertainty Whether Nanotechnology-enabled Products May Harm Human Health and the Environment. EHS concerns arise when there is a lack of scientific knowledge to guide the assessment of the potential risks and proposed benefits of a new technology on human health and the environment. To create that scientific knowledge base for nanotechnology, the NNI agencies whose missions encompass health and the environment began research to understand the interactions of nanomaterials with biological systems in parallel to fundamental materials research and product development as early as 2001. This EHS research is guided by the NNI Strategy for Nanotechnology-Related Environmental, Health, and Safety Research. [1] This strategy identifies, targets, and accelerates the research needed for risk assessment, risk management, product development, and science-based regulation. As research data accumulate and are transferred into knowledge, design and engineering of nanomaterials is improved and an increasingly stable climate for development and commercialization of nanotechnology-related products is established, outcomes that may increase consumer confidence and product use. The NNI agencies understand the need to communicate safety information as research data are developed. The 2011 nanoEHS research strategy, now in final review, identifies research needs for risk communication. [2] The NNI Strategic Plan outlines several 3—5-year objectives under Goal 4: Responsible Development of Nanotechnology that provides agencies with concrete steps to develop effective means to engage the public in ongoing dialogue on nanotechnology.

Perceptions that Regulatory Uncertainty is Harming the Business Environment. There is concern about the potential for safety regulations to slow economic growth. However, transparent, consistent, and scientifically—-based regulations decrease uncertainty about the regulatory and economic climate.

The NNI regulatory agencies have reviewed their existing authorities against our current scientific understanding of the human and environmental impact of size and emergent properties of nanoscale materials and have determined existing regulatory authorities to be, for the most part, appropriate to ensure the safety of the American people. Modifications to existing rules and safety evaluation procedures will be made only where necessary to ensure product safety. Regulatory agencies are also working with their industrial stakeholders to assist them in navigating the nanotechnology regulatory landscape.

US nanotechnology regulatory policy is coordinated through the White House Emerging Technologies Interagency Policy Coordination Committee (ETIPC). The committee has developed a set of broad principles to guide the development and implementation of policies for oversight of emerging technologies at the agency level and additional guidance specific to regulatory oversight of nanotechnology is to be issued. [3]

In combination, these components of a science-based research and regulatory approach to nanomaterials and nanotechnology-enabled products will promote the

[1] http://www.nano.gov/node/254

[2] The draft of the 2011 strategy is available at http://strategy.nano.gov/blog/generic/page/draft-nni-ehs-strategy.

[3] http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Principles-for-Regulation-and-Oversight-of-Emerging-Technologies-new.pdf

positive economic climate necessary for U.S. technological and industrial leadership while protecting public health and the environment.

Q2. In your testimony, you state that the "NSET Subcommittee anticipates incorporating participation and input from industry and other stakeholders on current and future nanotechnology signature initiatives". How will the Subcommittee obtain this input? Will they target specific industries or use input from a broad sample of nano-related industries? Was industry and outside stakeholder input utilized when developing the current signature initiatives?

2a. How will the NSET Subcommittee incorporate participation & input from industry and other stakeholders on current & future NSIs? How will the Subcommittee obtain this input? Was industry and outside stakeholder input utilized when developing the current signature initiatives?

The Nanotechnology Signature Initiatives (NSIs) mechanism and the initial NSI topics are the result of an extensive internal Executive Branch process. The mechanism and three initial topics received strong endorsement from industry and other stakeholders when they were publicly released. As this new NSI process enters its next phase of development, processes for seeking input and participation from industry and other stakeholders on future signature initiatives are being explored.

Previous stakeholder input. The NSET Subcommittee's charter formally designates the President's Council of Advisors on Science and Technology (PCAST) as the NNI private sector interface. PCAST, in its capacity as the designated National Nanotechnology Advisory Panel (NNAP), has reviewed the NNI three times. In its most recent review, completed in March 2010, PCAST endorsed the concept of the NSIs and the three initial NSI topics, and then called for development of at least five such initiatives over the next 2–3 years. The NSET Subcommittee charter also specifies that the subcommittee may also interact with and receive ad hoc advice from other Federal advisory bodies and private sector groups, consistent with the Federal Advisory Committee Act. Accordingly, the NSET Subcommittee established three additional channels for external stakeholder input during 2010, as it was formulating its updated NNI Strategic Plan (released in February 2011): (a) an NNI Strategy Portal website (http://strategy.nano.gov), (b) a formal Request for Information published in the Federal Register, and (c) an NNI Strategic Planning Stakeholder Workshop, held in July 2010. The NSIs were regarded positively by participants in all three venues.

Options for future stakeholder input. Several options are under consideration. First, PCAST (or the NNAP) will continue to serve as the NSET Subcommittee's primary private-sector interface, and future NNAP reviews of the NNI will carefully evaluate the NSI process and the topics that have been selected through it. Second, the NNI Strategy Portal remains active, and may be re-tooled to seek specific stakeholder input on the NSI activity and suggestions for future NSI topics. Third, the February 2011 NNI Strategic Plan states that NNI will work with industry across sectors to develop technology roadmaps, or long-term R&D plans, as appropriate, in support of new public/private partnerships and signature initiatives. This input may take the form of roadmapping workshops at which industry views will be sought out, and at which other stakeholders will also be welcome. NIST[4] and NSF[5] have already held two such workshops in support of the sustainable nanomanufacturing signature initiative. Finally, NNCO has just created a new Industry and State Liaison (ISL) staff position. The ISL staff member at NNCO will be tasked with seeking stakeholder input on signature initiatives as well as other aspects of the NNI.

2b. Will they target specific industries or use input from a broad sample of nano-related industry?

2b. The NSIs are targeting issues of national importance, not specific industries. For the three existing signature initiatives:

The "Nanoelectronics for 2020 and Beyond" initiative is focused on maintaining the economic and national security benefits that resulted from the sustained improvements in performance and affordability of semiconductor electronics described by Moore's Law. Naturally, this has involved working closely with the semiconductor and electronics industries. The

"Solar Energy Collection and Conversion" initiative targets improvement in U.S. energy security, which in turn has major implications for national security. It also supports research on new sources of energy that have the potential for reduced environmental impact.

[4] http://www.nist.gov/cnst/thenewsteel.cfm
[5] http://www.internano.org/nanosystems

The "Sustainable Nanomanufacturing" initiative endeavors to retain within the United States a significant portion of the economic "value added" from nanotechnology innovations by assuring that these innovations are not just invented here, but also made in the United States. A good case in point is the semiconductor industry, which involves manufacturing at the nanoscale, and which provides many high-paying jobs in the United States, not just for scientists and engineers but also for skilled technicians and other manufacturing workers. In order to establish a realistic scope, this initiative targets production-worthy scaling of three classes of materials that have the potential to affect multiple industry sectors with significant economic impact (carbon nanomaterials, cellulosic nanomaterials, and optical metamaterials).

For future signature initiative topics, there are no pre-conceived target industries. The criteria for signature initiative topics are:

- They address an area of high national priority, e.g., national security, energy independence, or health or are supportive of other Presidential priorities or the President's A Strategy for American Innovation.
- TThey are ripe for significant advances through accelerated, targeted research.
- Achievement of the research goals requires multiple agency participation at the programmatic level.

Q3. The FY 12 Budget Request highlights three signature initiatives related to solar energy, nanomanufacturing, and nanoelectronics. Why is there a need for signature initiatives? Will a focus on these areas take away from other much needed nano-related research? Based on the budget charts for these activities, it appears that this is a new line item for many agencies, as they are showing zeroes in FY 11 funding. I feel certain that most of these agencies have been investing in these areas for years. Can you please explain the discrepancy?

Q3a. Why is there a need for signature initiatives?

A3a. The NNI has been successful at increasing communication and coordination among U.S. Government agencies involved in nanotechnology R&D, including multi-agency Funding Opportunity Announcements. The signature initiatives build on this success by developing a more integrated and focused mechanism for interagency collaboration. Through this enhanced coordination, existing agency resources will be leveraged more effectively, duplication of efforts will be minimized, and goals accomplished more expeditiously.

Restricted budgets provide a second rationale for an NSI mechanism. While the NNI has, by most accounts, been a very successful basic research initiative with numerous NNI-funded innovations entering the market place, prioritization of the NNI investments into key areas of significant benefit to the American people will leverage funding more effectively and structure investments to maximize tangible returns.

We also note that one of the three major issues that the 2010 PCAST review of the NNI addressed was "Nanotechnology Outcomes-An analysis of what the Federal nanotechnology investment has delivered and recommendations to enhance the outcomes, especially economic outcomes."[6] PCAST's recommendations in this regard include that the NNI should "increase its emphasis on nanomanufacturing and commercial deployment of nanotechnology-enabled products, and that the agencies within the NNI must interact and cooperate more with one another to ease the translation of scientific discovery into commercial activity".[7] The Signature Initiative on Sustainable Nanomanufacturing directly addresses these recommendations. The other two initial signature initiative topics also address them; the objective is to accelerate the development of novel nanoelectronics and solar energy technologies to the point at which they have the potential to be competitive in the marketplace and commercially viable. Because the magnitude of the effort needed to make each initiative successful-multiple agencies funding both basic and applied research in close cooperation with industry-and because the expected returns on the investment are large but difficult for any one company to appropriate, it is reasonable for the government to support the NSIs.

Q3b. Will a focus on these areas take away from other needed nano-related research?

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[6] President's Council of Advisors on Science and Technology, Report to the President and Congress on on the Third Assessment of the National Nanotechnology Initiative, 2010, p. viii. (http://www.nano.gov/node/623)

[7] Ibid., p. ix.

A3b. No. The NNI retains a core of fundamental research that is essential to maintaining the flow of new ideas into the innovation pipeline. While PCAST recommended increased NNI emphasis on manufacturing and commercialization, it also indicated that this should be done "while maintaining or expanding the level of basic research funding in nanotechnology." The FY 12 NNI budget request is consistent with this recommendation: Program Component Areas (PCAs) 1 and 2 (fundamental phenomena and processes and nanomaterials, respectively) combined still account for a majority of the NNI funding request, while increased investments in nanomanufacturing (PCA 5) and devices and systems (PCA 3) are requested.

