NANOTECHNOLOGY: FROM LABORATORIES TO COMMERCIAL PRODUCTS

HEARING

BEFORE THE

SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED THIRTEENTH CONGRESS

SECOND SESSION

MAY 20, 2014

Serial No. 113–75

Printed for the use of the Committee on Science, Space, and Technology

Available via the World Wide Web: http://science.house.gov

U.S. GOVERNMENT PRINTING OFFICE

88–145PDF WASHINGTON : 2014

For sale by the Superintendent of Documents, U.S. Government Printing Office
Internet: bookstore.gpo.gov Phone: toll free (866) 512–1800; DC area (202) 512–1800
Fax: (202) 512–2104 Mail: Stop IDCC, Washington, DC 20402–0001

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HON. LAMAR S. SMITH, Texas, *Chair*

DANA ROHRABACHER, California
RALPH M. HALL, Texas
F. JAMES SENSENBRENNER, JR., Wisconsin
FRANK D. LUCAS, Oklahoma
RANDY NEUGEBAUER, Texas
MICHAEL T. McCAUL, Texas
PAUL C. BROUN, Georgia
STEVEN M. PALAZZO, Mississippi
MO BROOKS, Alabama
RANDY HULTGREN, Illinois
LARRY BUCSHON, Indiana
STEVE STOCKMAN, Texas
BILL POSEY, Florida
CYNTHIA LUMMIS, Wyoming
DAVID SCHWEIKERT, Arizona
THOMAS MASSIE, Kentucky
KEVIN CRAMER, North Dakota
JIM BRIDENSTINE, Oklahoma
RANDY WEBER, Texas
CHRIS COLLINS, New York
BILL JOHNSON, Ohio

EDDIE BERNICE JOHNSON, Texas
ZOE LOFGREN, California
DANIEL LIPINSKI, Illinois
DONNA F. EDWARDS, Maryland
FREDERICA S. WILSON, Florida
SUZANNE BONAMICI, Oregon
ERIC SWALWELL, California
DAN MAFFEI, New York
ALAN GRAYSON, Florida
JOSEPH KENNEDY III, Massachusetts
SCOTT PETERS, California
DEREK KILMER, Washington
AMI BERA, California
ELIZABETH ESTY, Connecticut
MARC VEASEY, Texas
JULIA BROWNLEY, California
ROBIN KELLY, Illinois
KATHERINE CLARK, Massachusetts

SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY

HON. LARRY BUCSHON, Indiana, *Chair*

STEVEN M. PALAZZO, Mississippi
MO BROOKS, Alabama
RANDY HULTGREN, Illinois
STEVE STOCKMAN, Texas
CYNTHIA LUMMIS, Wyoming
DAVID SCHWEIKERT, Arizona
THOMAS MASSIE, Kentucky
JIM BRIDENSTINE, Oklahoma
CHRIS COLLINS, New York
BILL JOHNSON, Ohio
LAMAR S. SMITH, Texas

DANIEL LIPINSKI, Illinois
FEDERICA WILSON, Florida
ZOE LOFGREN, California
SCOTT PETERS, California
AMI BERA, California
DEREK KILMER, Washington
ELIZABETH ESTY, Connecticut
ROBIN KELLY, Illinois
EDDIE BERNICE JOHNSON, Texas

CONTENTS

May 20, 2014

NANOTECHNOLOGY: FROM LABORATORIES TO COMMERCIAL PRODUCTS

TUESDAY, MAY 20, 2014

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to call, at 10:05 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Larry Bucshon [Chairman of the Subcommittee] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
RANKING MEMBER

Congress of the United States
House of Representatives
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
2321 RAYBURN HOUSE OFFICE BUILDING
WASHINGTON, DC 20515–6301
(202) 225–6371
www.science.house.gov

Subcommittee on Research and Technology

Nanotechnology: From Laboratories to Commercial Products

Tuesday, May 20, 2014
10:00 a.m. to 12:00 p.m.
2318 Rayburn House Office Building

Witnesses

Dr. Timothy Persons*, Chief Scientist, United States Government Accountability Office*

Dr. Lloyd Whitman*, Interim Director of the National Nanotechnology Coordination Office and Deputy Director of the Center for Nanoscale Science and Technology, National Institute of Standards and Technology*

Dr. Keith Stevenson*, Professor, Department of Chemistry & Biochemistry, The University of Texas at Austin*

Dr. Mark Hersam*, Professor, Department of Materials Science & Engineering, McCormick School of Engineering & Applied Science, Northwestern University*

Mr. Les Ivie*, President & CEO, F Cubed, LLC*

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

HEARING CHARTER

Nanotechnology: From Laboratories to Commercial Products

Tuesday, May 20, 2014
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

PURPOSE

On Tuesday, May 20, 2014, the Subcommittee on Research and Technology will hold a hearing entitled *Nanotechnology for the 21st Century*. The purpose of this hearing is to examine the current state of nanotechnology research and development (R&D) as well as future opportunities and challenges. In addition, the hearing will discuss policy issues surrounding nanotechnology applications and activities, federal funding levels for nanotechnology R&D, and key legislative initiatives including the interagency National Nanotechnology Initiative (NNI).

WITNESS LIST

- **Dr. Timothy Persons**, Chief Scientist, United States Government Accountability Office
- **Dr. Lloyd Whitman**, Interim Director of the National Nanotechnology Coordination Office and Deputy Director of the Center for Nanoscale Science and Technology, National Institute of Standards and Technology
- **Dr. Keith Stevenson**, Professor, Department of Chemistry & Biochemistry, The University of Texas at Austin
- **Dr. Mark Hersam**, Department of Materials Science & Engineering, McCormick School of Engineering & Applied Science, Northwestern University
- **Mr. Les Ivie**, President & CEO, F Cubed

BACKGROUND

Introduction

Nanotechnology loosely refers to the subject of technology developed at the nano-scale, or sizes ranging from less than 1 nanometer to hundreds of nanometers. For perspective, a nanometer is approximately 1/10,000th of the thickness of a human hair.[1] Therefore, nanotechnology includes the production and application of physical, chemical, and biological systems on the size scale of atoms and molecules as well as the integration of these nanostructures into larger systems.

[1] http://books.google.com/books/about/Biobusiness.html?id=rLCqudQZlLMC p. 30

According to the 2014 Battelle Global R&D funding forecast, "nanomaterials are expected to be even more important over the next three years ... as a key area of technology development."[2] Advances in nanotechnology will also spur breakthroughs in other diverse areas including materials and manufacturing, solid state electronics, medicine and healthcare, energy, biotechnology, information technology, and national security. Nanotechnology R&D, as a long-term investment, will likely result in significant growth to the nation's economy.

Government Accountability Office (GAO) Report on Nanomanufacturing

At the request of Chairman Lamar Smith of the House Science, Space and Technology Committee, the GAO conducted a study and released a report entitled "Nanomanufacturing: Emergence and Implications for U.S. Competitiveness, the Environment, and Human Health" [3] last February, that examined current issues related to nanotechnology and nanomanufacturing. The report identified various concerns, including:

(1) the valley of death – gaps in funding or support for technology development and manufacturing development;
(2) the lack of participation in setting standards for nanomanufacturing and nanotechnology;
(3) the lack of national vision for nanomanufacturing capability; and
(4) the need for integrated framework to help assess and address the environmental, health and safety implications.

The report also discussed the need for the National Nanotechnology Coordination Office (NNCO) to increase public awareness about benefits and risks of nanomanufacturing.

National Nanotechnology Initiative

The National Nanotechnology Initiative (NNI) was launched in 2001 with a multi-agency federal investment of $497 million and first authorized by Congress in 2003 with the *21st Century Nanotechnology Research and Development Act* (P.L. 108-153). The four goals of the NNI are to:

(1) advance world-class nanotechnology research and development,
(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, and
(4) support the responsible development of nanotechnology.

The primary purpose of creating the NNI is to ensure coordination across disparate Federal agencies for their R&D investments in nanotechnology. Currently, twenty federal agencies fund NNI research or have regulatory responsibilities. About 95% of this funding is spent by the National Institutes of Health (NIH), National Science Foundation (NSF), Department of Energy (DOE), National Institutes for Standards and Technology (NIST), National Aeronautics and Space Administration (NASA) and Environmental Protection Agency (EPA). The President's FY 2015 budget request for NNI across these agencies is $1,536.9 billion, a decrease from $1,550.2 billion spent in FY 2013 and $1,537.5 billion estimated to be spent this fiscal year.[4]

---

[2] http://www.battelle.org/docs/tpp/2014_global_rd_funding_forecast.pdf , p. 31
[3] http://www.gao.gov/products/GAO-14-181SP
[4] http://www.nano.gov/sites/default/files/pub_resource/nni_fy15_budget_supplement.pdf, Table 2

In addition, NNI created the National Nanotechnology Advisory Panel (NNAP), called for a triennial review of the NNI by the National Academies, and established functions for the National Nanotechnology Coordination Office (NNCO). The NNCO provides technical and administrative support to the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee, serves as a central point of contact for Federal nanotechnology R&D activities, and provides public outreach on behalf of the NNI. The NNCO Director and NNCO Deputy Director are detailed from a Federal agency to the National Science and Technology Council (NSTC) and are appointed by the White House Co-Chair of the NSTC Committee on Technology.

Currently, the NNI investments are guided by a strategic plan published in February 2014.[5] Priorities for NNI funding by Program Component Area are: Foundational Research (35% of NNI funding); Applications, Devices, and Systems (24%); Signature Initiatives (19%); Infrastructure & Implementation (16%); Environment, Health, and Safety (7%).[6] The Nanotechnology Signature Initiatives are its own Program Component Area in the FY 2015 Budget Supplement[7] with the following priorities defined by Office of Science and Technology Policy as:

- Nanotechnology for Solar Energy Collection and Conversion;
- Sustainable Nanomanufacturing;
- Nanoelectronics for 2020 and Beyond;
- Nanotechnology Knowledge Infrastructure; and
- Nanotechnology for Sensors and Sensors for Nanotechnology

National Academies of Science Report on the NNI

In 2013, the National Research Council (NRC) undertook its third triennial review of the NNI, as mandated in the *21st Century Nanotechnology Research and Development Act* (P.L. 108-153). The resulting report raised several concerns and identified five crosscutting topics: (1) the lack of information about the current research being undertaken, (2) the need to enhance planning, management, and coordination by developing and implementing interagency plans, (3) the development of a website to effectively serve all stakeholders, (4) improving the assessment of project progress toward specified goals, and (5) the benefits from identifying, sharing, and implementing best practices.

NSF Funding of the National Nanotechnology Infrastructure Network

The National Nanotechnology Infrastructure Network (NNIN), which supports the infrastructure of the NNI was only authorized for ten years, ending in FY 2013.[8] The NSF solicited proposals in 2013 to establish a Next-Generation NNIN to succeed the former program through FY 2018. Two university teams submitted proposals, and the NSF announced in April that it would not fund either proposal. Although the NNIN funding will last until August 2015, some services are slated to be discontinued. After August 2015, access to NNIN facilities and staff will be at the discretion of individual laboratories.[9] The NSF has noted that it will "bridge funding to support the current NNIN facilities and staff for the immediate future in order to minimize disruptions to

[5] http://www.nano.gov/node/1113
[6] http://www.nano.gov/node/1128
[7] http://www.nap.edu/catalog.php?record_id=18271
[8] http://www.nsf.gov/pubs/2013/nsf13521/nsf13521.htm
[9] http://www.nnin.org/

ongoing nanotechnology user projects and student education", with the hope of soliciting "a future NSF nanotechnology infrastructure support program".[10]

Current Legislation

In this current Congress, the following bills have been introduced that contain nanotechnology policy issues:

- H.R. 394: Nanotechnology Advancement and New Opportunities Act
- H.R. 1385: Safe Cosmetics and Personal Care Products Act of 2013
- H.R. 4159: America Competes Reauthorization Act of 2014

NNI Budget, by Agency, 2013–2015 [11]

(dollars in millions)

Agency	2013 Actual	2014 Estimated*	2015 Proposed
CPSC	1.3	2.0	2.0
DHS	14.0	24.0	32.4
DOC/NIST	91.4	97.8	82.6
DOD	170.1	175.9	144.0
DOE**	314.2	303.3	343.1
DOT/FHWA	2.4	2.0	1.5
EPA	14.6	15.5	16.8
DHHS (total)	485.4	469.5	469.6
FDA	16.1	17.0	17.0
NIH	458.8	441.5	441.5
NIOSH	10.5	11.0	11.1
NASA	16.4	17.9	13.7
NSF	421.0	410.6	412.4
USDA (total)	19.5	19.1	18.8
ARS	2.0	2.0	2.0
FS	5.0	4.0	4.0
NIFA	12.5	13.1	12.8
TOTAL***	**1,550.2**	**1,537.5**	**1,536.9**

* 2014 numbers are based on 2014 enacted levels, and may shift as operating plans are finalized.
** 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).
*** In Tables 2–6, totals may not add, due to rounding.

[10] http://www.nsf.gov/news/news_summ.jsp?cntn_id=131012
[11] http://www.nano.gov/sites/default/files/pub_resource/nni_fy15_budget_supplement.pdf, p. 8

Chairman BUCSHON. The Subcommittee on Research and Technology will come to order.

Good morning. Welcome to today's hearing titled "Nanotechnology: From Laboratories to Commercial Products." In front of you are packets containing the written testimony, biographies, and truth-and-testimony disclosures for today's witnesses. I now recognize myself for five minutes for an opening statement.

Nanotechnology is an area of great promise for the future of the U.S. economy, the leaps and bounds in 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. Just recently, I learned of a new technology developed at Sandia National Laboratories and the University of New Mexico Cancer Center in which a hybrid particle, made up of a porous silicon nanoparticle core, contains small peptides that are targeted to proteins expressed specifically by cancer cells. It is an ideal vehicle to deliver the custom drug combinations needed for personalized medicine and may transform how we deliver antibiotics and antivirals.