Q3c. Based on the budget charts for these activities, it appears that this is a new line item for many agencies, as they are showing zeros in FY 11 funding. I feel certain that most of these agencies have been investing in these areas for years. Can you please explain the discrepancy?

A3c. Yes, some of these agencies have had substantial investments in areas related to the signature initiative topics for years, however none of the participating agencies have line items in their budgets for the Nanotechnology Signature Initiatives. The numbers that are reported for the signature initiatives in the NNI Supplement to the President's 2012 Budget are crosscuts on other line items. The reason that some agencies report no funding for FY 11 in this report is that as of the time the report was prepared, none of the agencies had received their FY 11 appropriations and therefore many agencies had not allocated funding to that level of detail. Others interpreted the guidance differently, and re-allocated funds within their interim FY 11 budgets towards these priority areas. What is new for the NSIs is the focused, targeted, interagency collaboration, the specific "expected outcomes," and the focus on exploiting advances in nanotechnology to achieve those outcomes.

Q4. With regard to the Signature Initiatives in the FY 12 Budget Request (solar energy, nanomanufacturing, nanoelectronics), why is it appropriate for the Federal government to identify specific issue areas for research focus ? How do we not pick technology winners and losers by doing this? Are these the most critical areas that the Federal government should be focusing its limited resources? What critical areas are missing? What other grand challenges do we face with nanotechnology? What role should the government play in setting "Grand Challenges"? What are some examples of "Grand Challenges" in nanotechnology and are we ready to tackle them yet?

Q4a. With regard to the Signature Initiatives. why is it appropriate for the Federal government to identify specific issue areas for research focus?

A4a. The U.S. Government has historically prioritized basic research topics, especially when budgets are restricted. Following the PCAST recommendation to maintain the NNI's basic research funding, a large portion of the total NNI investment remains devoted to funding of investigator-initiated research topics: anyone with a new idea for a nanoscience or nanotechnology research topic can propose that idea for funding through the NNI agencies' core programs. However, it is also appropriate for a portion of the investment to be targeted to national priorities, especially in areas where the extensive internal NNI review process has concluded that there is potential for nanotechnology to have a significant impact on these national priorities, and where the efforts of multiple agencies are needed to realize this potential.

Q4b. How do we not pick technology winners and losers by doing this?

A4b. Ultimately, the marketplace will pick the technology winners and losers. The task of the Federal Government is to 1) prioritize research investments that may have particular promise for commercial or military applications; 2) support pre-competitive basic and applied research that will help to mature technologies, products, and services; and 3) structure investments in a manner that maximizes the potential for U.S. industry to take advantage of nanotechnology-enabled opportunities.

Q4c. Are these the most critical areas that the Federal government should be focusing on with its limited resources?

A4c. Yes. As described above under 2d, the three current signature initiative topics were chosen because the nanotechnology basic research had matured to the point where materials, platforms, tools, and approaches are ripe for significant advances through close and targeted program-level interagency collaboration. Additionally, and as discussed previously, the potential applications in each NSI topic areas address major national priorities, and plans are under development to engage industry and other stakeholders.

4d. What other grand challenges do we face with nanotechnology? What role should the government play in setting "Grand Challenges?" What are some examples of "Grand Challenges" in nanotechnology and are we ready to tackle them yet?

4d. "Grand Challenges" were topics of national importance included in the original NNI Implementation Plan of 2000.[8] The NNI investment strategy no longer includes separately identified "Grand Challenges", in part because many of the original "Grand Challenges" fell within the mission of a single agency. The 2004 NNI Strategic Plan introduced the seven Program Component Areas (PCAs) to organize and track NNI investments. The PCAs were revised in the 2007 NNI Strategic Plan to break the previous "societal dimensions" PCA into separate PCAs for environment, health, and safety (EHS, PCA 7) and education and societal dimensions (PCA 8). The Nanotechnology Signature Initiatives that were initially proposed in the NNI Supplement to the President's FY 11 Budget have some elements in common with the original NNI "Grand Challenges." For example, both mechanisms direct a portion of the NNI investment portfolio to basic and applied research that targets specific objectives of national importance. Unlike "Grand Challenges", the new Nanotechnology Signature Initiatives outline more specific expected outcomes, plans to achieve those outcomes through multi-agency collaborations, and identification of topics that clearly fall within the missions or needs of more than one agency.

Q5. It is clear that nanotechnology promises many amazing breakthroughs while also being surrounded by a great deal of hype, mostly positive, a little negative. Help me put this in perspective and get a better sense of the real potential—over the next five to ten years, how do each of you think nanotechnology will impact our lives and our economy?

A5. While we cannot predict the future, the potential of nanotechnology to revolutionize a variety of industrial sectors and to profoundly affect our economy and our lives is a near certainty. As Dr. Teague stated in his testimony, there are a number of breakthroughs and advances that are already available or will be commercially available in the near term. For example, nanotechnology-based medicines are now in clinical trials. Some use nanoparticles to deliver toxic anti-cancer drugs targeted directly to tumors, minimizing drug damage to other parts of the body. Nanotechnology is helping scientists make our homes, cars, and businesses more energy-efficient through new fuel cells, batteries, and solar panels, as well as through new nanomaterials that are stronger, lighter, and more durable than the materials we use today in buildings, bridges, and automobiles.

Nanotechnology has the potential to 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. To frame this more broadly in terms of impact, it hard to quantify the potential of the emerging field of nanotechnology, just as it is hard to accurately explain the tremendous impact of the IT revolution. Consider this: the fact that we have much faster computers, and that we can quantify exactly how much faster they are, is not in and of itself an accurate assessment of the impact of the field on our lives or the economy. It is in what we can do with these faster computers and how that has changed virtually every part of our society that truly illustrates that point.

The bottom line is that nanotechnology is expected to be as ubiquitous as IT. Nanotechnology, by definition, is an enabling technology that is applicable to virtually every field of science, technology, and engineering, and as such, it is quickly providing the ability to fundamentally change the way we create and utilize everything around us. This case is already true in the electronics field; if you are not currently using nanotechnology, you are simply not a competitor in the field.

Nanotechnology funding has a remarkable return on investment when viewed in terms of expected job creation and the potential for significant economic growth. 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.[9] A variety of sources have come to the conclusion that nanotechnology will be between a $1–3 trillion business by 2015.[10]In fact, just one NNI agency program-the National Science Foundation's Nanoscale Science and En-

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[8] National Nanotechnology Initiative: The Initiative and its Implementation Plan, NSTC/NSET Report, July 2000, pp 47–68 (available at: http://nano.gov/sites/default/files/pub—resource/nni—implementation—plan—2000.pdf.)

[9] Roco, Mirkin, and Hersam, Nanotechnology Research Directions for Societal Needs in 2020, Springer, Boston and Berlin, 2010. (http://wtec.org/nano2/)

[10] 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)

gineering Centers (NSECs)-has contributed to 175 nanotechnology-related startup companies and collaborations with more than 1200 other companies. This is an indicator of the potential of NNI investments to stimulate economic activity, and shows a clear desire on the part of industry to actively collaborate on NNI projects.

Government support for nanotechnology research and development is required to ensure that the United States can maintain a competitive position in the worldwide nanotechnology marketplace while realizing nanotechnology's full potential.

Q6. Per my request at the hearing and as you are aware, the House passed legislation to reauthorize the NNI once in the 110th Congress and twice in the 111th Congress, only to see it die in the Senate. I would hope that the nanotechnology research world has changed somewhat in the past three years since this Committee last held a hearing on the topic and drafted legislation. Using H.R. 554 from the last Congress as a basis (attached), please provide feedback by commenting on the merits of that bill and any areas that you see room for improvement or changes.

A6. The responses below were developed principally by the NNCO staff in cooperation with Dr. Teague, OSTP, and the NNI agencies. We thank the Committee for this question and appreciate the opportunity to comment on provisions within H.R.554. Our staff is well aware of previous legislative attempts to reauthorize the NNI, and have performed periodic analyses of them as these bills have progressed. These analyses are somewhat lengthy and cannot be fully covered here. Below we will provide only a summary of the most important points.

In general, H.R.554 contains many positive updates and improvements to the original NNI authorizing legislation. In particular, we point to the provisions aimed at enhancing cooperation and partnering of the NNI with industry and State nanotechnology initiatives, and also the topical emphases supporting education, commercialization, and infrastructure.

However, we also feel that many of the provisions establish programmatic reporting requirements which may prove very burdensome to NNI agencies, and thus provide a disincentive to continue participating in the NNI. Specific examples include an expansion in the number and scope of strategic planning documents and the creation and maintenance of extensive databases, which may prove costly and have no specific funding dedicated to them. Additionally, the statement in a number of provisions of specific topic areas to be researched or reported on may hinder the evolution of NNI priorities over the coming years.

More specific issues which we have identified with the previous legislation include:

- Recommendation of an independent Nanotechnology Advisory Panel: The last two Administrations have strongly recommended that this panel remain a subcommittee of the PCAST, to keep it integrated with the rest of the scientific advisory process which advises the OSTP and the President, and to minimize costs. The previous three PCAST reviews have proven very valuable and have significantly improved the functioning of the NNI.
- TIP focus on Nanotechnology: This provision requires the National Institute of Standards and Technology (NIST) to encourage the Technology Innovation Program (TIP) to fund nanotechnology programs, and report the details of these efforts. This statutory emphasis on nanotechnology does not exist for other technology sectors, and in fact the TIP emphasis on funding areas of national importance might be skewed by such a singular provision.
- Research in Areas of National Importance: While this provision may be valuable in principle, the specific phrase "The Program shall include." could impinge on the planning of a balanced portfolio of research topics in the future. We recommend the alternate phrasing "The Program may include."
- Nanomanufacturing Research Program Component Area: As with the previous bullet, the specific phrasing that the Nanomanufacturing PCA "shall contain" the list of specific research topic areas may restrict planning of a balanced portfolio of research topics in the future. Again, we recommend the alternate phrasing "The Program Component Area may include."