As a cardiothoracic surgeon and medical professional, I find this application of nanoscience to medicine not only fascinating but also having important implications for our Nation to keep medical costs down and subsequently may have some affect on national security and our economy.

In 2013 the National Science Foundation nanotechnology investment supported 5,000 active projects over 30 research centers and several infrastructure networks for device development, computation, and education. It impacted over 10,000 students and teachers. Approximately 150 small businesses were funded to perform research and product development in nanotechnology through the Small Business Innovation Research and Small Business Technology Transfer Programs. It is also my understanding that three new exciting directions are planned for 2015, including nanostructure composite materials, nanoscale optics, and photonics.

Unfortunately, despite these promising activities funded directly by the National Science Foundation, the President's budget for key directorates that carry out nanotechnology research within the NSF's Research and Related Activities Account is disappointing with a $1.5 million overall decrease.

On the other hand, the Frontiers in Innovation Research and Science and Technology, or FIRST Act, of which I am an original cosponsor, passed our Subcommittee this past March with increases to several key directorates that fund nanotechnology basic science research. In addition to the NSF, the National Nanotechnology Initiative, or 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 still remains an emerging, important, and relevant area. The House passed an NNI reauthorization bill in both 110th and 111th Congresses only to see it die in the Senate.

This hearing today provides us with an opportunity to get feedback on the future of NNI and have a serious discussion about the national priorities for this technology. The President's proposed budget for NNI in Fiscal Year 2015 is $13.3 million less than Fiscal Year 2013 and is estimated to be less than it spent in Fiscal Year 2014. These budget numbers are concerning, especially for an area of R&D that holds an important place in our Nation's economy and national security.

I look forward to hearing from the witnesses and to a productive and fruitful discussion on U.S. nanotechnology investments, priorities, and policies. Again, thank all of you for joining us today.

[The prepared statement of Mr. Bucshon follows:]

PREPARED STATEMENT OF SUBCOMMITTEE ON CHAIRMAN LARRY BUCSHON

I would like to welcome everyone to today's Research and Technology Subcommittee hearing titled "Nanotechnology: From Laboratories to Commercial Products."

Nanotechnology is an area of great promise h for the future of the U.S. economy, the 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. This is especially important as gas prices continue to remain high.

Just recently, I learned of a new technology (developed at Sandia National Laboratories and the University of New Mexico Cancer Center) in which a hybrid particle, made up of a porous silica nanoparticle core, contains small peptides that are targeted to proteins expressed specifically by cancer cells. It is an ideal vehicle to deliver the custom drug combinations needed for personalized medicine, and will transform how we deliver antibiotics and antivirals.

As a cardiothoracic surgeon and medical professional, I find this application of nanoscience to medicine not only fascinating but also having important implications for our Nation's national security and economy, including ways to lower medical costs.

In 2013, the National Science Foundation (NSF) nanotechnology investment supported 5,000 active projects, over 30 research centers and several infrastructure networks for device development, computation, and education. It impacted over 10,000 students and teachers. Approximately 150 small businesses were funded to perform research and product development in nanotechnology through the Small Business Innovation Research (SBIR) and the Small Business Technology Transfer (STTR) Programs. It is also my understanding that three new exciting directions are planned for 2015, including nanostructured composite materials, nanoscale optics, and photonics.

Unfortunately, despite these promising activities funded directly by the NSF, the President's budget for key directorates that carry out nanotechnology research within NSF's Research and Related Activities Account (RRA) is disappointing, with a $1.5 Million overall decrease. On the other hand, the Frontiers in Innovation, Research, Science and Technology (FIRST) Act, of which I am an original co-sponsor, passed our Subcommittee this past March with increases to several key directorates that fund nanotechnology basic science research.

In addition to the NSF, 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 still remains an emerging, important and relevant area. The House passed an NNI reauthorization bill in both the 110th and 111th Congresses, only to see it die in the Senate. This hearing today provides us with an opportunity to get feedback on the future of NNI and have a serious discussion about national priorities for this technology.

The President's proposed budget for NNI in fiscal year (FY) 2015 ($1,536.9M) is $13.3 Million less than FY2013 ($1,550.2), and is estimated to be less than what is spent for FY14 (1,537.5). These budget numbers are concerning, especially for an area of R&D that holds an important place in our nation's economic and national security.

I look forward to hearing today's testimony and to a productive and fruitful discussion on U.S. nanotechnology investments, priorities, and policies. Again, thank you all for joining us today.

Chairman BUCSHON. I now recognize the Ranking Member, the gentleman from Illinois, Mr. Lipinski, for his opening statement.

Mr. LIPINSKI. Thank you, Chairman Bucshon, and thank you for holding this hearing today on nanotechnology.

It has been a little more than three years since this Committee last held a hearing on nanotech, so I am happy we are 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 relatively modest federal investment is many times what we have already witnessed. I am fond of saying I drank the nanotech Kool-Aid the first time I visited Chad Mirkin's lab at Northwestern University. I am very happy that we have someone from Northwestern here today.

I was amazed by what could be done at the scale of a single atom. In nanotechnology there is now a branch of engineering that simply did not exist 26 years ago when I was getting my degree in mechanical engineering at Northwestern also. By controlling individual atoms, we can create new materials and products, and with that, companies and jobs.

The Science Committee recognized the promise of nanotechnology early on-holding our first hearing close to 15 years ago to review federal activities in the field. The Committee was subsequently instrumental in the development and enactment of the statute in 2003 that authorized the interagency National Nanotechnology Initiative, the NNI, as the Chairman spoke about.

We have passed a widely supported bipartisan update to the NNI bill in the House three times since 2008. Unfortunately, all three times this bill has died in the Senate. I hope with the Chairman's help we will have an opportunity to take up an NNI reauthorization bill once again in this Congress, and who knows, maybe the fourth time will be the 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 cost. These opportunities include ways to strengthen technology transfer and streamline the reporting requirements for the program. I welcome thoughts from our witnesses today on how we can continue to improve upon the existing program.

Nanotechnology is a broad field encompassing much more than just material science or semiconductors. For instance, nanotechnology is beginning to help us understand biology at the cellular level. We are now seeing applications that were not even imagined

13 years ago when NNI 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. I am sure that we will hear about some of those applications from today's witnesses, including Mr. Ivie from F Cubed.

Part of our discussion on nanotechnology must include the barriers and opportunities surrounding nanomanufacturing. I know that Dr. Persons will talk about some of the challenges the United States is facing in this area today, including a need for more U.S. involvement in international standards setting, continued sustained investment in this area, and a national vision for U.S. nanomanufacturing capability.

Finally, I think it is also important to talk about the environmental, health, and safety, or EHS research, that must be part of any comprehensive nanotechnology research strategy. I know that Professor Hersam was part of a report on nanotechnology research directions that included a review of recommendations for nano EHS research and hope we can spend some time during the Q&A on this important topic.

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

[The prepared statement of Mr. Lipinski follows:]

PREPARED STATEMENT OF SUBCOMMITTEE RANKING MINORITY MEMBER DAN LIPINSKI

Thank you Chairman Bucshon for holding this hearing today on nanotechnology. It has been a little more than three years since the committee last held a hearing on nanotechnology, so I am happy we are 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 relatively modest federal investment is many times what we'vealready witnessed.

I'm fond of saying that I "drank the nanotech kool-aid" the first time I visited Chad Mirkin'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 26 years ago when I was getting my degree in mechanical engineering. By controlling individual atoms we can create new materials and products, and with that, companies and jobs.

The Science Committee recognized the promise of nanotechnology early on, holding our first hearing close to 15 years 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 that with the Chairman's help we will have an opportunity to take up an NNI Reauthorization bill once again in this Congress. Who knows, maybe the 4th time will be the 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. These opportunities include ways to strengthen technology transfer and streamline the reporting requirements for the program. I welcome thoughts from our witnesses today on how we can continue to improve upon the existing program.

Nanotechnology is a broad field encompassing much more than just materials science or semiconductors. For instance, nanotechnology is beginning to help us understand biology at the cellular level. We are now seeing applications that were not even imagined 13 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. I am sure that we will hear about some of those applications from today's witnesses including Mr. Ivie from F Cubed.

Part of our discussion of nanotechnology must include the barriers and opportunities surrounding nanomanufacturing. I know that Dr. Persons will talk about some of the challenges that the United States is facing in this area today including a need for more U.S. involvement in international standard setting, continued sustained investment in this area, and a national vision for a U.S. nanomanufacturing capability.

Finally, I think it is also important to talk about the environmental, health, and safety—or EHS—research that must be part of any comprehensive nanotechnology research strategy. I know that Professor Hersam was part of a report on nanotechnology research directions that included a review and recommendations for nano-EHS research and hope we can spend some time during the Q&A on this important topic.

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 the balance of my time.

Chairman BUCSHON. Thank you, Mr. Lipinski. I now recognize the Ranking Member of the full Committee, Ms. Johnson, for her opening statement.

Ms. JOHNSON. Thank you very much, Mr. Chairman, and good morning.

This morning, we are discussing nanotechnology. As a long-time member of the Committee, I am proud that the Committee recognized a need for an increased level of investment and better interagency coordination in this area almost 15 years ago. That recognition led to the creation of the National Nanotechnology Initiative, or the NNI as it is called, which has invested nearly $20 billion in nanotechnology research and development since 2001.

The investment in NNI is one of the reasons that the United States is a global leader in nanotechnology research and development. Unfortunately, like too many other research areas, our leadership position is now being challenged. In a 2014 report on nanomanufacturing, which I am sure Dr. Persons will discuss this morning, the GAO reported that the United States is facing challenges to maintaining its leadership position in nanotechnology and nanomanufacturing. Several of our global competitors like the European Union and Japan are making significant and sustained investments in nanotechnology while we are busy debating on how much to cut our research agencies. If we are going to maintain competitiveness, then the United States needs to make strong and sustained investment in nanotechnology and enact federal policies that help technology and manufacturing development and play a central role in international standards development.

While we need to strengthen our leadership position in nanotechnology, we should also recognize that there are opportunities to work with our global partners. One area for collaboration is the area of environmental, health, and safety research, or EHS research. Unlike the nanomanufacturing research, there is no obvious competitive advantage in EHS research. Instead, all global nanotechnology partners benefit from a greater understanding of potential environmental, health, and safety aspects of nanotechnology.

As a former nurse, I recognize the need to understand and mitigate the potential risks to new technologies, including nanotechnology. Without a strong EHS research program on nanotechnology, we would be left with the uncertainties of surrounding potential risks for people and environments that are exposed to nanomaterials and nano-enabled products.

In addition to concerns about public health and safety, I am worried that these uncertainties could also lead to unsubstantiated negative public perceptions about nanotechnology, which could have serious consequences for its acceptance and use. 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 to funding for many years and I applaud the current Administration's increased emphasis on EHS. But I remain concerned about our new slow progress in this area of research.

We need a strong nano EHS research program to protect the public and to ensure that any nanotechnology regulations will be grounded in science, not perception. I hope to hear from our witnesses today about their thoughts on this issue.

And in closing, I am hopeful that we can work together to ensure that the United States remains the leader in nanotechnology and nanomanufacturing while working with our global partners.

I want to thank the witnesses for being here and I want to thank you, Mr. Chairman. And I yield back the balance of my time.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF FULL COMMITTEEE

RANKING MEMBER EDDIE BERNICE JOHNSON

Thank you, Mr. Chairman. This morning we are discussing nanotechnology. As a long-time Member of this Committee, I am proud that the Committee recognized the need for an increased level of investment and better interagency coordination in this area almost 15 years ago.

That recognition led to the creation of the National Nanotechnology Initiative, or the NNI as it is called, which has invested nearly $20 billion in nanotechnology research and development since 2001.

The investment in the NNI is one of the reasons that the United States is the global leader in nanotechnology research and development. Unfortunately, like too many other research areas, our leadership position is now being challenged.

In a 2014 report on Nanomanufacturing, which I am sure Dr. Persons will discuss this morning, the GAO reported that the United States is facing challenges to maintaining its leadership position in nanotechnology and nanomanufacturing. Several of our global competitors like the European Union and Japan are making significant and sustained investments in nanotechnology while we are busy debating how much to cut our research agencies.

If we are going to remain competitive, then the U.S. needs to make strong and sustained investments in nanotechnology; enact federal policies that help technology and manufacturing development; and play a central role in international standards development.

While we need to strengthen our leadership position in nanotechnology, we should also recognize that there are opportunities to work with our global partners. One area for collaboration is in the area of environmental, health and safety research or EHS research.

Unlike with nanomanufacturing research, there is no obvious competitive advantage in EHS research. Instead, all global nanotechnology partners benefit from a greater understanding of potential environmental, health, and safety aspects of nanotechnology.

As a former nurse, I recognize the need to understand and mitigate the potential risks to new technologies including nanotechnology. Without a strong EHS research program on nanotechnology, we will be left with uncertainties surrounding potential risks for people and environments that are exposed to nanomaterials and nano-enabled products. In addition to concerns about public health and safety, I am worried that these uncertainties could also lead to unsubstantiated negative public perceptions about nanotechnology, which could have serious consequences for its acceptance and use.

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.

I applaud the current Administration's increased emphasis on EHS, but I remain concerned about our slow progress in this area of research. We need a strong nano-EHS research program to protect the public and to ensure that any nanotechnology regulations will be grounded in science not perception. I hope to hear from our witnesses today about their thoughts on this issue.

In closing, I am hopeful that we can work together to ensure that the United States remains the leader in nanotechnology and nanomanufacturing while working with our global partners.

I want to thank the witnesses for being here today. Thank you, Mr. Chairman and I yield back the balance of my time.

Chairman BUCSHON. Thank you, Ms. Johnson.

If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

At this time, I would like to introduce our witnesses, a very distinguished panel. Our first witness today is Dr. Timothy Persons, Chief Scientist of the United States Government Accountability Office. He is also the Co-Director of the GAO Center for Science, Technology, and Engineering, a group of highly specialized scientists, engineers, mathematicians, and information technologists. He works with the GAO's chief technologist to lead the production of technology assessments for the U.S. Congress.

Prior to joining the GAO, Dr. Persons has held key leadership roles in the national security community. In 2007 Dr. Persons was awarded a Director of National Intelligence Science and Technology Fellowship focusing on computational imaging systems research. He received his bachelor's in physics from James Madison, a master's in nuclear physics from Emory University, and a master's in computer science and a Ph.D. in biomedical engineering from Wake Forest.

Our second witness is Dr. Lloyd Whitman, Interim Director of the National Nanotechnology Coordination Office and Deputy Director of the Center for Nanoscale Science and Technology at the National Institute of Standards and Technology.

Dr. Whitman received a bachelor's in physics from Brown and a master's and Ph.D. in physics from Cornell. After a National Research Council post-doctorate research fellowship at NIST, Dr. Whitman joined the research staff at the National Research Laboratory. At NRL, Lloyd was the head of the Surface Nanoscience and Sensor Technology Section. In addition to leading research at NRL, Dr. Whitman served as a Science Advisor to the Special Assistant to the Secretary of Defense for Chemical and Biological Defense and Chemical Demilitarization Programs.

Our next witness is Dr. Keith Stevenson, Professor in the Department of Chemistry & Biochemistry at the University Of Texas at Austin. Dr. Stevenson is a well-established electrochemist, materials chemist, and nanoscientist with over 145 referred publications, six patents, and five book chapters. He is the Director of the 38 million Center for Nano- and Molecular Science and Technology. He is also acting Thrust Leader on an 11.2 million DOE Energy Frontiers Research Center at UT Austin.

In addition to being the State Director of the Welch Foundation Summer Scholars Program, he is one of the founding faculty members of a program now known as the Freshman Research Initiative at UT Austin.

At this point I now recognize the Ranking Member Mr. Lipinski to introduce our next witness.

Mr. LIPINSKI. Thank you.

As a Northwestern alum, I am very excited to have a Professor from Northwestern University here this morning even though he has his Ph.D. from the University of Illinois.

Dr. Hersam is a Professor—Yes, that is the Chairman's school.

Dr. Hersam is a Professor of Material Science and Engineering Department, as well as being Director of the Materials Research Center. His interdisciplinary research group focuses on analyzing and manipulating nanomaterials at the atomic and molecular scale. Professor Hersam is a nationally recognized leader in research in nanotechnology, a member of several scientific societies, and winner of numerous teaching and research awards.

In addition to his work at Northwestern, Dr. Hersam founded a company NanoIntegris that is a leading supplier of high purity semiconducting and metallic inks.

It is my pleasure to welcome Dr. Hersam to our Committee today.

Chairman BUCSHON. And our final witness is Mr. Les Ivie, President and CEO of F Cubed, LLC. Mr. Ivie was also Founder and Chief Operating Officer of Gas Clip Technology, Inc. Prior to founding F Cubed, he was Chief Technology Officer at Honeywell International.

Mr. Ivie was Senior Vice President and Chief Operating Officer of Zellweger Luwa AG in Switzerland. He was a Founder, Board Member, and later Chairman of the Board of Textillio AG, an Internet company based in Zurich, Switzerland. Mr. Ivie held a variety of positions at United Technologies Corporation.

Mr. Ivie graduated from Portland State University with a bachelor of science and mathematics and a bachelor of science and economics from the University of Denver with a master's of business administration.

I would like to thank all of our witnesses for being here. It is going to be an interesting hearing.

As our witnesses should know, spoken testimony is limited to five minutes each after which Members of the Committee have five minutes each to ask questions. Your written testimony will be included in the record of the hearing.

At this point I now recognize Dr. Persons for five minutes to present his testimony.

TESTIMONY OF DR. TIMOTHY PERSONS, CHIEF SCIENTIST, UNITED STATES GOVERNMENT ACCOUNTABILITY OFFICE

Dr. PERSONS. Chairman Bucshon, Ranking Member Lipinski, Ranking Member Johnson, and Members of the Committee, good morning.

I am pleased to be here to discuss the ongoing transition of nanotechnology from the laboratory into commercial products, or also known as nanomanufacturing.

As a reminder, nanotechnology is defined as the control or restructuring of matter at the atomic or molecular scale, about—a range of about 1 to 100 nanometers, the latter being about 1/1000 the thickness of a human hair.

Last year, the Controller General of the United States convened a strategic forum on this topic, which brought together experts from a wide range of relevant backgrounds to discuss the status and implications of this issue. We recently issued a report on the forum, a portion of which I am covering in today's remarks.

Specifically, my testimony will highlight how the United States compares with other countries in nanotechnology R&D and competitiveness, identify some key challenges to innovation, briefly present some key policy issues, and discuss two examples of public-private partnerships designed to promote U.S. innovation in nanomanufacturing.

And I ask that Figure 1 be brought up on the screen.

[Slide]

Dr. PERSONS. This slide illustrates several examples of some nanoscale science discoveries in transition from the lab into real-world nanotechnology-enabled products. Moving from left to right, the first column of the figure contains examples of nanoscale components discovered by the basic science community. The second column contains new or enhanced prototypes enabled by the nano components, and the third column then shows new or improved products of the commercial sector which may require manufacturing at large-scale, that is either size and number.

As a quick example, following the top row of the chart, research on nanoscale transistors enables more powerful and sophisticated semiconductor chips, which then result in lighter, faster, and more powerful computers and smartphones like what used to be a supercomputer I hold essentially in the palm of my hand because of nanotechnology. The experts at our forum told us that the United States likely leads in nanotechnology R&D today but the United States faces global-scale competition. In terms of R&D funding levels, the United States is still considered the overall leader, yet is possibly lagging in public sector support in comparison to some other major nations. For scientific publications, the United States is considered the leader in quality, yet it terms of quantity has already been surpassed by China.

Turning to U.S. competitiveness in nanomanufacturing itself, the four industry sectors we studied indicate that the United States remains the leader in some areas, namely nanomedicine and semiconductor design. On the other hand, experts said the United States has been challenged in semiconductor manufacturing, the development of nano-enabled concrete materials, as well as lithium-ion batteries for electric vehicles, even though a recent announcement by a major American manufacturer of electric vehicles to build a large battery production plant could reverse this latter assessment.

Our forum participants identified several challenges, including significant global competition, the unintended consequences of prior off-shoring of manufacturing, direct foreign threats to U.S. intellectual property, and the fact that the United States currently lacks a holistic strategy for nanomanufacturing.

Moreover, another major challenge is a key funding gap called the "missing middle," which I hold up in Figure 2, which occurs between the proof-of-concept and production environment demonstration phases of the manufacturing innovation process. This challenge was a particular concern to our experts in terms of the barrier it represents to small and medium-sized U.S. enterprises where a good deal of innovation occurs.

In terms of policy issues, forum participants said the United States could improve its competitive posture by pursuing one or more of the following three approaches: first, strengthen innovation across the U.S. economy by continuing and/or updating policies and programs which support innovation in general; second, promote innovation in U.S. manufacturing possibly in the form of public-private partnerships; third, design a holistic strategy for U.S. nanomanufacturing led and facilitated but not overly driven by the federal government.

Insufficient efforts by the United States to participate in international development of basic nanotechnology standards and the need for a revitalized integrative and collaborative approach to environment, health, and safety issues were other policy considerations our participants identified. Two examples of public-private partnerships designed to address the "missing middle" were identified in our study. The first is the Center for Nanomanufacturing Systems for Mobile Computing and Mobile Energy Technologies, or NASCENT, a manufacturing innovation ecosystem founded at the University of Texas at Austin in 2012. NASCENT is designed to partner with industry and create processes and tools for manufacturing nano-enabled components in the mobile and energy sectors, among others.

The second is the College of Nanoscale Science and Engineering, or CNSE, in Albany, New York, established in 2004. CNSE is a precompetitive R&D prototyping and educational public-private partnership for advancing nanotechnology for the semiconductor industry. Equipped with state-of-the-art tools and partnered with a global consortium of the major computer chip manufacture, CNSE's collaborative work allows for the development of chips just short of mass production.

In conclusion, based on the views of a wide range of experts, nanoscale control and fabrication are creating important new opportunities and challenges for our Nation. As such, our experts see potential benefit in pursuing forward-looking strategies designed to help the global economic position of the United States as it moves further into the 21st century.

Chairman Bucshon, Ranking Member Lipinski, and Members of the Committee—Ranking Member Johnson, excuse me—this concludes my statement. I am happy to answer any questions you may have.

[The prepared statement of Dr. Persons follows:]

United States Government Accountability Office

GAO

Testimony
Before the Subcommittee on Research and Technology, Committee on Science, Space, and Technology, House of Representatives

For Release on Delivery
Expected at 10:00 a.m. ET
Tuesday, May 20, 2014

NANOMANUFACTURING AND U.S. COMPETITIVENESS

Challenges and Opportunities

Statement of Timothy M. Persons, Chief Scientist,
U.S. Government Accountability Office

Chairman Bucshon, Ranking Member Lipinski, and Members of the Subcommittee:

Thank you for the opportunity to be here today to discuss nanomanufacturing and U.S. competitiveness,[1] including opportunities, challenges, and related issues. As you know, in July of 2013, at the request of Committee Chairman Lamar Smith and former Committee Chairman Ralph Hall, the Comptroller General of the United States convened a strategic forum on nanomanufacturing. The forum brought together experts from a wide range of relevant backgrounds[2] to discuss the status, issues, and implications of nanotechnology's ongoing movement from the laboratory to commercial markets, mass manufacturing, and the global marketplace.[3] In January 2014, we issued a synthesis report from this initiative, which includes key messages stemming from forum discussions as well as four nanomanufacturing industry profiles.[4]

Based on views expressed by forum participants as well as a broader array of expert interviews, my testimony today will *first*, present a brief background on nanomanufacturing and discuss how the United States compares with other countries in research and development (R&D) and competitiveness in nanomanufacturing; *second*, identify the key challenges facing the United States in nanomanufacturing and discuss their significance; *third*, identify some key policy issues concerning nanomanufacturing; and *fourth*, discuss a few examples of public-private partnerships and how they are designed to promote U.S. innovation in

[1]For purposes of this testimony, we define national competitiveness as the productivity with which a nation utilizes its set of institutions, policies, and human capital and natural endowments to produce goods and services, for the prosperity of its people. See also Council on Competitiveness (2007).

[2]Addendum I lists forum participants, whom we selected with the assistance of the National Academies.

[3]Nanotechnology has been defined as the control or restructuring of matter at the atomic and molecular levels in the size range of about 1-100 nanometers (nm); 100 nm is about 1/1000th the width of a hair.

[4]See GAO 2014; that report also lists experts we consulted additional to forum participants (App. III) and provides detailed information on our Scope and Methodology (App. V).

nanomanufacturing. We conducted our work in accordance with GAO's quality assurance framework.[5]

Background and Discussion of How the United States Compares with Other Countries

According to forum participants, nanomanufacturing is an emerging megatrend that will bring diverse societal benefits and new opportunities—potentially creating jobs through disruptive innovation.[6] Further, nanomanufacturing has characteristics of a general purpose technology (GPT)—such as electricity or computers, or historically, innovations such as the smelting of ore and the internal combustion engine.[7] As one participant said: "Everything will become nano."

Figure 1, below, provides examples of nanomanufacturing products that illustrate four diverse areas being affected by nanomanufacturing. Different manufacturing activities occur at different stages of the value chain.[8]

[5]Notably, we recognize that many forum participants are active in nanotechnology research or manufacturing—and thus could benefit from increased government funding or other supportive efforts; therefore, we developed the forum with an emphasis on achieving a balance of views, to the extent possible.

[6]"Disruptive innovation" refers to a new technology that creates a new market (and a new value chain or "value network") and that ultimately, and often unexpectedly, overtakes an existing technology. See Christensen and Raynor (2003). For example, innovations such as the Ford Model T production line have been described as creating new markets, displacing earlier technologies, and in some cases, creating jobs.

[7]Addendum II lists historical examples of GPTs.

[8]We drew these examples from four of the nine areas listed by the National Nanomanufacturing Network (NNN). Other areas listed by NNN (which the four examples in fig. 1 may overlap in some cases) include (1) information technology and telecommunications; (2) aerospace and automotive; (3) forest and paper products; (4) environment, infrastructure, and national security; and (5) clothing, textiles, and personal care.

Figure 1: Diverse Value Chains Involving Nanoscale Materials, Components, or Devices, as of 2013—Looking Forward

Stage 1: Evolving nanoscale materials, components, or devices	Stage 2: Nano-enabled products or intermediates	Stage 3: Improved, nano-enhanced or new products
Nano-transistors	further improved semiconductor chips	ever-faster computers,[a] smaller smartphones
Copper nano-wires[b]	lithium-ion batteries	more powerful battery-powered vehicles
Carbon nanotubes	concrete additives that conduct electricity	road pavement with remote sensing
Protein nanoparticles	carriers of chemo-therapeutic drugs	chemotherapy targeted to cancer cells (only)

Source: Forum presentation (Persons 2013).

Note: We defined a value chain, for purposes of reporting on the forum, as a series of key steps starting with the processing of raw materials and continuing to the production of a finished consumer product; each step adds value—and may or may not involve a different company or intermediate product. The figure uses three main stages, drawn from a conceptualization by Lux Research (see Bradley 2010 and Holman 2007), to summarize four examples of nanotechnology value chains.

[a]With respect to "ever faster computers," digital development has generally followed "Moore's law" (briefly, a doubling of processing power every 18 months) in part by utilizing chips with nano-features; however, further advances and more innovations in nanotechnology—such as the use of a new generation of nanomaterials in conjunction with 3D chip architecture and optical interconnects—or other novel approaches may be needed for continuous improvement in future decades.

[b]Copper nano-wires represent one example of how nanotechnology might be used to enhance lithium-ion (Li-ion) batteries for vehicles.