OSTP staff would welcome the opportunity to discuss their views with the Committee members and staff in greater detail as future re-authorization legislation is developed.

Questions from Ranking Member Daniel Lipinski

Q1. During his oral testimony, Dr. Tour stated that there is no need to increase federal investments in environmental, health, and safety (EHS) risk research because, in his experience, the private sector already does sufficient testing on their products to meet regulatory requirements. Do you agree with this statement ? Is industry investing sufficiently in EHS risk research and testing to protect the public, the environment, and workers from potential downsides of nanotechnology ? Please elaborate on your answer. Why are federal investments in EHS risk research under the National Nanotechnology Initiative (NNI) so important, and why has the Administration increased those investments over the last couple of years ? How will the new NNI EHS Strategy help guide the Agencies to integrate and leverage their EHS research ?

Q1a. Do you agree with Dr. Tour's statement?

A1a. Dr. Tour's statement suggests that safety assessment of individual nanotechnology-enabled products and platforms is sufficient testing for all aspects of nanoEHS research. This is true if all products fall under the purview of U.S. regulatory authorities, however many products and commercial uses of nanotechnology fall outside this scope.

For nanotechnology—-enabled products that fall under the regulatory auspices of FDA, CPSC, USDA, and EPA, existing regulatory authorities help to ensure the safety of the American people and their environment. If questions about the adequacy of regulatory oversight are identified, agencies are able to review those regulations and testing requirements and modify them, as necessary, to ensure safety. However, there are many consumer products that fall outside of these regulatory authorities. Examples include children's toys, air filtration devices, clothing, and a myriad of electronic devices. The market for nanotechnology-enabled commercial products is estimated at up to $3 trillion by 2015, a figure that suggests that many nanomaterials and nanotechnology-enabled products will fall outside of the safety testing authorities of U.S. regulatory agencies. [11]

Numerous research studies have demonstrated that a change in the location of a single surface modification on a nanomaterial can alter its physical and chemical properties, and hence, its behavior in biological systems. Therefore, there is a need for more generalizable, basic research about classes of nanomaterials and categories of biological responses, as well as product-specific safety testing. EHS research funded by the NNI research-mission agencies includes basic research that is critical to the development of the nanotechnology knowledge base that will simultaneously promote product development as well as applied product-specific testing, to protect public health and the environment.

Q1b. Is industry investing sufficiently in nanoEHS research?

A1b. Because of intellectual property and confidential business information rules, it is not possible to estimate with any accuracy the industrial investment in nanoEHS research. Furthermore, industry addresses safety issues for its product line and gaps in research between product lines would develop, thus impeding the development of a robust knowledge base. Industry has expressed repeated support for EHS research and for clarity in the regulatory landscape; several industries have developed hazard assessment programs; and many have instituted worker protection programs. These programs may have generalizable components, but they are developed to address a specific industry's issue and address very specific risk considerations.

Q1c. Why are federal investments (in EHS) important and why have they been increasing?

A1c. Federal investments in nanoEHS research are critical to the development of the vast data and knowledge base necessary to perform the risk assessment and risk management that promotes a positive nanotechnology business climate and facilitates the responsible development of nanotechnology. This scope of research—both applied (product or process specific) and basic—is beyond the scope of what can be achieved and publicly shared by industry. It is critical to the successful achievement of all NNI goals-from R&D to tech transfer, workforce development, as well as use of nanomaterials in green chemistry and manufacturing, and remediation of the environment, and for global acceptance of U.S. nanotechnology-enabled solutions and products, and to U.S. global leadership.

[11] 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)

The NNI investment in nanoEHS research has been increasing as agencies built an early foundation of research that can now be expanded to achieve the objectives for EHS research laid out in Goal 4 of the Strategic Plan: Responsible Development of Nanotechnology.

Q1d. How will the new NNI EHS Strategy help guide the Agencies to integrate and leverage their EHS research ?

A1d. The 2011 NNI nanoEHS research strategy, now in final review before public release, contains guiding principles to assist agencies' development of their mission-specific nanoEHS research strategies, and frameworks within which to shape their implementation plans.[12] These principles and frameworks were developed by trans-agency writing teams and are based on integration of the well-established scientific constructs of risk assessment and product life cycle assessment, constructs that cut across agency missions and identify critical research needs that are shared across agencies.

The nanoEHS research strategy also contains principles to target and accelerate research, such as criteria to select which nanomaterials to study, guidance to maximize data quality, and mechanisms to partner with industry and international stakeholders. To promote the continuous coordination that is essential to ensure the integration of agency implementation plans, the NSET Nanotechnology Environment and Health Implications (NEHI) working group established an implementation and coordination framework that includes: increasing agency participation in NNI EHS research, refocusing the NEHI Working Group monthly meetings, coordinating existing and fostering expanded agency efforts to address priority EHS research needs and identified gaps, and adaptively managing the NNI EHS Research Strategy as new data and research needs become apparent.

[12] The draft final nano EHS research strategy is available at http://strategy.nano.gov/blog/generic/page/draft-nni-ehs-strategy

Response by Dr. Jeffrey Welser, Director, Nanoelectronics Research Initiative, Semiconductor Research Corporation

Questions Submitted by Chairman Mo Brooks

Q1. What impacts are environmental, health, and safety concerns having on the development and commercialization of nanotechnology related products and what impact might these concerns have in the future?

A1. The semiconductor industry has been building products with nano-sized features (e.g. the nanoscale junctions of transistors which are involved in transmitting, processing, and storing information) for some time with a proven track record of strong environmental, occupational health and safety commitment and results. These nano-sized features are etched or otherwise modified into the semiconductor matrix, e.g., a silicon wafer, and are not discrete engineered nanomaterials, and do not pose a unique or novel health risk. Today, the use of nanomaterials in the semiconductor industry is limited to the use of slurries containing nano-sized particles in chemical mechanical polishing (CMP), a manufacturing step in the production of semiconductors. However, these particles are not incorporated into the product, but instead are used to "polish" or "smooth" the surface of the semiconductor wafer during manufacturing.

Although nanomaterials are not used today, the semiconductor industry and its members are engaged in active research programs to explore the role of engineered nanomaterials in future semiconductor/ICT innovations and applications. The semiconductor industry understands that there are environmental, health, and safety concerns related to the use of discrete engineered nanomaterials in consumer products, and that because of the limited information available, there are uncertainties regarding the potential risks associated with the use of discrete engineered nanomaterials. The semiconductor industry has taken proactive steps to respond to this uncertainty. Members of the semiconductor industry are among the first companies to create safe work practices and health and safety training for its employees who work with engineered nanomaterials. The semiconductor industry and its members are actively supporting and partnering with governmental agencies, academic institutions, and other organizations to develop the necessary environmental, health, and safety information that lead to greater human health and environmental protection, and we are committed to the responsible and sustainable development of nanotechnology and use of engineered nanomaterials.

Q2. Are current federal and private research efforts adequate to address concerns about environmental, health, and safety impacts of nanotechnology? Why does the federal government need to increase spending on EHS activities in FY 12 by 36 percent over FY 10 (44 percent over FY 11 CR)?

A2. In light of the potential significance of nanotechnology in future technological advancement and economic growth, federal support for research in this area, including EHS impacts, should continue to be a priority of federal spending. Continued and increased federal support for EHS activities related to nanotechnology is warranted because the promise of this technology will be influenced, in part, by the scientific community's understanding of the EHS impacts of this technology. The ultimate acceptance by the consumer and the public of this technology, both in the U.S. and globally, will also be dependent on the perception of EHS impacts.

The key question for NNI, however, is not simply on the magnitude of the EHS spending, but rather whether that spending is targeted at the right areas. Priority should be given to high quality research that addresses broad needs and nanomaterials with the greatest potential for impacting health or the environment. NNI also should support efforts to advance best practices and standards that remove barriers to commercialization and use.

Q3. It is clear that it is important to improve our understanding of any environmental, health, and safety issues associated with nanotechnology and resolve uncertainties related to the regulatory regime that will govern nanotechnology-related products. What should our priorities be for research on environmental, health, and safety issues? How should these priorities be set? What role should the federal government, academia, and industry, respectively, play in conducting such research?

A3. Examples of areas that NNI should prioritize include:

- Development of tools and methods for accurate measurement and testing of nanomaterial interactions with biological systems and the environment. Research on rapid screening methods (that may both use nanotechnology and can be applied to characterization of nanomaterials) to reduce the time, cost, and need for animal testing. The Nanotechnology Characterization Laboratory is a valuable resource for evaluation of cancer nanotechnology that advances characterization techniques broadly.

- Engaging in international standards activities related to nanomaterials definition, characterization, and risk assessment.
- Promoting wide dissemination of information, such as the Nano Registry of nanomaterials supported by NIH and the workplace information available from NIOSH.
- Focusing implications research (toxicology, environmental fate and transport, etc.) on materials that are most likely to find application. Many materials that are the subject of NNI university research will not transition into practical application.

Q4. Your testimony states "with more federal money focused on near-term—rather than long-term—research projects, the country runs the risk of under-funding the scientific research pipeline which our industries rely on for future innovation." Please explain the risk associated with near-term research over long-term research. How can we ensure dollars are best being utilized in terms of project subject matter, not simply duration of project?

A4. In general, technology industries invest a large amount into R&D each year—the semiconductor industry, for example, invests 17% of revenue on average. The majority of this is necessarily focused on areas that will have near-term impacts on new products and innovations, but given the nature of technology research, it has never been able to fund the scientific research that is needed to form the basis of new technology innovations. Even when there were more large industrial labs, such as Bell Labs, it still required almost $5B (2004 dollars) in mostly government investment over ten years to deliver the first prototype of a semiconductor diode. DoD funded this with a partnership between the government, university, and industry labs in order to insure technical superiority in air missile technology. Bell then invested an additional $25M—a very large investment by an individual company's perspective—to create the first commercial version that launched the IT revolution.