Comparison for Nanotechnology R&D: Two Indicators

According to experts, the United States likely leads in nanotechnology R&D today but faces global-scale competition—which one forum participant described as a "moon race." Two indicators of how the U.S. compares with other countries are R&D funding levels and scientific publications.

With respect to R&D funding, there is some uncertainty about international comparisons because relevant definitions may vary across nations—and some countries may not adequately or effectively track R&D investments or not share such information externally. However, forum participants viewed the United States as currently appearing to lead in terms of overall (that is, combined public and private) funding of nanotechnology R&D. When public funding alone was considered, a participant in the July 2013 forum presented projections showing the United States as likely being surpassed by some other nations.

With respect to scientific publications, the United States appears to dominate in numbers of nanotechnology publications in three highly cited journals[9]—which is an apparent indication of U.S. competitiveness in quality research. However, China overtook the United States in 2010 through 2012 (the most recent year reported) in terms of the quantity of nano-science articles published annually.

Comparison for Nanomanufacturing: Four Industry Areas

Turning to U.S. competitiveness in nanomanufacturing itself, profiles of four nano-industry areas, developed for the forum, and related forum discussions indicate the following:

- **Nanotherapeutics:** According to experts, one of the most promising medical applications for nanotechnology is nanotherapeutics, the delivery of medicine using nanoparticles (particles having one or more dimensions on the order of 100 nanometers—100 billionth of a meter—or less). The potential of nanotherapeutics is the ability to target the delivery of drugs to specific cells—e.g., cancer cells—thereby reducing negative side effects. As one expert said, nanotherapeutics have "the potential to address problems in drug delivery for cancer and other diseases that cannot be solved using contemporary technologies." Experts viewed the United States as currently leading in the commercialization and manufacturing of nanotherapeutics. However, experts also cautioned that: (1) other regions or countries (for example, Europe and South Korea) are investing in nanotherapeutics—by, for example, supporting public-private partnerships; (2) in the United States, many efforts to commercialize nanotherapeutics are being carried out by small companies, which typically cannot sustain the costs of clinical trials and regulatory review; and (3) private U.S. investors may be reluctant to invest in new drugs because of uncertainty about approval by the U.S. Food and Drug Administration (FDA).
- **Energy storage:** By contrast, experts said the United States is struggling in the area of lithium-ion batteries for hybrids, plug-in hybrids, and fully electric vehicles (EV). Battery-powered vehicles now

[9]This is based on an analysis by Roco (2013) of three journals: *Science*, *Nature*, and *Proceedings of the National Academy of Sciences*. Note that another forum participant cautioned that these journals might have favored U.S. authors.

represent about 3 to 4 percent of the U.S. and worldwide auto markets. Factors limiting demand for these vehicles include (1) the cost of an advanced battery, which increases the price of a battery-powered vehicle above that of a comparable all-gasoline car, and (2) the long battery-recharging times required by plug-in hybrids and EVs, and the EVs' limited driving ranges. Potentially, nano-improved batteries will cost less than those currently available, have decreased recharge times, and provide the power to lengthen driving ranges. Although U.S. research developed the underlying technology, almost all lithium-ion batteries are currently manufactured in Asia. According to varied forum participants: (1) the manufacture of smaller lithium-ion batteries for consumer electronics has long been centered in Asia because, as one participant put it, the United States "gave up on [that industry] some time ago;" (2) Asian firms appear to have a competitive advantage in the manufacturing process, which is similar for small lithium-ion batteries and the larger ones manufactured for vehicles; and (3) some U.S. researchers now look to Asia for opportunities to pursue innovation in lithium-ion batteries. While some experts felt that "the jury is still out" on future U.S. success in this area—or that new versions of lithium-ion batteries requiring different manufacturing processes would present new opportunities—others were less positive.[10]

- **Semiconductors:** The diffusion of semiconductor[11] chips with nanoscale features is pervasive in this $300-billion industry, and the technology continues to evolve. For example, production of a number of the components in semiconductors currently takes place at the nanoscale—that is, at scales of less than 100 nanometers (nm). In 2012, semiconductors with features spaced 22 nm apart and with layers just a few nanometers in thickness entered high-volume production. As previously noted, further advances and more innovations in nanotechnology—such as the use of a new generation of nanomaterials in conjunction with 3D chip architecture and optical interconnects—or other novel approaches may be needed for continuous improvement in future decades. Experts told us that the United States is dominant in the design of new advances in

[10]However, according to recent news reports, Tesla Motors Inc.—an American manufacturer of all electric vehicles—has announced plans to construct a new plant to manufacture batteries in the United States for its vehicles.

[11]A semiconductor is the generic term for the various devices and integrated circuits that regulate and provide a path for electrical signals. As such, semiconductors are the foundation of the electronics industry.

semiconductors. However, they also said that U.S. manufacturing in this area has declined (although some plants are located here) and that the United States does not have a strategy to assure U.S. leadership in the semiconductor industry.

- **Nano-based concrete:** Concrete is the most heavily used construction material in the world—with about 5-billion cubic yards annually produced worldwide—and demand for it is expected to increase to meet the infrastructure needs of a growing global population. Nanomaterials can enhance the performance of the concrete used to construct this infrastructure. These materials might potentially result in roads, bridges, buildings, and structures that are more easily built, longer-lasting, and better-functioning than those that currently exist. Experts offered differing views on U.S. global competitiveness in the commercialization and use of nanomaterials in concrete. A key forum participant said that while cement for domestic use is produced in the United States, today's dominant companies—which are spearheading development of new technologies—are headquartered elsewhere (although this industry was previously dominated by the United States). Additionally, some experts said that other countries are spending more resources than the United States to promote commercialization; for example, one expert said that China established a national technology center to improve its competitiveness and domestic production of high-value, nano-based construction products. On the positive side, chemical admixtures are one means to introduce nano-materials into concrete—and the United States has a 15% market share of chemical sales, worldwide.

Key Challenges Facing U.S. Nanomanufacturing

According to forum participants and experts interviewed, challenges to U.S. competitiveness in nanomanufacturing include U.S. funding gaps, significant global competition, and lack of a U.S. vision for nanomanufacturing, among others.

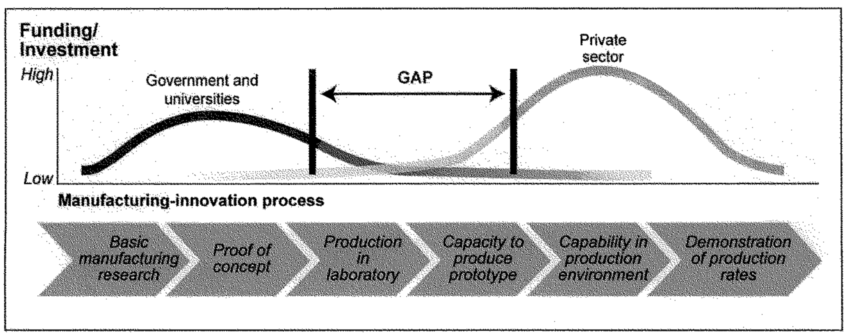
U.S. Funding Gaps and Possibly a Diversion of Venture Capital

Participants said that in the United States, government often funds research or the initial stages of development, whereas industry typically invests in the final stages. As a result, U.S. innovators may find it difficult to obtain either public funding or private investment during the middle stages of innovation. For nano-innovators, this support gap can characterize the middle stages of both (1) efforts to develop a new technology or product, and/or (2) efforts to develop a new manufacturing process. Thus, U.S. innovators may encounter two support gaps, which participants termed:

- the ***Valley of Death*** (the lack of funding or investment for the middle stages of developing a technology or product), and
- the ***Missing Middle*** (a similar lack of adequate support for the middle stages of *developing a process or an approach to manufacture the new product at scale*).

The *Valley of Death* begins after a new technology or product has been validated in a laboratory environment and continues through testing and demonstration as a prototype in a non-laboratory environment (but before industry acquires it as a commercial technology or product). The *Missing Middle* occurs during analogous stages of the manufacturing-innovation process, as illustrated below (fig.2). Participants further said that substantial amounts of funding/investment are needed to bridge the *Valley of Death* and the *Missing Middle*—and that high costs can be a barrier to commercialization, especially for small and medium-sized U.S. enterprises.

Figure 2: Missing Middle: Funding/Investment Gap in the U.S. Manufacturing-Innovation Process



Source: GAO, adapted from Executive Office of the President (2012, 21).

Additionally, some said that recently, venture capital (VC) funding has been diverted from physical science areas like nanotechnology to fund new ventures in Internet services that may provide larger and faster returns on investment.

Significant Global Competition

Varied forum participants and experts interviewed made statements to the effect that other nations do more than the United States in terms of government investment in technology beyond the research stage. According to participants, the funding and investment gaps that hamper U.S. nano-innovation (such as the *Missing Middle*) do not apply to the same extent in some other countries—for example, China and Russia—or are being addressed. Multiple participants referred to the European Commission's upcoming Horizon 2020 program, specifically mentioning a key program within Horizon 2020: the European Institute of Innovation and Technology or EIT, which emphasizes the nexus of business, research, and higher education. The 2014-2020 budget for the EIT portion of this European Commission initiative is €2.7 billion (or close to $3.7 billion in U.S. dollars as of January 2014).

Lack of a U.S. Vision for Nanomanufacturing

Multiple forum participants said that the United States lacks a vision or strategy for a nanomanufacturing capability.[12] However, one explained that such a strategy could be designed by (1) proceeding from a vision or goal to the examination of the social, technological, economic, environmental, and political elements of the relevant systems and their interactions with one another; (2) understanding the basic science, engineering, and manufacturing involved; and (3) consulting the full range of stakeholders. This participant said that although systems thinking and the design of a grand strategy, based on a vision, are often employed following a crisis that motivates a nation, such an effort could be usefully pursued in advance of a crisis, using foresight. Such an effort would reflect the statements of another participant who said, in effect, that the future of nanomanufacturing for the United States is limited only by our ability to envision what we want to see realized. This approach would likely draw upon the U.S. federal government to develop and articulate the strategy—in coordination with industry, academia, nonprofits, and state and local governments. Additionally, some federal effort is implied for implementation, but the level of funding and the mix of funding

[12]Our post-forum communication with an official at the National Science Foundation indicated that although NSF currently funds some centers that focus on new concepts and the development of methods for nanomanufacturing, there is, at this time, no program devoted to supporting nanomanufacturing centers such as these.

sources (not specifically discussed at the forum) would likely be specified as part of developing a vision and strategy for nanomanufacturing.[13]

Other Competitiveness Challenges

Forum participants described further challenges to U.S. competitiveness in nanomanufacturing, including

- the earlier loss of an industry, as discussed above for lithium-ion batteries—or even extensive prior offshoring in some industries, which can be important, in part because, as one participant said: "when we design here [and] ship [manufacturing] abroad, we lose this shop-floor-innovation kind of mentality" and
- threats to U.S. intellectual property on the part of some other countries or entities within those countries—which occur with respect to both university research and private R&D on, for example, manufacturing processes.

Some Key Policy Issues Concerning Nanomanufacturing

Forum participants suggested the need to address policy issues in U.S. research funding, challenges to U.S. competitiveness in nanomanufacturing, and other areas, including environmental, health, and safety (EHS) issues.

U.S. research funding. Forum participants said it is essential for the United States to maintain a high level of investment in fundamental nanotechnology research. This is because (1) some other countries are now making significant investments in R&D and (2) ongoing research breakthroughs will drive the future of nanomanufacturing. One participant emphasized that as nanotechnology increasingly moves into manufacturing, it may be important to consider not only continuing funding for fundamental nanotechnology research, but also targeting some funding to *early stage research on nanomanufacturing processes.*

Challenges to U.S. competitiveness in nanomanufacturing. Forum participants said the United States could improve U.S. competitiveness in nanomanufacturing by pursuing one or more of three approaches, which

[13]This approach (developing a vision and strategy for U.S. nanomanufacturing) is briefly revisited later in this testimony.

might be viewed either as alternatives or as complementary approaches.[14] These three approaches are described in table 1, below.

Table 1: Three Approaches to Enhancing U.S. Competitiveness in Nanomanufacturing—Proposed Actions and Rationale

Approach	Proposed actions	Rationale
1. strengthen innovation across the U.S. economy	Continue or update policies and programs that help strengthen innovations generally—for example, education and infrastructure.	The U.S. government often acts to supply goods and services critical to innovation when private markets fail to do so; beyond these measures, firms are better able to decide how to allocate resources.
2. promote innovation in U.S. manufacturing	Establish U.S. centers, encourage clusters, or design programs to address the *Valley of Death* or the *Missing Middle* (gaps in U.S. funding or investment).[a]	A strong manufacturing base is essential to the economy and to innovation itself. Addressing the *Valley of Death* and the *Missing Middle* will "level the playing field" and avoid other adverse effects.
3. design a grand strategy for U.S. nanomanufacturing	Define a vision for U.S. manufacturing. Design a grand strategy for achieving this vision—an effort that might be led by the federal government.	Nanomanufacturing may be a future general purpose technology (GPT) and thus is potentially classifiable as a public good with anticipated benefits for the entire society—justifying targeted federal support. It may also create jobs.

Source: GAO analysis of forum information.

[a]Two public-private partnerships that focus specifically on nanomanufacturing are the NASCENT Center at the University of Texas at Austin and the College of Nanoscale Science and Engineering (CNSE) at New York State University, which are discussed later in this testimony.

Other policy areas identified. Forum participants also identified

- the need to remedy the currently insufficient effort by the United States to participate in the international development of basic nanotechnology standards;
- concerns about the reliability of international investment information—and a possible pathway forward: convening international conferences on public investment and other related data; and
- the need for a revitalized, integrative, and collaborative approach to environmental, health, and safety (EHS) issues.

With respect to the third point, above, forum participants said that significant research is needed to discern or anticipate EHS implications of manufacturing with nanomaterials and using nanotechnologies. Participants noted the presence of significant funding—both governmental and private—for nanotechnology research, but one participant suggested that relatively little funding supports research on

[14]We note that some advocates of particular approaches have raised objections to the others.