To understand the underlying public benefits associated with nanotechnology creation and diffusion, one must be cognizant of the complex relationships between basic and applied science, innovation, market and systemic failures, and technologically enabled economic progress. Individual firms have an incentive to perform near-term, applied nanotechnology research that can ultimately be commercialized and profitable. While this is understood, it's helpful to take a step back and look at the larger, comprehensive picture—a picture that is enabled by government funded basic research. This phenomenon is well-supported by economic theory and case studies.

Economic theory provides solid justification for a government role in helping to form the bedrock of the nano-enabled future. Market failure analysis demonstrates that, without government intervention, nations will ultimately result in a less than optimal level of research and knowledge. Such is the case with the nanotechnology sector. The "perfect competition" model assumes no uncertainty in production and utility functions, and that all the factors relevant to production and societal welfare are traded openly on the market. The very nature of nanotechnology R&D embodies uncertainty, especially at the nascent stages we find ourselves in.

Arrow cites three classical economic reasons, based heavily upon welfare economic theory, behind the failure of the market to allocate resources at the optimal level. They include indivisibilities, inappropriability, and uncertainty. Firms, operating under normal market conditions, depend upon the government to fund pre-competitive scientific knowledge that spawn and enable new industries. These new industries or processes can represent major new technological shifts, evidenced by the progression from vacuum tubes to the transistor era. Nanotechnology basic research will foster the ecosystem that forms pre-existing, underlying knowledge. This knowledge serves as the precursor to widespread industrial production and commercialization approximately ten years down the road or more.

The second issue that brings about market failure is the "inappropriability" factor. When producers cannot realize the benefits of knowledge in the short-term, they in turn have little incentive to invest in basic research. Such is the case with advanced nanoelectronics and the nation's quest to discover the next logic switch. While the semiconductor industry widely recognizes that a nanotechnology solution is the only way to surpass the physical limits of current scaling technology post-2020, no one company or even groups of companies possess the infrastructure or the funds to invest in the basic research associated with this broad, national innovation challenge. Therefore the government must play a central role.

Nanotechnology firms or companies that use nano-applications, invest heavily in the near-term, applied research, especially if anticipated breakthroughs are production relevant and there are probable opportunities for private profit driven by market forces. Therefore, it is basic research (the type of nanotechnology research that is arguably the most beneficial to society and that significant advances affecting many industries will stem from) that suffers from market failure in the biggest way. Basic research explores fundamental questions and concepts. "The goal of scientific activity is discovery, the goal of technological effort is productive results," states Rosegger. Firms specializing in nanotechnology and applications have little incentive to carry out such-long term research, due mostly to the third factor Arrow and Nelson highlight: uncertainty. Basic research results may not be applicable or pay off in the end. The long timeframe between the commencement and the creation of something worth selling is often beyond the outlook of firms looking to maximize profits in the short-run. The inability of the market to embrace substantial long-term risks leads to this overall under-investment. Insurance firms will not insure research results, unlike a farmer whose crop is damaged due to storms or floods. Research is risky. Some investments in nanotechnology will yield dead ends, while others will pay off beyond imagination. Society benefits either way, as the research is conducted by people. These people attain a first rate education, experience and valuable tacit knowledge that will later be used in the marketplace.

Several recent case studies highlight the economic impact of the federal investment in scientific research. Shultz documents how early government investment in nanotechnology research has helped the University at Albany's College of Nanoscale Science and Engineering (CNSE) serve as the center of a cluster of over 250 industrial affiliates in upstate New York. The program has attracted over $6 billion in public and private funds over the course of the past decade. "Since 2001, there has been qualitative and quantitative evidence of the emergence of a nanotechnology cluster in the Capital Region of NY. Upstate NY has become home to multiple nanotechnology firms and experienced growth in the employment in nanotechnology related industries," states Shultz. For instance, private semiconductor manufacturing investments in the region are skyrocketing with the addition of a new chip foundry ($5-$6 billion initial investment, with the possibility of future expansion) being erected nearby CNSE. In a separate study of the economic impact of the federal investment in the Human Genome Project, the authors found that $3.8 billion in government funding "helped drive $796 billion in economic impact." These are good examples of fundamental research that has produced a host of new capabilities, businesses and jobs. There are many others.

In order to find new breakthroughs, early-stage research on nanoelectronics (or other nano areas) must look broadly at many different potential paths; some of the discoveries will lead to breakthroughs for the semiconductor industry, some will lead to breakthroughs for other industries—or even create new industries—and all will add to the scientific knowledge needed to build our innovation future, sometimes in ways we can't foresee yet. Therefore the proportion of funding done by government and industry needs to follow this same "funnel" flow: At the early stage, government must invest in many broad ideas to feed into the funnel; as the potential of specific ideas because more apparent, industry should be more closely involved and contribute more funding; when the ideas look like they could impact a specific product area in the relatively near-term (3–5 years), the majority of funding and direction should come from industry.

And by having industry consortia involved throughout this funnel process—even at the beginning when the work is more exploratory and predominantly funded by the government—the identification and acceleration of good ideas towards products can be achieved. Early interest from industry also serves as a good verification that the project subject matter is likely to have large impact on future innovations, leading to higher economic impact and job growth.

Q5. With regard to the Signature Initiatives identified in the FY 12 Budget Request (solar energy, nanomanufacturing, and nanoelectronics), why is it appropriate for the Federal government to identify specific issue areas for research focus? How do we not pick technology winners and losers by doing this? Are these the most critical areas that the Federal government should be focusing its limited resources? What critical areas are missing? What other grand challenges do we face with nanotechnology? What role should the government play in setting "Grand Challenges?" What are some examples of "Grand Challenges" in nanotechnology and are we ready to tackle them yet?

A5. In times of limited resources, it is especially critical that the Federal government balance supporting a broad range of basic science research with focusing on areas of research most likely to result in future economic impact. The Signature Initiatives are a good attempt to do this by picking areas where there is a clear national need for new technological breakthroughs and where the new capabilities offered by nanotechnology could result in relevant scientific discoveries. While it is never possible to predict exactly where the next breakthrough will occur, setting Grand Challenges helps to focus limited resources in areas of high potential, and the three areas currently chosen for Signature Initiatives all seem to be appropriate. Moreover, by specifying that these Initiatives should be pursued by multiple agencies, and in conjunction with industry consortia as appropriate, the limited resources are better coordinated across the government and better leverage private investments—avoiding redundancy and accelerating the overall progress. They also encourage students to enroll in STEM fields related to these Signature Initiatives and spur academia to perform research, knowing they are a priority for the nation.

To avoid picking "winners and losers", it is important that the Grand Challenge areas are all broadly defined, so that they do not force researchers in to looking at just one solution area. For example, the Nanoelectronics Signature Initiative has as its primary goal the discovery of new technology—an alternate state variable device—that can advance the entire semiconductor and electronics industry, but it does not specify what that state variable or device should be. It does highlight several areas that currently appear promising (e.g. carbon electronics, nanophotonics, and quantum information processing), but it does not limit the potential research directions in any way. It also emphasizes increased investments in the research infrastructure at universities, necessary both to keep the U.S. at the forefront of nanoelectronics research and maintain the pipeline of relevantly-educated students.

This approach is similar to the way the Nanoelectronics Research Initiative (NRI) structures its own public-private partnership program. The NRI vision is to maintain a "goal-oriented, basic-science research" mission, where academics are made aware of the high-level challenges and needs of the nanoelectronics industry, but allowed to explore a broad range of research topics that could potentially address these challenges—or create whole new approaches that would circumvent them entirely. In choosing other areas for Grand Challenges or Signature Initiatives, this same vision is appropriate, and three criteria in particular should be met:

1. The basic research that is funded is top-notch and leading edge.
2. The researchers who are proposing research are aware of potential applications and of relevant industry needs.
3. To the extent possible, "potential future customers" of the basic research (i.e. industry and other developers of practical applications down the road) should be connected to the Federally funded research.

Q6. It is clear that nanotechnology promises many amazing breakthroughs while also being surrounded by a great deal of hype, mostly positive, a little negative. Help me put this in perspective and get a better sense of the real potential—Over the next five to ten years, how do each of you think nanotechnology will impact our lives and our economy?

A6. While nanotechnology has the potential to revolutionize everything from medical care to energy production, predicting exactly where the next breakthroughs will occur and what their impact will be is very difficult. However, the area of electronics stands out historically as having had outsized impacts on the economy, as well as enabling breakthroughs in many other areas of science and technology. As mentioned in my testimony, U.S. semiconductor companies generated over $140 billion in sales—representing nearly half the worldwide market, and making semiconductors the nation's largest export industry. The industry directly employs over 180,000 workers in the U.S., and another 6 million American jobs are made possible by semiconductors. Moreover, studies show that semiconductors, and the Information Technologies they enable, represent three percent of the economy, but drive 25 percent of economic growth. This remarkable impact has largely been due to the power of scaling to increase the function / dollar of semiconductor chips each year, and hence there is an urgent need to find nanoelectronic devices that will continue to drive this economic engine. At the same time, future nanoelectronic semiconductors will be crucial for solving many of the other major challenges facing society today.

Why do we need even more capable technology? Imagine a future in which a child with diabetes no longer has to prick her finger to check her glucose or get insulin shots thanks to an implanted artificial pancreas; when smart tools and sensors enable a highly efficient electric grid that saves billions of dollars in wasted energy costs and avoids the need for new power plants based on non-renewable energy;

where cell phones automatically translate your conversation into any language required; or powerful systems to design and manufacture new materials for radically lighter, yet safer, cars and planes. In addition, nanoelectronics is crucial to maintaining the U.S. leadership in High Performance Computing (HPC). HPC has been behind nearly every major scientific advance and innovation in the past decade, in energy, materials science, engineering, life sciences, and defense and security. In biology in particular, the sequencing of the human genome was arguably as much a triumph of computing technology as it was of medical science. And increased computational capability is crucial for advancing microbiology and chemistry, from the study of protein folding to new drug discovery.

While we don't know exactly what all the new breakthroughs in nanotechnology will bring in the next decade, we do know that almost all of them will rely on breakthroughs in advanced nanoelectronics to be realized.

Q7. Per my request at the hearing and as you are aware, the House passed legislation to reauthorize the NNI once in the 110th Congress and twice in the 111th Congress only to see it die in the Senate. I would hope that the nanotechnology research world has changed somewhat in the past three years since this Committee last held a hearing on the topic and drafted the legislation. Using H.R. 554 from the last Congress as a basis (attached), please provide feedback by commenting on the merits of that bill and any areas that you see room for improvement or changes?

A7. Passage of legislation authorizing activities for support of nanotechnology research and development would send a clear message to the Federal research agencies that nanoscale science and engineering is a priority of the Congress and to the private sector, including investors, that nanotechnology has the potential to provide significant benefits. The latest bill (H.R. 554) clearly strives to build upon the original act (PL 108–153), which put into law the framework for what has been a highly successful multi-agency program. Various amendments appear to clarify issues, for example related to the support of the National Nanotechnology Coordination Office (NNCO), however, there are some concerns about H.R. 554.

The bill requires that the NNI strategic plan include a description of research in areas of national importance, encourages Federal-State-industry-university partnerships, and establishes a process to ensure that our research facilities have the equipment and operating funding necessary to support the needed research. These are all good attributes of the legislation and will further research in nanoelectronics and other areas that are useful to the semiconductor and other industries.

In its current form, the bill calls for a significant number of new management and oversight activities that are notable in their extent, specificity, and detail. We do not know of any other Federal research program that has such detailed spelling out of activities in the authorizing legislation. A concern is that the time and cost of fulfilling all of the specified activities and reports takes away from resources that would otherwise go toward accomplishing the research goals of the program. Moreover, given the program is primarily about interagency coordination and collaboration, one wonders if agencies will be disincentivized from participating, thereby decreasing the very activities that are intended to be encouraged. By funding nanotechnology research, an agency must, for example:

- Report information about each project on EHS, other societal dimensions, or nanomanufacturing;
- Participate in development of multiple research plans, one on EHS that is updated annually, and a detailed annual report;
- Fund the NNCO and periodic reviews of the program by the National Research Council; and
- Provide detailed information annually on nanotechnology-related SBIR and STTR proposals received vs. funded.

The bill also requires a new Presidential advisory panel, rather than allowing for an existing body to be designated. Currently the duties of the National Nanotechnology Advisory Panel are being carried out by the President's Council of Advisors on Science and Technology (PCAST), the highest level Presidential science and technology advisory body. Requiring a separate body loses the benefit/option of having such high level attention and scrutiny and adds considerable cost.In addition to the extensive prescribed management, the tone and emphasis of H.R. 554 seems skewed toward activities related to "societal dimensions" of nanotechnology, particularly the planning, overseeing, and tracking of research on the environmental, health, and safety (EHS) risks that may be associated with nanotechnology. For example, a separate subpanel of the advisory panel is required to evaluate the EHS and other societal aspects. All informal, precollege, or undergraduate nanotechnology education must include education regarding EHS of nanotechnology. The NNCO is to maintain a public database of information about individual projects on EHS and other societal dimensions, as well as nanomanufacturing. Why single out these areas? We have heard that efforts are underway to develop publicly accessible information for research in all areas (via research.gov), thereby making this provision unnecessary.

Section 3(a) creates a Coordinator for Societal Dimensions of Nanotechnology at the level of an Associate Director in the Office of Science and Technology Policy. The individual is responsible primarily for overseeing implementation of various planning, reviewing, and reporting activities called for in the bill. This new position is not necessary; these functions seem more appropriate for the NNCO and we have learned that the current NNCO Deputy Director has been named EHS Coordinator for the program. It appears that in order to accomplish the level of planning, coordination, and reporting already called for has led to the development of a well-organized, functioning interagency management structure. The saying, "If it ain't broke, don't fix it" comes to mind.

Section 5, entitled Research in Areas of National Importance, directs that agencies identify and support those areas of greatest potential benefit in collaboration with each other and with the private sector so as to ensure efficient uptake. We feel this is a valuable addition to the program; in fact, it is the section of the bill that is most clearly focused on the benefits of nanotechnology and therefore would provide some balance to bill if it were moved to follow Section 2. As the Nanoelectronics Research Initiative has demonstrated, such approaches can be extremely effective at focusing research, easing technology transfer, and promoting joint/leverage support for fundamental scientific research.

As Congress works to reauthorize the NNI, it should continue to highlight nanoelectronics to ensure the U.S. will lead in this area which is essential to economic growth and societal progress:

1. Continue to include specific authorization for support in *research areas of national importance* and explicitly note that *nanoelectronics research* is one such area;
2. Request that the *National Academies* include a nanoelectronics study as part of its triennial external review of the NNI;
3. Address the need for nanoelectronics research infrastructure, i.e. *equipment* and equipment operating funds, at universities and national laboratories;
4. Specifically encourage direct *industry-government partnerships*—including state government involvement—in support of nanoelectronics research at universities and national laboratories.

In addition to the above overarching comments, we offer the following specific recommendation.

- In Sec. 2 (8), we strongly encourage inserting "engineering" in the definition of Nanotechnology so that it reads, "The term 'nanotechnology' means the science, engineering, and technology that will enable." This is more complete and engineering connects science and technology through practical application of discovery research.

Question Submitted by Ranking Member Daniel Lipinski

Q1. Do you agree that current federal investments in environmental, health, and safety (EHS) risk research are important to industries, such as your own, that do or will benefit from developments in nanotechnology? Why? What specific aspects of EHS research are of primary importance to the semiconductor industry? Does the semiconductor industry invest in those areas of research? If so, at what level relative to federal investments? What do you see as the relative roles of the government and industry related to EHS risk research? Are there specific areas of EHS research in which the federal government should increase its investments? Does the new NNI EHS Strategy address those areas adequately? By what mechanisms could government and industry work more collaboratively to address risk-research needs for nanotechnology?

A1. Federal investment to address EHS concerns associated with emerging technologies, such as nanotechnology, is a critical part of a robust and complete research program. Broadly, there is general awareness that nanoparticles can behave differently from their larger scale counterparts. These differences can lead to beneficial applications, such as more efficient catalysts for cleaner combustion and other processes. The federal investment in EHS research is contributing to the widespread understanding of how nanoparticles interact with biological systems and helping all stakeholders—researchers, regulators, environmental groups and public health officials, workers, consumers, and others—to be informed. This is critical to realizing maximum benefits from nanotechnology while at the same time assessing any risks.

Whereas the Federal EHS research should focus on providing broad understanding of potential risks and the tools with which to measure and assess those, industry focuses on materials and processes related to specific products. The semiconductor industry has made, and continues to make, significant investments into addressing EHS concerns associated with our industry. For example, the industry funds the SRC/SEMATECH Engineering Research Center for Environmentally Benign Semiconductor Manufacturing based at the University of Arizona specifically to do research on EHS issues important to our industry (not just related to nanotechnology). This Center is constantly looking at the materials and processes that are relevant to the industry to identify potential concerns early on, and to find ways to mitigate these and improve our processes overall. Based in part on its work, the industry has an accomplished record of success in reducing emissions, phasing out the use of potentially harmful chemicals, and minimizing risks to workers.

It is important to note that this Center was originally started in 1996 with joint funding from NSF and SRC/SEMATECH, and since 2006 when NSF funding ended industry has continued to support the program. This experience illustrates the vital role that federal funding plays in initiating key initiatives and leveraging the support of private industry. It also is an example of industry and government working together to support research to address industry-related EHS research needs. It should be noted that SRC has implemented this type of federal-private partnership with NSF and NIST for research in a number of fields in addition to EHS aspects of nanotechnology.

Responses by Dr. Seth Rudnick, Chairman, Board of Directors, Liquidia Technologies

Questions for the Record submitted by Chairman Mo Brooks

Q1. What impacts are environmental, health and safety concerns having on the development and commercialization of nanotechnology-related products and what impact might these concerns have in the future?

A1. In our (life science) business, the existing EH&S policies and procedures are being rigorously applied to our products, and appropriately so through the FDA. We feel these existing policies and procedures are indeed adequate as they exist and we would hope that additional resolutions only be instituted if proven to be needed; however, it is not obvious that regulatory changes need to be made in the life science arena.

Q2. It is clear that it is important to improve our understanding of any environmental, health and safety issues associated with nanotechnology and resolve uncertainties related to the regulatory regime that will govern nanotechnology-related products. What should our priorities be for research on environmental, health and safety issues? How should these priorities be set? What role should the federal government, academia and industry, respectively, play in conducting such research?

A2. Clearly current policies and procedures for the approval of vaccines and drugs seem to be adequate as presently crafted and implemented. However, there may be needs for updated EH&S rules and regulations for products outside of FDA jurisdiction. It is worth noting that nanomaterials are often heterogeneous systems; as stated in another way, they are intrinsically "mixtures." Current EH&S policies and procedures, as well as the basic science of EH&S, are inherently structured to deal with uniform or singular entities. As such, we believe two things are needed: (1) calibration-quality standard nanomaterials and (2) new, fundamental approaches to the EH&S study of mixtures. Calibration-quality particles that are cost-effective and readily available to researchers to perform their studies are desperately needed. Such nanomaterial samples are different in scale and cost to that which is provided by NIST, which are primarily intended to calibrate instrumentation.

Q3. With regard to the Signature Initiatives identified in the FY 12 Budget request (solar energy, nanomanufacturing, and nanoelectronics), why is it appropriate for the Federal government to identify specific issue areas for research focus? How do we not pick technology winners and losers by doing this? Are these the most critical areas that the Federal government should be focusing its limited resources? What critical areas are missing? What other rand challenges do we face with nanotechnology? What role should the government play in setting "Grand Challenges?" What are some examples of "Grand Challenges" in nanotechnology and are we ready to tackle them yet?