EHS implications, an observation that is consistent with our previous reporting on the National Nanotechnology Initiative (GAO, 2012).

Examples of Public-Private Partnerships Designed to Promote Innovation in Nanomanufacturing

Two examples of U.S. public-private partnerships that are designed to promote innovation in nanomanufacturing are housed in universities.[15] A related example with similar goals is a user facility that is located within a federal laboratory.

The NASCENT Center

The Center for Nanomanufacturing Systems for Mobile Computing and Mobile Energy Technologies (NASCENT) was founded at the University of Texas at Austin in 2012, with funding from NSF. Two key objectives are:

- to create processes and tools for manufacturing nano-enabled components for mobile computing, energy, healthcare, and security—as well as simulations for testing potential nanomanufacturing approaches, and
- to provide an ecosystem with computational and manufacturing facilities—for example, large-area wafer-scale and roll-to-roll nanomanufacturing,[16] as well as the university's resources, including faculty, staff, and students.

The Center's overall goal is to facilitate the rapid creation and deployment of new products and to mitigate the risks associated with the *Valley of Death* and the *Missing Middle*. A co-director of NASCENT told us that another goal is to use "10 years of NSF funding to develop the center infrastructure so it will . . . [become] self-supported from industrial partnerships and other [non-NSF] funding sources." Center partners include

[15]Government funding for one of the university-based centers is provided by a federal grant from the National Science Foundation. For the other, the government portion of the funding is provided primarily by a state government.

[16]See Morse (2011).

- industrial partners—such as toolmakers, materials suppliers, and device makers—that will provide both technical and financial support;
- companies ranging from start-ups to well-established firms that will implement or adopt technology created by the center; and
- "translational research partners" such as technology incubators and technology funds.

The College for Nanoscale Science and Engineering

The College of Nanoscale Science and Engineering (CNSE), established in 2004, is part of the State University of New York and is located in Albany—within the existing regional (Hudson Valley) ecosystem centered on the semiconductor industry. CNSE is designed as a unique research, development, prototyping, and educational public-private partnership for advancing nanotechnology. A chief CNSE partner is SEMATECH—a global consortium of major computer chip manufacturers that coordinates cutting-edge R&D projects on semiconductors and is headquartered at CNSE. CNSE has more than 300 members and strategic partners that include large U.S.- and non-U.S.-headquartered private companies such as IBM, Intel, Samsung, and Global Foundries; small and medium-sized companies; universities from across the United States; and regional community colleges and economic development organizations, as well as government-agency sponsors. CNSE facilities allow the development of semiconductors just short of mass production—which is relevant for companies attempting to transition from an innovative concept to a prototype and to prepare for large-scale production. CNSE has developed models of pre-competitive collaboration among its partners, which use high-tech CNSE equipment that would be too costly for many individual companies to purchase.

The Center for Nanoscale Science and Technology

The Center for Nanoscale Science and Technology (CNST) is hosted by a federal laboratory at the National Institute of Standards and Technology (NIST). CNST is a user facility with baseline sponsorship through the Department of Commerce, which is augmented by external commercial funds in the form of user fees paid by industry, academia, government labs, and states. CNST supports the U.S. nanotechnology enterprise from discovery to production by providing industry, academia, NIST, and other government agencies access to world-class nanoscale measurement and fabrication methods and technology. The CNST's shared-use nanotechnology-fabrication capability (called NanoFab) gives researchers economical access to and training on a commercial state-of-the-art tool set required for cutting-edge nanotechnology development. The simple application process is designed to get projects started in a few weeks.

Looking beyond the current commercial state of the art, the CNST's nanotechnology-metrology capability offers opportunities for researchers to collaborate on creating and using the next generation of nanoscale measurement instruments and methods.

Concluding Remarks

Based on the views of a wide range of experts, nanoscale control and fabrication are creating important new opportunities for our nation—as well as the need not only to recognize challenges, but also, where challenges exist, to act in response to them. The United States leads in some areas of nanomanufacturing, but faces increasing international competition. Challenges specific to U.S. competitiveness include, among others:

- the U.S. funding gap known as the *Missing Middle*,
- possible weaknesses associated with prior extensive offshoring in some U.S. industries, and
- the lack of a national vision and strategy for the United States to lead or sustain a high level of competitiveness in global nanomanufacturing markets in the years ahead.

Experts outlined three main approaches for responding to these challenges: (1) reviewing and renewing policies that undergird U.S. innovation; (2) supporting public-private partnerships that address U.S. funding gaps—especially as these apply to nanomanufacturing; and (3) defining a vision and strategy for achieving and sustaining a high level of U.S. competitiveness in nanomanufacturing. The potential benefit that experts see in pursuing forward-looking approaches such as these is to help chart a favorable course for the global economic position of the United States as we move further into the twenty-first century.

Chairman Bucshon, Ranking Member Lipinski, and Members of the Committee, this concludes my statement. I would be happy to answer any questions you may have.

GAO Contacts and Staff Acknowledgments

If you or your staff have any questions about this testimony, please contact me at (202) 512-5648 or personst@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this testimony. GAO staff members who made key contributions to this testimony include Judith Droitcour, Assistant Director, and Eric M. Larson, Analyst-in-Charge.

Appendix I: List of Forum Participants

Gene L. Dodaro (Host), Comptroller General of the United States

George Allen, Former U.S. Senator and former Governor of Virginia

Tina Bahadori, Environmental Protection Agency

Sarbajit Banerjee, University at Buffalo, State University of New York

Lynn L. Bergeson, Bergeson & Campbell PC

Bjorn Birgisson, KTH Royal Institute of Technology

Bill Canis, Congressional Research Service

Vicki L. Colvin, Rice University

Joseph DeSimone, University of North Carolina

Bart Gordon, Former Chairman, Committee on Science and Technology, U.S. House of Representatives, and Partner at K&L Gates LLP

John Ho, QD Vision, Inc.

Hamlin M. Jennings, Massachusetts Institute of Technology

Brian David Johnson, Intel Corporation

Michael Liehr, College of Nanoscale Science and Engineering, State University of New York

Scott E. McNeil, Frederick National Laboratory for Cancer Research, and Science Applications International Corporation

Manish Mehta, National Center for Manufacturing Sciences

Celia Merzbacher, Semiconductor Research Corporation

Michael F. Molnar, Advanced Manufacturing National Program Office and the National Institute of Standards and Technology

Matthew Nordan, Venrock

Susan E. Offutt, U.S. Government Accountability Office

Timothy M. Persons, U.S. Government Accountability Office

James M. Phillips, NanoMech Corporation

Robert Pohanka, National Nanotechnology Coordination Office

David Rejeski, Woodrow Wilson International Center for Scholars

Mihail C. Roco, National Science Foundation

Sheila R. Ronis, Walsh College

Françoise Roure, Organisation for Economic Co-operation and Development

Paul Schulte, Centers for Disease Control and Prevention

Charles Wessner, The National Academies

Appendix II: Examples of General Purpose Technologies

Era	Event	Era	Event
9000–8000 BC	Domesticated plants	1800s	Railway
8500–7500 BC	Domesticated animals		Iron steamship
8000–7000 BC	Smelting of ore		Internal combustion engine
4000–3000 BC	Wheel		Electricity
3400–3200 BC	Writing	1900s	Motor vehicle
2800 BC	Bronze		Airplane
1200 BC	Iron		Mass-production, continuous-process factory
Early Medieval	Waterwheel		Computer
1400s	Three-masted sailing ship		Lean production
1500s	Printing		Internet
Late 1700s–early 1800s	Steam engine		Biotechnology
	Factory system	Early 2000s	Nanotechnology[a]

Source: Lipsey et al. (2005, 132).

Note: Lipsey et al. (2005, 98) define a general purpose technology as "a single generic technology, recognizable as such over its whole lifetime, that initially has much scope for improvement and eventually comes to be widely used, to have many uses, and to have many spillover effects."

[a]"Nanotechnology has yet to make its presence felt as a general purpose technology, but its potential is so obvious and developing so quickly that we [Lipsey et al.] are willing to accept that it is on its way to being one of the most pervasive general purpose technologies of the 21st century" (Lipsey et al. 2005, 132).

Appendix III: List of References

Bradley, Jurron. 2010. "The Recession's Impact on Nanotechnology." *The Lux Research Analyst Blog,* February 4. (Based on the Lux Research report, *The Recession's Ripple Effect on Nanotech: State of the Market Report.* Boston, Massachusetts: Lux Research, Inc., June 9, 2009.)

Christensen, Clayton M., and Michael E. Raynor. 2003. *The Innovator's Solution: Creating and Sustaining Successful Growth.* Boston, Massachusetts: Harvard Business School Publishing Corporation.

Council on Competitiveness. 2007. *Competitiveness Index: Where America Stands.* Washington, D.C.: Council on Competitiveness, January.

Executive Office of the President. 2012. *Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing.* Washington, D.C.: Executive Office of the President, July.

GAO (U.S. Government Accountability Office). 2012. *Nanotechnology: Improved Performance Information Needed for Environmental, Health, and Safety Research.* GAO-12-427. Washington, D.C.: GAO, May 21.

GAO (U.S. Government Accountability Office). 2014. *Nanomanufacturing: Emergence and Implications for U.S. Competitiveness, the Environment, and Human Health.* GAO-14-181SP. Washington, DC: January.

Holman, Michael. 2007. "Nanotechnology's Impact on Consumer Products." (Slide presentation at a meeting organized by the Directorate-General for Health and Consumers, European Commission, October 25, 2007.) New York, New York: Lux Research, Inc.

Lipsey, Richard G., Kenneth Carlaw, and Clifford Bekar. 2005. *Economic Transformations: General Purpose Technologies and Long-term Economic Growth.* New York: Oxford University Press, Inc.

Morse, Jeffrey D. (ed.). 2011. *Nanofabrication Processes for Roll-to-Roll Processing: Report from the NIST-NNN Workshop.* Workshop on Nanofabrication Technologies for Roll-to-Roll Processing. Seaport Convention Center, Seaport Boston Hotel, Boston, Massachusetts, September 27-28.

Persons, Timothy M. 2013. "Comptroller General Forum on Nanomanufacturing: Overview." Slide presentation at the Comptroller

General Forum on Nanomanufacturing. Washington, D.C.: U.S. Government Accountability Office, July 23–24.

Roco, Mihail C. 2013. "Global Investment Profile in Nanotechnology—Comparing U.S. to Selected Economies." Slide presentation at the Comptroller General Forum on Nanomanufacturing. U.S. Government Accountability Office, Washington, D.C., July 23.

GAO's Mission

The Government Accountability Office, the audit, evaluation, and investigative arm of Congress, exists to support Congress in meeting its constitutional responsibilities and to help improve the performance and accountability of the federal government for the American people. GAO examines the use of public funds; evaluates federal programs and policies; and provides analyses, recommendations, and other assistance to help Congress make informed oversight, policy, and funding decisions. GAO's commitment to good government is reflected in its core values of accountability, integrity, and reliability.

Obtaining Copies of GAO Reports and Testimony

The fastest and easiest way to obtain copies of GAO documents at no cost is through GAO's website (http://www.gao.gov). Each weekday afternoon, GAO posts on its website newly released reports, testimony, and correspondence. To have GAO e-mail you a list of newly posted products, go to http://www.gao.gov and select "E-mail Updates."

Order by Phone

The price of each GAO publication reflects GAO's actual cost of production and distribution and depends on the number of pages in the publication and whether the publication is printed in color or black and white. Pricing and ordering information is posted on GAO's website, http://www.gao.gov/ordering.htm.

Place orders by calling (202) 512-6000, toll free (866) 801-7077, or TDD (202) 512-2537.

Orders may be paid for using American Express, Discover Card, MasterCard, Visa, check, or money order. Call for additional information.

Connect with GAO

Connect with GAO on Facebook, Flickr, Twitter, and YouTube. Subscribe to our RSS Feeds or E-mail Updates. Listen to our Podcasts. Visit GAO on the web at www.gao.gov.

To Report Fraud, Waste, and Abuse in Federal Programs

Contact:

Website: http://www.gao.gov/fraudnet/fraudnet.htm
E-mail: fraudnet@gao.gov
Automated answering system: (800) 424-5454 or (202) 512-7470

Congressional Relations

Katherine Siggerud, Managing Director, siggerudk@gao.gov, (202) 512-4400, U.S. Government Accountability Office, 441 G Street NW, Room 7125, Washington, DC 20548

Public Affairs

Chuck Young, Managing Director, youngc1@gao.gov, (202) 512-4800
U.S. Government Accountability Office, 441 G Street NW, Room 7149
Washington, DC 20548

GAO

NANOMANUFACTURING AND U.S. COMPETITIVENESS: CHALLENGES AND OPPORTUNITIES

Testimony Before the Subcommittee on Research and Technology, Committee on Science, Space, and Technology, House of Representatives

TUESDAY, MAY 20, 2014

STATEMENT OF TIMOTHY M. PERSONS, CHIEF SCIENTIST
U.S. GOVERNMENT ACCOUNTABILITY OFFICE

GAO

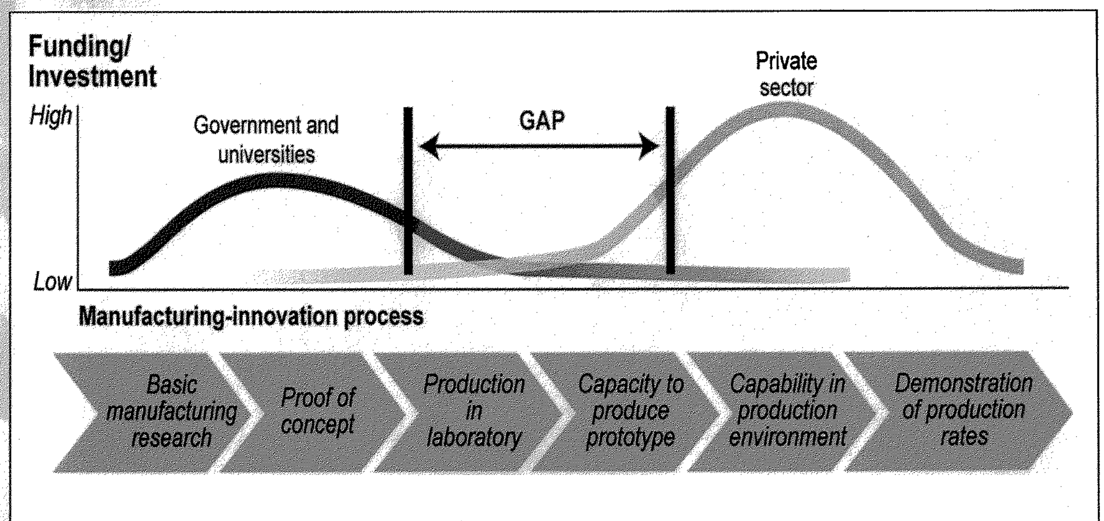
Diverse Value Chains Involving Nanoscale Materials, Components, or Devices, as of 2013—Looking Forward

Stage 1: Evolving nanoscale materials, components, or devices	Stage 2: Nano-enabled products or intermediates	Stage 3: Improved, nano-enhanced or new products
Nano-transistors	further improved semiconductor chips	ever-faster computers,[a] smaller smartphones
Copper nano-wires[b]	lithium-ion batteries	more powerful battery-powered vehicles
Carbon nanotubes	concrete additives that conduct electricity	road pavement with remote sensing
Protein nanoparticles	carriers of chemo-therapeutic drugs	chemotherapy targeted to cancer cells (only)

Source: Forum presentation (Persons 2013).