A3. It is hard to imagine that nanomedicines, vaccines and diagnostics (the life sciences) are not specifically called out as a Signature Initiative. The application of nanosystems in the life sciences is poised make some of the most important and most immediate impacts on our society and our economy. The U.S. needs to continue to lead this important area which not only paves the way for more efficient and safer vaccines and therapeutics, but earlier detection which will save an enormous number of lives and drive down costs, having extraordinary impact on global health. Our company is poised to release better vaccines which may be 100x cheaper than the current multibillion dollar products. We have been able to accomplish this by co-opting the top-down nanomanufacturing tools of the computer industry to enable entirely new concepts in the design of vaccines. Indeed this has enticed the Bill and Melinda Gates Foundation to make their first equity investment ever in a biotech company.

Q4. It is clear that nanotechnology promises many amazing breakthroughs while also being surrounded by a great deal of hype, mostly positive, a little negative. Help me put this in perspective and get a better sense of the real potential—over the next five to ten years, how do each of you think nanotechnology will impact our lives and the economy?

A4. In our field, consider that within the timeframe you suggest we expect to see a new, superior influenza vaccine with high response in the elderly (the elderly are currently underserved by today's vaccine technologies); a next generation malaria vaccine; a dramatically cheaper pneumococcal vaccine-so much cheaper that it has the potential to drive down costs in the developed world and enable global access in a way that currently is not possible; more effective inhaled medicines to treat asthma, COPD, PHT, and cystic fibrosis; and perhaps most importantly, effective cancer therapeutics that have fewer side effects and next generation cancer vaccines which harness the body's own immune system to fight the cancer.

Q5. Per my request at the hearing and as you are aware, the House passed legislation to reauthorize the NNI once in the 110th Congress and twice in the 111th Congress only to see it die in the Senate. I would hope that the nanotechnology research world has changed somewhat in the past three years since this Committee last held a hearing on the topic and drafted the legislation. Using H.R. 554 from the last Congress as a basis (attached), please provide feedback by commenting on the merits of that bill and any areas that you see room for improvement or changes?

A5. Our primary comment is that the life science arena needs to be a significant focus along side of solar energy, nanomanufacturing and nanoelectronics.

Responses by Dr. James Tour, Professor of Chemistry, Computer Science and Mechanical Engineering and Materials Science, Rice University

Questions Submitted by Chairman Mo Brooks

Q1. What impacts are environmental, health, and safety concerns having on the development and commercialization of nanotechnology-related products and what impact might these concerns have in the future?

Q2. It is clear that it is important to improve our understanding of any environmental, health, and safety issues associated with nanotechnology and resolve uncertainties related to the regulatory regime that will govern nanotechnology-related products. What should our priorities be for research on environmental, health, and safety issues? How should these priorities be set? What role should the federal government, academia, and industry, respectively, play in conducting such research?

A1–2. Nanotechnology stands alone for one reason in particular: it is extraordinarily broad. That breadth allows nanotechnology to bring together formerly separate fields of study to maximize the strengths and utility of each. It has also enhanced the education of a new generation of students. But breadth also has its disadvantages: chief among these is that researchers and manufacturers are becoming overwhelmed with calls for compliance to unclear safety regulations [1] while regulators are becoming frustrated because noncompliance is the inevitable consequence.

We acknowledge and respect the efforts of our colleagues working across a broad array of organizations when they devise protocols that encourage prudence and safety. This is laudable and worthwhile, and as nanotechnologists ourselves, we are pleased to be part of a community that is attempting to avoid the environmental and human disasters that have blemished other areas of research. We echo here the occasional frustrations of those experts who find that the generalities in nanotechnology can make compliance to recommendations exceedingly difficult noting, for instance, that attempts to implement voluntary reporting have generally failed [2]. Clearly, regulations are needed to keep the practice of science safe. At the same time, nanotechnology must not be regulated out of existence. Prudence motivates us to practice our science safely, but also to refrain from stifling overreaction, or what others have termed, "paralysis by analysis [3]," in the calls for fences around nanotechnology.

Oftentimes things are most easily demonstrated by view of an analogy. Let us consider the field of "metertechnology." Metertechnology is defined here as research and technology development at the length scale of approximately 0.1–1 meters. If regulatory demands on nanotechnology were mirrored in this new field, the metertechnologist would be required to:

- "provide long-term environmental and health monitoring and research into early warnings," +
- "systematically scrutinize claimed benefits and risks," +
- "identify and work to reduce scientific 'blind spots' and knowledge gaps," + and
- "account fully for the assumptions and values of different social groups" +

+ footnote below1A[3]

How do metertechnologists follow such directives? Are they adequately specific? Or would proper compliance paralyze the research and manufacture of metertechnology-based items? It is clear that properties and hazards of materials for a given size domain are often not generalizable across length scales. However, ill-defined calls, such as those identified above, are too broad to provide meaningful input to an individual or manufacturer seeking to ensure the safety of their particular research or products. How have other fields of science dealt with these issues?

[1] http://www.rsc.org/chemistryworld/News/2009/June/16060901.asp Accessed Feb 1, 2010.
[2] Maynard, A. & Rejeski, D. Nature 460, 174 (2009).
[3] Hansen, S., Maynard, A., Baun, A. & Tickner, J.A.. Nature Nanotech. 3, 444–447 (2008). Quoting recommendations originally published by the European Environmental Agency. Harremoes, P. et al. European Environmental Agency, Copenhagen, 1896–2000 (2001).

[3] Hansen, S., Maynard, A., Baun, A. & Tickner, J.A.. Nature Nanotech. 3, 444–447 (2008). Quoting recommendations originally published by the European Environmental Agency. Harremoes, P. et al. European Environmental Agency, Copenhagen, 1896–2000 (2001).

The organic chemist well-appreciates that each new organic compound must be studied for its own set of toxicities. Changing the orientation of a single methyl group, for example, can cause a steroid to change from being a highly beneficial pharmaceutical to something of no utility or even frighteningly toxic. Some polychlorinated biphenyls (PCBs) are toxic, but that does not encompass all organic compounds, and not even all phenyl-containing compounds or chlorine-containing compounds. Vinyl chloride is a potent carcinogen, but its polymerization product, poly(vinyl chloride), is used to make pipes that deliver drinking water. These facts come as no surprise to the organic chemist, who studies each compound individually, and restricts any generalizations so that they apply only to a well-defined and specific class of materials. The product of a chemical reaction is not the sum of its parts.

For nanomaterials, the effects of size scaling can be just as significant as that of manipulating chemical side groups. For example, a long multi-walled carbon nanotube has been identified to be toxic in inhalation experiments, acting much like asbestos in its interactions with biological organisms[4]. But it has also been observed that the body is able to clear foreign objects whose lengths are comparable to or less than the diameter of phagocytic cells (10—20 microns) 1A5. If one chemically cuts a nanotube so that it is 30 nm long, and also renders its surface hydrophilic so that it dissolves readily in blood plasma, is it still toxic? Unfortunately, media reports of the conclusions of individual research studies relevant only for specific conditions could lead to inappropriate extrapolations regarding nanomaterial safety by the public and even other scientists who are not toxicity experts[6].

In contrast to the simplified views at times promulgated by the media6, within the scientific communities working in this area, there is a growing understanding that details of individual nanoparticles need to be considered, rather than generalizations. A 2008 review of the nanotoxicity literature includes numerous studies demonstrating that modifications in nanomaterial surface properties yield significant alterations in their biological responses[7]. These conclusions are similar to those of a recent Toxicological Sciences review, which highlight the importance of "an overall picture of material-specific rather than nanogeneralized risk", and state that "generalities with regard to biocompatibility do not appear to be valid"[8].

Recent challenges in Europe surrounding regulation of carbon nanotubes illustrate this gulf between regulation and scientific understanding as well as the difficulties of overly broad terminology. Companies must provide safety data for nanomaterials as part of the 2008 Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) agreement regulating chemicals in the EU. But it is unclear how nanotubes should be classified, and what protocols should be used to evaluate possible hazards1. This ambiguity has led one group of companies to pursue a strategy based on treating nanotubes as new types of chemicals, while a separate and larger collection of companies plan to treat and regulate nanotubes as a form of bulk graphite1. At the same time, and in contrast to the nanotube classification strategies being considered to meet REACH requirements, a series of publications on the safety of carbon materials in Carbon9 came to the conclusion that "carbon nanomaterial samples are typically complex mixtures and.that their toxicity depends on the specific formulation, in particular: (i) hydrophilicity . . . (ii) metals content and bioavailability, and (iii) state of aggregation . . . "

We offer several general suggestions to assist recommendations and decisions:

1. When making safety and handling recommendations to nanotechnologists, use calls that are realistic to execute. Apply the "metertechnology" test, and if it makes little sense to apply it to the meter-scale, then reconstruct the recommendation so that it would be sensible regardless of the size-domain.
2. Use toxicity standards that are understood in other fields of science such as chemistry or drug development. It is particularly important to recognize that broad generalizations could simultaneously unfairly stigmatize new innovations and miss new hazards.
3. Help stakeholders identify the highest quality nanotoxicology studies. An important recent step towards this goal is the International Council on Nanotechnology (ICON) nanoEHS virtual journal10, an online repository of health and environmental literature that allows the rating of papers. This

[4] Poland, C.m Duffin, R., Kinlock, I., Maynard, A., Wallace, W., Seaton, A., Stone, V., Brown, S., MacNee, W. & Donaldson, K. Nature Nanotech. 3, 423–428 (2008).
[5] Guo, L., et al. Mater. Sci. Forum 544–545, 511–516 (2007).
[6] http://www.azonano.com/details.asp?ArticleId=2448 Accessed Feb 1, 2010.
[7] Lewinski, N., Colvin, V., & Drezek, R. Small 4, 26–49 (2008).
[8] Stern, S.T., & McNeil, S.E. Toxicological Sciences 101, 4–21 (2008).

helps to communicate the most critical new knowledge to stakeholders such as academic nanotechnologists and relevant funding agencies facilitating development of appropriate risk assessment methods specific to new nanomaterials.

4. Consider sectioning "nanotechnology" into a number of narrowly defined fields when drafting recommendations rather than applying a single set of recommendations to all nanomaterials. These might include (a) C60 and related small fullerenes which are pseudo 0 D carbon materials, (b) carbon nanotubes which are pseudo 1 D carbon materials, (c) graphene which is a 2 D carbon material, (d) gold nanoparticles (e) silver nanoparticles, and so on. Each of these fields would then further need to consider features such as particle size, surface coatings and charges, aggregation states and typical trapped impurities such as exogenous metals or solvent.
5. Avoid confusing "nanotechnology" as an idea that drives discovery and innovation with "nanotechnology" as something that is best regulated as an entity itself. Given the challenges created by the breadth of the field and the limits of current scientific understanding, regulation might be better focused on the specific materials used and particular products created rather than on an underlying scientific regime or rubric.

The industry and scientific researchers understand that even though we are still indentifying the EHS issues surrounding nanotechnology, the government still has a vital function to play. The federal government needs to partner with researchers and the nanotechnology industry to ensure that adequate rules and regulations are promulgated which are realistic while protecting the environment, health and safety. In addition, with so many governmental agencies having a role in the development of this emerging industry, it is imperative that any rules and regulations be coordinated across all agencies and done so with scientific input. In this regard, here are further recommendations and needs for consideration:

1. There does not appear to be a primary U.S. trade association, based in DC that represents the interests of the U.S. nanotechnology community (or coordinates nanotechnology interests across industry segments/industry trade associations) to U.S. politicians and regulators. This presents a major challenge to members of Congress and to regulators since they are accustomed to working with key trade associations that serve the important role of unifying the industry around standards, best practices, responses to legislation/regulation and relationships with members of Congress and regulators. In the absence of a primary trade association, regulators are required to sort through a far more complex and conflicting web of relationships within the nanotechnology community than is required for other industries with an established "presence" in DC (represented by groups such as the American Petroleum Institute or the Chemical Manufacturers Association, etc.) This is an inherent weakness of an industry that is only now moving into the commercialization phase with the entire attendant infrastructure needs such trade associations. It is not a role of Congress to create such a trade association, but it is something that the NNI and OSTP can encourage industry to formulate. In the absence of such an association, it will be extremely difficult, if not impossible, for regulatory agencies to hire and retain technical professionals who are capable of regulating this technology in its various applications. A good example of this type of knowledge gap occurred during the Deepwater Horizon incident last year. Government regulators conceded that industry knew far more about how to respond to the emergency than did government regulators. This created an awkward situation for regulator and business alike and contributed to the broad shut down of all drilling in the Gulf out of a fear of public outrage over the perceived weakness of the regulators.
2. As more U.S. regulatory agencies deal with the testing of nanotechnology, congress needs to ensure that NNI works with NIST to create uniform standards for testing to reduce duplicative and inconsistent testing. If we look at just the EPA, OSHA and FDA, there is a high likelihood that as these agencies get more heavily involved in the regulation of nanotechnology, they will request funding for duplicative reasons. A uniform testing standard will help to avoid unnecessary testing.
3. Nanotechnology is being developed at a time when the pressure to regulate is shifting away from nation-states to international standard-setting bodies that may or may not be connected to government structures. As manufacturing shifts overseas into countries without a mature regulatory infrastruc-

ture, manufacturers increasingly seek to create voluntary or globally implemented standards that will allow them to operate seamlessly across international boundaries. This may make countries with strong regulatory structures, that are not harmonized globally, less attractive for the businesses spawned by nanotechnology precisely because its regulation is not consistent with or appreciative of the need for a global standard. If nanotechnology has the potential to revolutionize manufacturing, it might also drive a similar revolution in the way we think about regulation in a global economy. As I answer below, we also need to review international organizations with which the U.S. regulators should coordinate concerning global standards.

4. The comments presented to the Subcommittee herein mention the important work of the EU's REACH agreement; however, it is less clear whether REACH should or should not be adopted in the U.S. We recommend an international collaborative work between EPA, for example, and its counterpart in the EU responsible for EHS regulation of nanotechnology to create standards that encourage global competition, but are not overly burdensome on the development of new technologies.
5. The lack of end-user/consumer education and the safety of nanotechnology is quickly becoming a major issue for marketers of products that utilize nanotechnology. It is critical for regulators to define what is safe and inform the public so that marketers can avoid the legal liabilities associated with ambiguous or misleading product claims. Government can play an extremely valuable role in the education of the American public on EHS issues related to nanotechnology.
6. When we say in the response (below) that "Nanotechnology . . . could permeate 50% or more of our materials, electronics and medical products . . . " we are not confident that our current regulatory structure will even allow this revolution to occur. The U.S. regulatory system is not known to be efficient and if there is a lack of qualified regulators to regulate, and a lack of urgency to ensure the competitiveness of U.S. manufacturers, then sluggish or draconian regulation in this area could contribute to a decline in the U.S. nano-manufacturing base.
7. As I discuss below, there should be a study on the impact of U.S. tort law on the commercialization of nanotechnology. This represents a major area of uncertainty for U.S. manufacturers, especially in the absence of proactive government regulation. Regulators must regulate in a manner that protects human health, the environment and the ability of U.S. businesses to compete globally.
8. Federal and state agencies have constitutional mandates that require them to protect human health and the environment. While there is much EHS work being done by the industry, we should not expect regulators to feel that this work satisfies their mandate. While companies are indeed doing their own EHS work, the agencies themselves cannot accept this practice without certifying it through some form of regulation. In addition, we must recognize that agencies are motivated oftentimes by broad application of the "precautionary principle" that may not be shared by business. The scientific community should acknowledge that there are public perceptions that agencies are required to manage that have nothing to do with the science of the issue. This is an area where researchers and regulators can work together to educate the public.

While a decade ago academics jockeyed to label their work as "nano", in part to maximize funding opportunities or embrace the excitement of a new field, now some are foregoing that title to avoid burdensome scrutiny, especially when the work appears to have commercial potential11. Unless we modify the way that nanotechnology is regulated, not only will future consumer product boxes proudly bear the label, "Nano-Free!," but researchers will abandon the nano label in favor of old banners such as "Chemistry," "Electronics" and "Biology." This would negatively impact innovation, safety, education, and the future of the field.

References:

[1] http://www.rsc.org/chemistryworld/News/2009/June/16060901.asp Accessed Feb 1, 2010.

[2] Maynard, A. & Rejeski, D. Nature 460, 174 (2009).

[3] Hansen, S., Maynard, A., Baun, A. & Tickner, J.A.. Nature Nanotech. 3, 444–447 (2008).Quoting recommendations originally published by the European Environ-

mental Agency. Harremoes, P. et al. European Environmental Agency, Copenhagen, 1896–2000 (2001).
[4] Poland, C.m Duffin, R., Kinlock, I., Maynard, A., Wallace, W., Seaton, A., Stone, V., Brown, S., MacNee, W. & Donaldson, K. Nature Nanotech. 3, 423–428 (2008).
[5] Guo, L., et al. Mater. Sci. Forum 544–545, 511–516 (2007).
[6] http://www.azonano.com/details.asp?ArticleId=2448 Accessed Feb 1, 2010.
[7] Lewinski, N., Colvin, V., & Drezek, R. Small 4, 26–49 (2008).
[8] Stern, S.T., & McNeil, S.E. Toxicological Sciences 101, 4–21 (2008).

Q3. With regard to the Signature Initiatives identified in the FY 12 Budget Request (solar energy, nanomanufacturing, and nanoelectronics), why is it appropriate for the Federal government to identify specific issue areas for research focus? How do we not pick technology winners and losers by doing this? Are these the most critical areas that the Federal government should be focusing its limited resources? What critical areas are missing? What other grand challenges do we face with nanotechnology? ole should the government play in setting "Grand Challenges?" What are some examples of "Grand Challenges" in nanotechnology and are we ready to tackle them yet?

A3. Federal funding for nanotechnology beyond the discovery phase is also needed to spawn the transitions from the laboratory to the manufacturing stage. This can be done using a competitive grants process that keeps the government from choosing its favorites, and permits competition through grant applications analogous to the competitive SBIR (Small Business Innovative Research) and STTR (Small Business Technology Transfer) programs. As in the SBIR/STTR programs, let governing science agencies decide the hot areas to fund, which ensures that the government is not picking the winners and losers. Let those at the NSF and DoD program manager level, for example, work with their teams to decide where the science shall be led. This is often done by those parties in consultation with the scientists.

As the budget debate continues to unfold in Congress, it is now more important than ever that we set funding priorities. Despite these funding challenges, the government still plays a vital role in creating incentives for private industry. The government can do so by setting "Grand Challenges", but should do so with significant input from both industry and the scientific community. These challenges should be transformational to our society, but still realistic. For example:

1. The government should set a challenge to develop a system for a wireless transmission of energy. Years ago it was unthinkable that you could transmit gigabytes of data across a wireless network, yet today one can wirelessly share a photo of a newborn child across the globe.
2. Another grand challenge for nanotechnology would be the re-wiring of the grid with a low electrical loss system that would permit the efficient transfer of electronics around the globe. If we had an efficient wiring system, then distribution of energy becomes simple and it need not involve barges filled with oil.
3. Another grand challenge would be the efficient sunlight-based splitting of water into hydrogen (H2) and either oxygen (O2) or hydrogen peroxide (H2O2). If this could be done more efficiently than we do today, then there would be an inexhaustible supply of fuel (H2) and the burned byproduct would be simply water and not the greenhouse gas CO_2.
4. Yet another key grand challenge would be the efficient conversion of CO_2 into small organic liquids such as methanol using sunlight-generated H2.
5. And finally, an efficient and inexpensive solar cell technology and light weight batteries (not based upon scare elements such as lithium) still represent grand challenges for nanotechnology.

Q4. It is clear that nanotechnology promises many amazing breakthroughs while also being surrounded by a great deal of hype, mostly positive, a little negative. Help me put this in perspective and get a better sense of the real potential—Over the next five to ten years, how do each of you think nanotechnology will impact our lives and our economy?