GAO

Missing Middle: Funding/Investment Gap in the U.S. Manufacturing-Innovation Process



Source: GAO, adapted from Executive Office of the President (2012, 21).

Timothy M. Persons, Ph.D.
Chief Scientist
United States Government Accountability Office

Biography

Dr. Timothy M. Persons was appointed the Chief Scientist of the United States Government Accountability Office (GAO - the investigative arm of the U.S. Congress) in July of 2008. As such, he is a member of the Senior Executive Service of the U.S. federal government. He is also the Co-Director of GAO's Center for Science, Technology, and Engineering (CSTE), a group of highly specialized scientists, engineers, mathematicians, and information technologists. In these roles he is an expert advisor and chief consultant to the GAO, Congress, and other federal agencies and government programs on cutting-edge science and technology (S&T), key highly-specialized national and international systems, engineering policies, best practices, and original research studies in the fields of engineering, computer, and the physical and biological sciences to ensure efficient, effective, and economical use of science and technology in government programs. He also works with GAO's Chief Technologist to lead the production of Technology Assessments for the U.S. Congress on topics such as additive manufacturing, nanomanufacturing, freshwater conservation technologies, climate engineering technologies, and next-generation nuclear detection and non-intrusive imaging systems. Prior to joining GAO, Dr. Persons held key leadership roles in the National Security Community.

Dr. Persons is a 2012 recipient of the Arthur S. Flemming award in recognition of sustained outstanding and meritorious achievement within the U.S. federal government; and a 2012 recipient of GAO's Big Picture Award for significant project achievement involving the ability to look longer, broader, and more strategically at key national or global issues. In 2007, Dr. Persons was awarded a Director of National Intelligence Science and Technology Fellowship focusing on computational imaging systems research. He was also selected as the James Madison University (JMU) Physics Alumnus of 2007. He has also served as a radiation physicist with the University of North Carolina at Chapel Hill. He received his B.Sc. (Physics) from JMU, a M.Sc. (Nuclear Physics) from Emory University, and a M.Sc. (Computer Science) and Ph.D. (Biomedical Engineering) degrees from Wake Forest University. He is a senior member of the Institute for Electrical and Electronic Engineers (IEEE), serves on the World Future Society Global Advisory Council, and has authored or co-authored an array of journal, conference, and technical articles.

Chairman BUCSHON. Thank you, Dr. Persons.

I now recognize Dr. Whitman for five minutes for his testimony.

TESTIMONY OF DR. LLOYD WHITMAN, INTERIM DIRECTOR OF THE NATIONAL NANOTECHNOLOGY COORDINATION OFFICE AND DEPUTY DIRECTOR OF THE CENTER FOR NANOSCALE SCIENCE AND TECHNOLOGY, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

Dr. WHITMAN. Chairman Bucshon, Ranking Member Lipinski, Ranking Member Johnson and Members of the Committee, it is a privilege to be here today to discuss nanotechnology and the U.S. National Nanotechnology Initiative, known as the NNI.

As Dr. Persons noted, the field of nanotechnology aims to understand and control matter at sizes of about 1 to 100 nanometers. A nanometer is one-billionth of a meter. If I reference a sheet of paper, it is about 100,000 nanometers thick, and a DNA double helix is about two nanometers in diameter. So nanotechnology involves working at the scale of atoms and molecules.

The reason this size range is so interesting is because things this small often have properties completely different than both larger objects of the same material and the individual atoms and molecules within. By changing the size and composition of nanoscale materials, one can create things with unique properties that have a tremendous range of promising applications.

Consider gold, for example. Bulk gold like that in jewelry is of course gold-colored and chemically inert, but gold nanoparticles, depending upon their size, may look pink or purple or red and can actually be used to catalyze chemical reactions. They can even be used to target and kill cancer cells. You can read about many other nanotech breakthroughs, including many aimed at improving our national security, at our Nano.Gov website.

So how did the NNI get where it is today? In the 1990s, the tools to make and measure things on the nanoscale developed very rapidly, making the promise of nanotech increasingly clear. In response to this promise, the NNI was launched in 2000 and authorized by Congress in 2003. There are now 20 federal agencies actively participating in the initiative supported by R&D funding totaling over $1.5 billion per year.

It is important to emphasize that the NNI is not a distinctly funded program with a centralized budget and management but rather a well-coordinated multiagency initiative. The NNI is coordinated through the Nanoscale Science, Engineering, and Technology Subcommittee of the National Science and Technology Council. The National Nanotechnology Coordination Office, which I direct, provides support for the Subcommittee and acts as the primary point of contact on the NNI, among other duties specified in the 2003 act.

The NNI functions as a collaborative effort of the participating federal agencies, thereby leveraging the funding, avoiding duplication, and providing an effective way for these agencies to work towards common goals and objectives. These goals are outlined in the NNI's strategic plan, which was just updated in February and are highlighted— and budget details, along with research accomplishments and plans, are highlighted every year in the NNI supplement to the President's budget.

Federal nanotechnology innovation in the United States is strong. We are advancing research, developing and maintaining the U.S. workforce and infrastructure, supporting responsible development, and fostering commercialization. The most recent reviews of the NNI by the National Nanotechnology Advisory Panel and by the National Academies agree with this assessment. However, there is always room for improvement.

This year's updated strategic plan describes a number of ways federal agencies will further strengthen the NNI laying out specific interagency objectives under each of the goals. The plan calls out the importance of the nanotechnology signature initiatives, which agencies collaboratively established to spotlight areas of national significance that can be advanced more rapidly through focused, coordinated research. It also introduces revised budget categories called program component areas, which have evolved over the years as the field has matured.

The sustained strategic federal investment in nanotechnology, combined with strong private sector investments, has made the United States the global leader in nano. For example, it is estimated that in 2012 U.S. companies invested over $4 billion in nanotech R&D, far more than investments made by companies in any other country. Although the annual federal investment is relatively modest in comparison, it plays a very different role, namely supporting a critical pipeline of foundational research innovations that will form the seeds for future industry investment. The NNI also demonstrates the government's long-term commitment to the field, very important to sustaining the private sector support needed to bring nanotech products from lab to market.

The 21st century Nanotechnology Research and Development Act of 2003 has provided an excellent framework for the coordination and oversight of the NNI. It has brought federal agencies together to develop and implement an efficient and effective national strategy for nanotech R&D, including a robust, well-coordinated program of environmental health and safety research needed to ensure that new nanotech products are safe.

In conclusion, the NNI has sustained vital support for fundamental groundbreaking research, development, infrastructure, and education and training, programs that collectively constitute a major U.S. innovation enterprise. It is essential that the United States continue to lead the way. The Nation's economic growth and global competitiveness depend on it.

So I thank the Chairman and the Members of the Committee for the opportunity to appear before you today and I would be pleased to answer any questions.

[The prepared statement of Dr. Whitman follows:]

Statement of Dr. Lloyd Whitman

Interim Director, National Nanotechnology Coordination Office

to the

Committee on Science, Space and Technology

Subcommittee on Research and Technology

United States House of Representatives

Hearing on

Nanotechnology: From Laboratories to Commercial Products

May 20, 2014

Chairman Bucshon, Ranking Member Lipinski, and Members of the Committee, it is my distinct privilege to be here with you today to discuss nanotechnology and the role of the National Nanotechnology Initiative in promoting its development for the benefit of the United States.

What is Nanotechnology?

Nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nanometers. 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. Encompassing nanometer-scale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale. Unusual physical, chemical, and biological properties can emerge in materials at the nanometer scale. These properties may differ in important ways from the properties of bulk materials and single atoms or molecules, and can enable novel applications not possible in bulk materials of the same chemical composition.

For example, in bulk form gold is chemically inert, while gold nanoparticles can act as catalysts to speed up chemical reactions. Gold nanoparticles may appear pink, purple, red, or other colors depending on their size and shape, and are under investigation for a wide variety of applications, including diagnosing and treating cancer. Bulk carbon ("soot") is considered a waste byproduct of combustion, whereas nanostructured carbon in the form of nanotubes or graphene (the subject of the 2010 Nobel Prize in Physics) exhibit remarkable electrical and mechanical properties that could enable the next generation of computers, composites that are stronger and lighter than steel, and a myriad of other potential applications. Semiconductor nanoparticles known as "quantum dots" are now being used in flat-panel TVs and light bulbs to provide more vivid and accurate colors. There are countless other examples; nanotechnology opens up an entirely new dimension in enabling the development of materials with tailored properties previously unknown or considered impossible.

The unique properties of nanostructured materials are already in use in a wide variety of nanotechnology-enabled products on the market today, from electronics to energy conversion, medicine, and advanced manufacturing.[1] These early applications are only the beginning of a revolution in technology and industry that will have a profound impact on our economy, health, and national security, and that can excite a new generation of students to choose careers in science, technology, engineering, and math.

What is the National Nanotechnology Initiative?

Recognizing this exciting potential, President Clinton created the National Nanotechnology Initiative (NNI) in 2000, and Congress formally authorized the NNI under the 21st Century Nanotechnology R&D Act of 2003.[2] Since then, with bipartisan support from three presidents and eight Congresses, Federal funding for nanotechnology across 11 Federal departments, agencies, and independent commissions has grown to over $1.5 billion per year, with a cumulative investment of over $20 billion since 2001. A total of 20 agencies with missions and activities related to nanotechnology participate in the NNI, which is coordinated through the National Science and Technology Council (NSTC). The Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the NSTC's Committee on Technology coordinates planning, budgeting, program implementation, and review of progress for the Initiative. The NSET Subcommittee is composed of representatives from participating agencies and the Executive Office of the President. The National Nanotechnology Coordination Office (NNCO), which I direct, acts as the primary point of contact for information on the NNI; provides technical and administrative support to the NSET Subcommittee, including the preparation of multiagency planning, budget, and assessment documents; develops, updates, and maintains the NNI website www.nano.gov; and provides public outreach on behalf of the NNI.

The NNI is a coordinated multi-agency initiative, not a distinctly funded "program" with a centralized budget. Each year the Office of Management and Budget sends a request to the participating agencies for data on their current and proposed spending on nanotechnology; the sums of these figures are reported to Congress in the NNI Supplement to the President's Budget, a document that also serves as the annual report to Congress called for in the Act.[3] Through the NSET Subcommittee and its working groups, and with support from the NNCO, the NNI fosters coordination and collaboration across agencies, leverages funding and avoids duplication of efforts, and provides a framework by which agencies work towards common goals and objectives that are outlined in the NNI Strategic Plan,[4] updated every three years (most recently in February 2014), also per the Act.

---

[1] Nanotechnology-enabled products are already valued at an estimated $1 trillion in annual sales today, projected to grow to $3 trillion by 2018, per Lux Research, Feb. 2014, *Nanotechnology Update: Corporations Up Their Spending as Revenues for Nano-enabled Products Increase* (available by subscription at http://portal.luxresearchinc.com/).
[2] Hereinafter referred to as "the Act."
[3] http://www.nano.gov/sites/default/files/pub_resource/nni_fy15_budget_supplement.pdf. Includes a list of all NNI participating agencies and descriptions of their current and planned activities.
[4] http://www.nano.gov/sites/default/files/pub_resource/2014_nni_strategic_plan.pdf. Includes complete list of all NNI goals and objectives, discussion of each agency's interests in and activities related to nanotechnology, and an explanation of the Program Component Areas, or budget categories, for 2013 and beyond.

Highlights of the National Nanotechnology Initiative

Our current Federal research and development program in nanotechnology is strong. The NNI agencies continue to further the NNI's goals of (1) advancing nanotechnology R&D, (2) fostering nanotechnology commercialization, (3) developing and maintaining the U.S. workforce and infrastructure, and (4) supporting the responsible and safe development of nanotechnology. The NNI Supplement to the President's 2015 Budget (see footnote 3 above) highlights progress of the NNI agencies with respect to each of these goals. In support of goal 1, R&D, the NNI is sustaining a broad R&D investment portfolio across 11 Federal departments, agencies, and independent commissions. In support of goal 2, commercialization, the NNI agencies are using programs such as Small Business Innovation Research (SBIR), Small Business Technology Transfer (STTR), and the National Science Foundation (NSF) Innovation Corps to fund and support small business activities and commercialization. Agencies are also engaged with public-private partnerships to leverage industry resources and expertise.[5] With respect to goal 3, infrastructure, the NNI is sustaining its long-standing investments in research centers and user facilities, and in nanotechnology education at all levels. Regarding responsible development of nanotechnology (goal 4), as part of agency efforts to ensure that new nanomaterials and nanotechnology-enabled products will be safe for public use from their inception to their disposal, the NNI released a comprehensive environmental, health, and safety (EHS) research strategy in 2011.[6] The NSET Subcommittee and its Nanotechnology Environmental and Health Implications (NEHI) Working Group continue to coordinate, facilitate, and monitor progress towards its implementation. NNI funding for EHS research has roughly tripled since 2006, and now represents over 7% of the annual NNI R&D investment.[7] The NNI also continues to support research on ethical, legal, and other societal implications issues associated with nanotechnology.

The most recent reviews of the NNI by the National Nanotechnology Advisory Panel (NNAP)[8] and by the National Academies[9] (called for by the Act) both concur that the initiative is strong. However, there is always room for improvement, as also suggested by the NNAP and the National Academies. The coordination and implementation of the NNI has been a dynamic process designed for continuous improvement as the Initiative progresses. For example, specific objectives designed to strengthen Federal nanotechnology activities under each of the NNI goals are enumerated in the 2014 NNI Strategic Plan. This year's plan, released in February, also sets out new Program Component Areas (or budget categories), including one for the Nanotechnology Signature Initiatives, which spotlight areas of national significance that can be more rapidly advanced through focused and closely coordinated interagency collaboration. This updated plan addresses NNAP and

[5] Examples include the SRC Nanoelectronics Research Initiative, and P3Nano, a partnership between USDA Forest Service Forest Products Laboratory and the U.S. Endowment for Forestry and Communities formed to advance the commercialization of cellulosic nanomaterials.

[6] http://www.nano.gov/sites/default/files/pub_resource/nni_2011_ehs_research_strategy.pdf

[7] http://nanodashboard.nano.gov/

[8] http://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST_2012_Nanotechnology_FINAL.pdf

[9] http://www.nap.edu/catalog.php?record_id=18271

National Academies recommendations, as well as input from a wide variety of stakeholders, gathered through workshops and Federal Register notices.

Congress plays a critical role in strengthening Federal nanotechnology R&D activities, providing oversight as well as the resources needed to carry out the activities described in the NNI Strategic Plan and the NNI Supplement to the President's Budget.

The sustained, strategic Federal investment in nanotechnology R&D combined with strong private sector investments in the commercialization of nanotechnology-enabled products has made the United States the global leader in nanotechnology. The most recent (2012) NNAP report analyzed a wide variety of sources and metrics and concluded that "... in large part as a result of the NNI the United States is today... the global leader in this exciting and economically promising field of research and technological development."[10] A recent report on nanomanufacturing by Congress's own Government Accountability Office (GAO) arrived at a similar conclusion, again drawing on a wide variety of sources and stakeholder inputs.[11] As discussed in the GAO report, nanomanufacturing and commercialization are key to capturing the value of Federal R&D investments for the benefit of the U.S. economy. The United States leads the world by one important measure of commercial activity in nanotechnology: According to one estimate,[12] U.S. companies invested $4.1 billion in nanotechnology R&D in 2012, far more than investments by companies in any other country. The NNI's Federal investments are relatively modest in comparison, but play a very different role, supporting a critical pipeline of basic research, generating new innovations that will provide opportunities for future industry investments in applied R&D, and demonstrating the Government's commitment to the field—critical to sustaining private sector investments in commercializing nanotechnology-based products.

The 21st Century Nanotechnology Research and Development Act of 2003 has provided an excellent framework over the past decade for the coordination and oversight of the NNI, in turn helping to establish and maintain U.S. global leadership in nanotechnology. Over these years, the NNI has brought together the agencies to develop and implement a national strategy for nanotechnology R&D, as called for in the Act in the form of periodic strategic plans, resulting in a strong Federal community of interest. The participating agencies actively communicate, coordinate, and collaborate within the NNI structure, which has enabled enhanced awareness of ongoing and planned activities within the agencies aligned with their respective missions, thus ensuring the greatest possible leveraging of resources for the American taxpayer. In particular, the Act has been very effective in helping the NNI agencies develop a robust, well-coordinated program of environmental, health, and safety research.

---

[10] Op. cit., cover letter, p. iii.
[11] http://www.gao.gov/assets/670/660591.pdf, p. 17: "...forum participants viewed the United States as, overall, likely leading in nanotechnology R&D at the present time."
[12] Lux Research, Op. Cit. (reference 1 above).

Federal agencies collaborate through the NSET Subcommittee's NEHI Working Group to periodically review the status of nanotechnology environmental, health, and safety. Through joint alignment of research activities, Federal agencies participating in the NEHI Working Group have:

- Coordinated and continued to implement research needs highlighted in the 2011 NNI EHS Research Strategy, which provides guidance to NNI agencies to ensure the safe, effective, and responsible development and use of nanotechnology. This includes efforts that pertain to risk management, regulatory decision-making, product use, research planning, and public outreach in nanotechnology. A few examples are as follows:
  - Workplace safety: Federal agencies continue to establish guidelines for safe handling of nanomaterials by both research and manufacturing workers through diligent program development by the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH). For example, OSHA has funded the development of a guide for laboratory workers on engineered nanomaterials (ENMs) and occupational safety and health, and has collected a compendium of resources on workplace exposure control methods for engineered nanomaterials. NIOSH has led an effort to develop methods for evaluating worker exposure using a multimetric approach (that includes mass, particle number, size distribution, and surface area). In addition, NIOSH has conducted ENM air-sampling assessments at about 40 research and industrial facilities, including laboratories at the National Institute of Standards and Technology, the National Institute of Environmental Health Sciences, and the U.S. Army Engineer Research and Development Center.
  - Consumer safety: The Consumer Product Safety Commission has established numerous agreements with other NNI agencies to quantify potential exposures and health impacts of ENMs in consumer products, including interagency agreements with NIOSH, NSF, the Environmental Protection Agency, and the Food and Drug Administration.
- Engaged stakeholders to discuss the assessment, management, and communication of potential risks associated with the use of nanomaterials. A recent workshop, held in September of 2013, facilitated stakeholder discussion of key elements needed to assess, manage, and communicate potential risks associated with use of nanomaterials and nanotechnology-enabled products.
- Supported the development of international standards for the responsible development of nanotechnology: Federal agency members have contributed to the substantial progress that has been made through coordinated international efforts to develop consensus standards pertaining to physico-chemical property measurements, biological property and EHS assays, nomenclature, and terminology for ENMs. As of April 1, 2014, more than 50 consensus standards have been released by standards development organizations supporting the areas referenced above.

As with many emerging areas of science and technology throughout history, while nanotechnology can be put to a wide variety of beneficial uses, there is potential for misuse. The NNI agencies responsible for national security have taken this potential seriously; for example, sponsoring in

2007 a workshop discussing potential applications and threats, *Nanotechnology for Chemical and Biological Defense 2030,* resulting in a comprehensive book on the topic.[13] In addition, the international community closely monitors this topic in the context of the Biological and Toxin Weapons Convention[14] and the Chemical Weapons Convention.[15]

It is worth noting that there has been a significant amount of R&D devoted to national security applications of nanotechnology, including detection, protection, and remediation of potential chemical, biological, radiological, and explosive threats. For example, the Defense Threat Reduction Agency has a substantial investment in nanotechnology, as documented in the NNI Supplement to the President's 2015 Budget.[16] These efforts effectively leverage other investments in basic research by agencies such as NSF. The NNI's Nanotechnology Signature Initiative on "Nanotechnology for Sensors and Sensors for Nanotechnology," with participation from eight NNI agencies, is a perfect example of NNI R&D coordination and leveraging. This coordinated effort could accelerate the successful development of nanotechnology-enabled sensors for defense against weapons of mass destruction, while also enabling development of sensors for environmental, agricultural, or biomedical applications.

Concluding Statement

The NNI investment has sustained vital support for fundamental, ground-breaking R&D, research infrastructure (including world-class centers, networks, and user facilities), and education and training programs that collectively constitute a major U.S. innovation enterprise. It is essential that the United States continue to lead the way in innovation enabled by nanotechnology and other emerging technologies — the Nation's economic growth and global competitiveness depend on it. I thank the Chairman and the Members of the Committee for the opportunity to appear before you today, and I would be pleased to answer any questions that the Committee may have.

[13] M. Kosal, *Nanotechnology for Chemical and Biological Defense* (Springer-Verlag, New York, 2009).
[14] National Research Council. *Trends in Science and Technology Relevant to the Biological and Toxin Weapons Convention: Summary of an International Workshop: October 31 to November 3, 2010, Beijing, China.* Washington, DC: The National Academies Press, 2011.
[15] https://royalsociety.org/~/media/policy/projects/brain-waves/2013-08-04-chemical-weapons-convention-and-convergent-trends.pdf.
[16] Op. Cit.; see in particular pp. 68-69. DOD's investments are also described in some detail in this report.

Short Narrative Biography of

Dr. Lloyd Whitman

Interim Director, National Nanotechnology Coordination Office

to the

Committee on Science, Space and Technology

Subcommittee on Research and Technology

United States House of Representatives

Hearing on

Nanotechnology: From Laboratories to Commercial Products

May 20, 2014

Dr. Whitman is currently serving as the Interim Director of the National Nanotechnology Coordination Office (NNCO) as a temporary, full-time detail from his position as Deputy Director of the Center for Nanoscale Science and Technology (CNST) at the National Institute of Standards and Technology (NIST). He received a B.S. in Physics from Brown University (with honors, *magna cum laude*), and M.S. and Ph.D. degrees in Physics from Cornell University. After a National Research Council Postdoctoral Research Fellowship at NIST, he joined the research staff at the Naval Research Laboratory (NRL). At NRL, Lloyd was the Head of the Surface Nanoscience and Sensor Technology Section, where he led a diverse portfolio of research studying semiconductor, organic, and biomolecular nanostructures, their use in novel functional surfaces, and their integration into advanced sensor systems for national security applications. In addition to leading research at NRL, Lloyd served as a Science Advisor to the Special Assistant to the Secretary of Defense for Chemical and Biological Defense and Chemical Demilitarization Programs. Lloyd joined the CNST as its founding Deputy Director in April 2008, overseeing the operations of the Center and working closely with the Director in leading the Center's strategies and programs. He also serves as the liaison to NIST's overall nanotechnology program, representing NIST and serving in 2013 as national co-chair on the National Science and Technology Council, Committee on Technology Subcommittee on Nanoscale Science, Engineering and Technology (NSET). Lloyd has over 160 publications and multiple patents in the areas of nanoscience and sensor technology, and numerous media citations and awards, including the Navy Meritorious Civilian Service Award.

Chairman BUCSHON. Thank you, Dr. Whitman.

I now recognize Dr. Stevenson for five minutes to present his testimony.

TESTIMONY OF DR. KEITH STEVENSON, PROFESSOR, DEPARTMENT OF CHEMISTRY & BIOCHEMISTRY, THE UNIVERSITY OF TEXAS AT AUSTIN

Dr. STEVENSON. Thank you, Chairman. And on behalf of the State of Texas and the University of Texas at Austin, I am happy to represent and provide testimony today on the nanotechnology state of affairs.

You have asked me to summarize the current state of R&D in the area, as well as provide future prospects. In addition, as Lloyd just spoke about, talk about the details and the impact of the National Nanotechnology Initiative and what it has done over the last 14 years.

I also have been asked to talk about the importance of the federal fundamental funding in this area, as well as how my university has contributed to the STEM-based initiatives and growth of the nanotechnology workforce.

First, I would like to address the importance of the nanotechnology initiative. I myself started my career in 2000 and grew up with the growth of this program. I think it is safe to say now this program has been assessed and reviewed and measured with many different types of quantitative outcomes, and it is clear to say that it has been very successful across many levels. In particular, I would say most importantly bringing fundamental new knowledge, new understanding to the area. The growth of—and establishment of over 50 journals dedicated to nanotechnology and science across many different subdisciplines, you are starting to lose count with that.

Additionally, the amount of infrastructure that has been built up across the Nation, every national lab has typically a subset of dedicated nanotechnology and nanofabrication tools. They also have many large-scale universities that interact with both national labs but also with other state institutions like the University of Texas at Austin that facilitate interactions not only from national labs but also with new industries.

Also, the training of the nanotechnology workforce, without the establishment of infrastructure on this scale, it is clear to say that we have really dedicated, well-trained staff that help enable the science based around the broad context of nanotechnology in this area.

The importance of continually investing in fundamental research is hard to describe in simple terms, but really I think what you can see from the past developments in the area is that the growth of this field has really accelerated things on many levels, not only just from the fundamental understanding like I said but the connections that it makes to the next level. It was talked about the ability to make new discoveries, but there does rely in some sense a continued investment at the next level to bridge the gap, as was highlighted by the GAO, to be able to transition those fundamental discoveries into actually new technologies, innovations, and products that we can then lead to the productivity of new areas.

There are several fundamental questions that we would like to be able to address. For instance, can we—we still need to figure out how we can perfect the synthesis and fabrication of precise multifunctional structures that really create new technologies. We don't really know how to scale nanoscience right now. It has been very costly in the sense and it is not very efficient.

Additionally, at UT Austin in particular, the ability to be able to train students in this area, we have invested in several different initiatives at many different levels. One is to really hook students at the very earliest level at STEM education, so what we could do is we recruit students at the freshman level and put them into the research lab and expose them to the concepts of nanoscience and technology. We have been able then to then escort them through a two-year program which then they then transition into more advanced science and engineering labs. And then from that they then typically are encouraged and given fellowships and internships at the next level to then go to graduate school in the STEM-based areas.

Additionally, at UT Austin we have established a core of—a suite of user instrumentation that has allowed us to train hundreds if not thousands of students in the area of nanoscience and technology. We have a graduate level portfolio program that gives them certification in the area. It is not a degree-granting program but it allows them to really work interdisciplinary across as many as 14 different departments to be able to really foster nanoscience.