A8. Nanotechnology, over the next decade, could permeate 50% or more of our new materials, electronics and medical products. Almost every new manufactured product in these domains can benefit from some level of nano enhancement. The new product might not be labeled as containing nano, for reasons stated above. Nonetheless, nano will be in there. Science education already involved a healthy dose of nano, and it will likely rise to reach 25% of the course content of science classes at the undergraduate college level over the next decade.

Q5. Per my request at the hearing and as you are aware, the House passed legislation to reauthorize the NNI once in the 110th Congress and twice in the 111th Congress only to see it die in the Senate. I would hope that the nanotechnology research world has changed somewhat in the past three years since this Committee last held a hearing on the topic and drafted the legislation. Using H.R. 554 from the last Congress as a basis (attached), please provide feedback by commenting on the merits of that bill and any areas that you see room for improvement or changes?

A8. As I said during my verbal testimony: if the funding for nanotechnology research is not renewed, the U.S. will suffer from an enormous brain drain as it has never seen before. The U.S. has benefited from the best brains in the world coming to our shores for the past many years. People's intellects are our best asset. And by God's grace, we have been the recipients of the world's top brains. Those brains have caused us to win the nuclear-race, the space-race and the Cold War. U.S. higher education and research is the Apple of America's eye and the envy of the world.

Alarmingly, however, foreign competition is now on our shores successfully wooing the best and the brightest away with assurances of funding for basic research and support for transitions to manufacturing. American researchers are industrious and self-driven-we have been trained that way. If we cannot get our science funded and transitioned in the US, we will go abroad. And top researchers will not wait a decade for recovery. The brain-drain has already begun, and it will continue at an alarming pace within the next 1–3 years if access to research and development funds becomes sparse. If American researchers start going abroad, the impact of the brain-drain would be devastating to near- and long-term economic development in the US.

I cannot comment on all the specific provisions of H.R. 554, but I strongly support the goal of reauthorizing the NNI. The absence of a reauthorization can be detrimental to the progress we have achieved thus far—risking our global competitive advantage. The 25 different federal agencies with nanotechnology-related activities need to work towards the same strategic plan, and without this reauthorization it makes the coordination amongst these agencies more complicated. In addition, H.R. 554 also sets out to achieve many of the goals laid out in the P–Cast reports, especially with regard to the development of public-private partnerships. However, while I understand you must be sensitive to the budget debate, I would recommend moving the NNI reauthorization from a three-year to a five-year plan. Having to renew this fight again in just three years adds uncertainty to an industry that needs stability.

As mentioned above, another area to consider addressing is how the current U.S. tort law on commercialization is impacting nanotechnology. This represents a major area of uncertainty for U.S. manufacturers, especially in the absence of a clear rules and regulations from the government. Regulators must regulate in a manner that protects human health, the environment while ensuring that U.S. business can compete in a growing global market.

Question Submitted by Ranking Member Daniel Lipinski

Q1. In your oral testimony, you stated that there is no need to increase federal investments in environmental, health, and safety (EHS) risk research because companies that you have been a part of "already have a lot of the testing that they are doing as part of their normal regulatory work that they are doing." Can you explain how federally funded EHS research duplicates what is being done by the private sector? With respect to all nanoparticles currently being used or being proposed for medical, industrial or other commercial use, are there any gaps in our knowledge of reactions that can occur between nanoparticles and the human body and /or environment? If yes, what companies are or will be addressing them? Can you quantify the private sector investments in EHS risk research? Do you believe that there are existing federal investments in EHS risk research that industry is not doing, but that are important to industries that do or will benefit from developments in nanotechnology? Would your answers vary across different industry sectors? If so, how? If not, why not?

A8. As I mention in my answer to question one, I still believe that the government can play a vital role in the EHS of nanotechnology. It is important that during these times of fiscal restraint, we set funding priorities accordingly and the continued funding of the basic research of nanotechnology will yield results that will help with the development of EHS standards, the two are not mutually exclusive. The industry of nanotechnology cannot fulfill this role alone—the federal government can play a crucial role in working with scientists and researchers to develop a clear set of rules and guidelines that industry can follow and adopt as we move into the nanomanufacturing stage.

For example, at Bayer MaterialScience (BMS), they have developed clear safe handling guidelines for carbon nanotubes. Attached to this document is an example of a brochure BMS has published for the use of such nanotubes. Additional information on nanotechnology stewardship can be found on their website at: http://www.BayCareOnline.com. I have also attached numerous other publications and papers from DuPont Corporation (references 1–8) that have looked at the toxicity and safety of nanoparticles. These should serve as a resource that shows the depth of research that is currently being performed on EHS of nanotechnology. The last two citations (references 9–10) are from our own work here at Rice University where we studied the toxicity of nanoparticles and the environmental fate of nano-sized graphene oxide.

Response by Mr. William Moffitt, President and Chief Executive Officer, Nanosphere, Inc.

Questions Submitted by Chairman Mo Brooks

Q1. What impacts are environmental, health, and safety concerns having on the development and commercialization of nanotechnology-related products and what impact might these concerns have in the future?

A1. Nanosphere's products actually have a positive impact on human health by providing for earlier detection of disease and low-cost, genetic testing in virtually any medical setting. To date, the company has experienced only minor requests regarding the ultimate safety of the nanoparticle components of the assays. The FDA has asked the company to validate that nanoparticles manufactured into the disposable test cartridges do not cross-contaminate other products produced in the same manufacturing environment. The company is in the process of conducting such tests, but there can be no assurance the FDA will find the company's tests sufficient. For the future, the greatest risk we face is the current lack of clear direction in the regulatory process as to how to handle risk assessment associated with nanotechnology. If this becomes overly burdensome, the company's costs will escalate and pricing will have to be increased to cover the costs of such additional testing. This, in turn, creates a competitive risk from foreign-manufactured products and creates potential cost barriers to use of these new diagnostic tools.

Q2. It is clear that it is important to improve our understanding of any environmental, health, and safety issues associated with nanotechnology and resolve uncertainties related to the regulatory regime that will govern nanotechnology-related products. What should our priorities be for research on environmental, health, and safety issues? How should these priorities be set? What role should the federal government, academia, and industry, respectively, play in conducting such research?

A2. Nanoparticles exist throughout the world. Indeed, the magnificent colors of the stained glass windows in many of the cathedrals in Europe are achieved through the use of colloidal gold, i.e. nanoparticle size gold. There is no evidence to date to suggest that such particles and technology will cause harm to the environment, but the use of in vivo (within the body) nanotechnology is new. The highest priority should be given to understanding the impact of nanotechnology for in vivo applications (drug carriers, imaging particles, etc). The second highest priority should be given to understanding the longer term potential impact on the health of workers involved in nanotechnology research and production. Environmental impact should likely follow as a third priority, only after the first priority above has been adequately addressed. It is possible the greater impact to the environment may arise from the technologies used to produce nanotechnology-based products as opposed to the nanotechnology itself (chemical processes, waste disposal, etc).

Q3. With regard to the Signature Initiatives identified in the FY12 Budget Request (solar energy, nanomanufacturing, and nanoelectronics), why is it appropriate for the Federal government to identify specific issue areas for research focus? How do we not pick technology winners and losers by doing this? Are these the most critical areas that the Federal government should be focusing its limited resources? What critical areas are missing? What other grand challenges do we face with nanotechnology? ole should the government play in setting "Grand Challenges?" What are some examples of "Grand Challenges" in nanotechnology and are we ready to tackle them yet?

A3. Nanotechnology holds the potential to make meaningful impact on virtually every industry. As such, it should be viewed as a potential source for resolution of some of our country's greatest problems, energy, health and global competitiveness. Directing resources and funding to solving our greatest problems does not necessarily default to picking the winners and losers. Rather, it represents appropriate allocation of fiscally tight resources to those areas that are causing the greatest economic strain. Ensuring that the US remains globally competitive and retains a leadership position in nanotechnology can protect jobs and improve our economy. At the same time, focus on our greatest needs, energy and health, will enable us have the highest possible impact on our greats problems with the scant resources available.

Following from the above paragraph, the critical initiative that is missing from the Signature Initiatives is health care. Nanosphere is a good example of the potential impact. Earlier detection of disease can lead to lower cost of care. Newly developed genetic tests are proving to make a significant impact on the safety and efficacy of some of the most prescribed drugs in the world, yet the high cost of such testing has historically been a barrier to adoption. Through nanotechnology we have reduced the cost of such testing to a level that makes the economic equation a positive gain for the health care system. We are only one example.

Q4. It is clear that nanotechnology promises many amazing breakthroughs while also being surrounded by a great deal of hype, mostly positive, a little negative. Help me put this in perspective and get a better sense of the real potential– Over the next five to ten years, how do each of you think nanotechnology will impact our lives and our economy?

A4. The hype has been generated from all of the potential that lies in this new science, with a little boost from Wall Street. But, the potential is real. As with all new areas of science, proven practical products that solve problems take a bit longer. Over the next 5-10 years I would expect to see meaningful progress in health care arising from nano-based products. Nanotechnology will enable more efficient energy systems as well. In short, over the next 5-10 years we will see the reality of the earliest advances in these key areas of concern to our economy. Real impact as measured against projections should be the measure of our success.

Q5. Per my request at the hearing and as you are aware, the House passed legislation to reauthorize the NNI once in the 110th Congress and twice in the 111th Congress only to see it die in the Senate. I would hope that the nanotechnology research world has changed somewhat in the past three years since this Committee last held a hearing on the topic and drafted the legislation. Using H.R. 554 from the last Congress as a basis (attached), please provide feedback by commenting on the merits of that bill and any areas that you see room for improvement or changes?

A5. The greatest area for improvement in H.R. 554 is the use of pre-established metrics for measuring the success of the bill and its underlying funding. How will we know we have a return on our investment? How will we justify continued expenditures? How will we know where to redirect funding, if and as required? Perhaps I am a naive guy from the business world, but I believe in measuring performance as a means of underwriting future decision making.

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