The outcome of this is that over 120 of these students are now at many levels, academic institutions, national labs, startup small businesses based on what they have learned as graduate students, and work for the government agencies.

And with that I would like to conclude and thank everyone for the opportunity to be able to testify on behalf of the State of Texas. Thank you.

[The prepared statement of Dr. Stevenson follows:]

Keith J. Stevenson
Professor of Chemistry
The University of Texas at Austin

Director, Center for Nano- and Molecular Science and Technology

May 20th, 2014

Testimony prepared for the hearing of
The Subcommittee on Research and Technology of the Committee on Science, Space, and Technology During the 113th Congress

Nanotechnology: From Laboratories to Commercial Products

Summary: Testimony is provided on the current state of nanotechnology research and development (R&D), as well as, its future opportunities and challenges. The National Nanotechnology Initiative (NNI) is discussed; and its successes on many levels (new knowledge generation, patents, technological innovations, infrastructure investments, and workforce training) are highlighted. The impact of federal funding in nanotechnology and the need for future investments are summarized. Additionally, forthcoming prospects of nanotechnology are envisioned to impact several sectors (Energy, Environment, Health, Medicine, Information Technology). Finally, the testimony will detail how the University of Texas at Austin, specifically the Center for Nano- and Molecular Science and Technology, has significantly impacted STEM education, and the nations nanotechnology workforce via establishment of focused research, educational and training programs, dedicated user-facilities, and grant-assistance programs.

Chairman, Rep. Lamar Smith (R-TX) of the Committee on Space, Science and Technology; and Chairman, Rep. Larry Bucshon (R-IN) of the Research and Technology Subcommittee, my name is Keith J. Stevenson, and I am a Professor of Chemistry and the Director of the Center for Nano- and Molecular Science and Technology (CNM) at The University of Texas at Austin. I appreciate the opportunity to appear before you today to provide my insight into the current state of nanotechnology research and development (R&D), as well as, its future opportunities and challenges. You have also asked me to address the National Nanotechnology Initiative (NNI) and the ways my University is addressing STEM and workforce needs.

In a relatively short interval for an emerging technology, nanoscience and nanotechnology research has provided significant economic impact in numerous sectors including semiconductor manufacturing, electronics, catalysts, medicine, agriculture, and energy production. Since 2001, the National Nanotechnology Initiative (NNI) has served as the vehicle for coordinating and reporting on activities in this dynamic field across the Federal Government. At least twenty departments, independent agencies, and independent commissions have participated in the NNI, representing a wide variety of missions, responsibilities, interests, and expertise. By many measures, the NNI has been assessed, evaluated and reviewed for impact on scientific production, commercialization, technology transfer, STEM and workforce development (see www.nano.gov for publications). Several reports now strongly document that NNI has been a tremendous success on many levels including scientific and technological merits and broader societal and environmental impacts. Yet, the current federal deficit is the result of significant cuts to the federal investments in fundamental research and higher education at a time when other nations (Europe, China, Korea, Saudi Arabia, Singapore, Russia), having learned from the unprecedented success of US technological innovation, have dramatically increased their investments in nanoscience and nanotechnology. As a result, the US risks losing its competitive advantage in advancing fundamental knowledge; in the discovery of breakthrough materials; in the commercialization of innovative technologies, and in the scale-up and manufacturing of new products. It is abundantly clear that continued and increased investments in research and education in nanoscience and nanotechnology are required for the US to maintain a strategic advantage in nanotechnology and related sectors (e.g. Communications, Electronics, Energy, Health, and Environment).

You have asked me to address the following questions:

1. What is the importance of federal funding to fundamental advances in the area of nanotechnology?
2. What fundamental questions in nano-science are fruitful to further investigation, and why are these questions appropriate for federal funding?
3. What and where is the future of applications of nanotechnology research?
4. What potential areas will most benefit from fundamental advances in nanotechnology? Please explain.
5. What additional ways could the federal government be supportive of nanotechnology initiatives and research?
6. How is your University working to address the relevant STEM and workforce needs in nanotechnology.

1. Importance of federal funding on fundamental advances in nanotechnology.

Since the launch of the National Nanotechnology Initiative (NNI) in 2001 the US has established itself as a foremost leader in nanoscience and technology and continues to maintain prominence in a variety of important science, engineering and technology areas. In particular, federal support has allowed us to learn a great deal about the unique and important properties of matter that emerge when confined to the nanoscale. A tremendous amount of new knowledge has arisen from federal support of nanoscale science and engineering evidenced by the establishment of at least 50 new scientific journals (e.g. Nature Nanotechnology, Nano Letters, ACS Nano, Nano Today, Small, Nanomedicine, Nanotoxicology) dedicated to nano-related topics with high scientific impact factors. The nano community is now well positioned to address more complex issues of how the functionality of these properties can be tuned and exploited in real world materials and devices, and more importantly how we can predict, design and control the functionality of new materials. For instance, the launch of several new research initiatives (Materials Genome, Mesoscale Science, Brain Initiative) are inextricably intertwined with the advances and breakthroughs made in nanoscience and nanotechnology. In many respects, these initiatives have sprung out of and build upon the fundamental advances made in the support of nanotechnology research.

2. Fundamental questions worthy of further investigation for fruitful outcomes.

There remain a multitude of fundamental questions that are worthy of further investigation whose pursuit for their answers will produce new scientific knowledge and advances. For example, five "grand challenges" adapted from DOE BESAC workshop reports that involve nanoscale science and engineering could include:

- *"How do we perfect cheap, efficient and scalable ways for the synthesis and fabrication of nanomaterials and nanostructures with tailored properties?"*
- *"How do we characterize and control nanoscale materials and phenomena?"*
- *"How do we study and evaluate the environmental, health, safety, economic and societal impacts of nanomaterials and nanotechnology?"*
- *"How can we predict and design new properties of nanomaterials?"*
- *"How do we foster the safe and ethical development of nanomaterials and technologies?*

These grand challenges in nanotechnology raise even more explicit fundamental questions that if answered in detail could enable tremendous scientific and technological advances. For instance, not only do we want to increase the efficiency of nanosynthesis and nanofabrication methods, can we develop methods with precise enough control to facilitate the assembly of elaborate multifunctional architectures, atom by atom, from the bottom up. Put another way: can we engineer functional systems at the atomic and molecular scale? The attempt to answer these questions provides the basis of nanotechnology. If we could do so, we could achieve several so-called "holy grails" in several areas including artificial photosynthesis (energy), single molecule cancer detection (disease diagnostics, health), and quantum computing (information technology). Yet it is important to emphasize that the pursuit is more important than achieving a specific outcome. "Use-inspired" and goal driven research has great value for steering and producing rewarding outcomes, but fundamentally the scientific process involves many diversions, explorations, and unexpected observations that produce fortunate discoveries not previously imagined or conceived.

3. Future applications of nanotechnology research.

It is almost impossible to forecast everything that nanotechnology will bring to the world considering that it is still a relatively underdeveloped field. However, in our journey to understand, to think, to envision, to innovate there will be many new significant scientific discoveries and breakthroughs that produce new applications. Several future applications of nanotechnology will be realized and will be evidenced by the continual growth of the number of relevant patents and scientific publications. One newly emerging theme is idea of guided self-assembly of multifunctional nanocomponents into three-dimensional circuits and fully-integrated devices. For instance, the nano-bio-medical subfield could design such systems to improve the tissue compatibility of implants, or to create scaffolds for tissue regeneration, and even construct three-dimensional "printed" artificial organs. Other applications will possibly emerge that involve molecular nanosystems and heterogeneous networks in which molecules and supramolecular structures serve as distinct multifunctional devices (nanobots) or self-powered, autonomous biosensors. The idea of "edible electronics" is emerging where medical devices could be taken orally or implanted in the body to measure biomarkers or monitor health problems. The edible battery also could be used to stimulate the targeted release of drugs for the treatment of cancer. Other bio-nano systems will also enable the direct interfacing of humans with wearable electronic devices for telecommunications and for continuous health and environmental monitoring.

4. Beneficial outcomes from fundamental advances in nanotechnology.

There are many beneficial outcomes that will result from fundamental advances in nanotechnology. I provide a few case examples where there will be broad impact.

Electronics and Computers. We will continue to see the improvement of flexible, light weight display screens on wearable electronics devices as well as the increase in the density of memory chips. Memory chips are now being developed for future information storage applications with feature sizes below 20 nm such as terabyte memory arrays and ultra-fast gigabyte nonvolatile memories. There will be a continued reduction in the size of transistors with lower power demands used in integrated circuits which will lead to faster, more powerful lightweight computers with a much smaller footprint.

Telecom and Datacom. The ability to engineer and integrate both optical and electrical nanomaterials will bring about tremendous advances in telecommunication and data communication sectors by providing low power, high speed, interference-free devices such as electrooptic and all-optical switches integrated on computer chips. These developments will lead to the further integration of related components such as the massive storage of data on compact storage devices with high-performance computing features. This in turn will enable new high speed communications and high performance information processing that will impact several sectors (Information Technology, Energy, Health, Medicine, Environment).

Energy. Nanoscience and technology will significantly impact the renewable energy sector. For instance, the incorporation of low-cost, earth abundant nanomaterials in energy conversion and storage device architectures will improve the efficiency, energy and power densities of fuel cells, capacitors, and batteries for portable applications, transportation, and large scale grid storage. These energy storage and conversion devices are important to many areas of technology, including portable electronics, medical devices, power tools, transportation and the storage of electricity produced by intermittent renewable sources (wind and solar). Advances in this area will accelerate the design and implementation of on-site energy generation and decentralized energy generation systems. These systems will change how we generate, deliver and use electricity. The development of decentralized generation networks enables collection of energy from many sources which offer the promise of reducing environmental impacts and improving our security of supply.

Environment. Nanotechnology will play a heavy role in addressing critical environmental problems for water purification and remediation. For instance, new nanomembrane technologies will enable efficient water purification processes, and facilitate the development of improved remediation strategies for clean-up of hazardous waste streams. Nanomaterials in various shapes/morphologies (particles, tubes, wires, fibers) with be made to function as adsorbents and catalysts for the detection and removal of toxic gases (SO_2, CO, NO_x, H_2S), inorganics contaminants (arsenic, nitrate, heavy metals), organic pollutants (polyaromatic hydrocarbons, Bisphenol A) and biological substances (spores, viruses, bacteria). Nanotechnology will also create new 'green' synthesis and processing technologies that can minimize the generation of undesirable by-products in effluents and emissions streams.

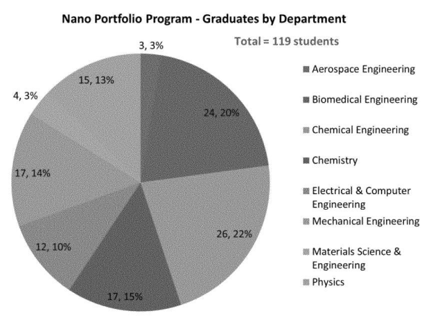
Health Care, Medicine, Biodiagnostics. There will be rapid advancement of the development of biological nanosensors for fast and accurate monitoring of health and biological functions at the point of care level. Nanotechnology is now facilitating the creation of 'lab on a chip' technologies involving the assembly of artificial organs to enable organ-based screens for drug development and treatment.

5. Needs for federal government support in nanotechnology.

There remains a critical need for the continued investment in basic research and in small- and intermediate-scale instrumentation for characterization and study of nanomaterials. The continued support of established larger-scale NNI facilities and networks is crucial, as well as, increased investments of multi-disciplinary research activities that integrate both theorists and experimentalists. The recent federal focus on the materials genome and mesoscale science initiatives are inextricably intertwined with advances in nanoscience and nanotechnology so support of nanotechnology will aid in advancing new research initiatives. Existing nanotechnology facilities should be leveraged to attract grant funding in other emerging areas. New investments for the training of a nanotechnology workforce (undergraduates, graduate students, postdoctoral fellows, and early stage scientists) is still vital for maintaining a competitive scientific and technological advantage. While the most recent focus on nanotechnology funding includes support of environmental, health and safety (EHS) areas, solar energy conversion, sustainable nanomanufacturing, and nanoelectronics, the support for work in newly emerging areas (nanophotonics, nanobiotechnology, energy, health and medicine) should be increased. While NNI and other mechanisms have facilitated the establishment of an extensive nanotechnology infrastructure for nanofabrication and characterization capabilities, increased and continued investments need to be made for evolving nanotechnology discoveries from the research laboratory into innovative technologies. Both new facilities and networks should be established and the existing capabilities and user facilities should be supported as they broadly support R&D on many levels including nanoscale characterization, synthesis, simulation and nanomanufacturing.

6. How is your University working to address the relevant STEM and workforce needs in nanotechnology.

Since its founding in the 2002 by Professor Paul Barbara, UT-Austin's Center for Nano- and Molecular Science and Technology (CNM) (www.nano.utexas.edu) has proven to be a great mechanism for the recruitment, retention, education and training of a nanotechnology workforce. The CNM early on established a new certification program in interdisciplinary nanoscience and technology fields for graduate students enrolled in department-level science and engineering programs. Now, nearly 120 graduate students have obtained their nanotechnology certification. These well-trained graduates are now working in academics, national laboratories, nanotech industries and small businesses.



The CNM also sustains grant-initiated educational outreach programs focusing on nanoscience by helping faculty PIs develop and host educational and outreach activities such as summer science camps, building tours of nanotechnology user facilities, and in conducting nanoscience demonstrations. Over this time, the CNM has produced several publications for communicating and educating the general public on nanotechnology. These activities help communicate how nanotechnology is relevant and engaging and acceptable by involving them in nanoscience experiments they can do themselves. Examples, include: "New Nanotech from an Ancient Material: Chemistry Demonstrations involving Carbon-based Soot," *J. Chem. Ed.* **2012**, *89*(10), 1280; and, "A Simple Method for Production of Nanoscale Metal Oxide Films from Household Sources," *J. Chem. Ed.* **2013**, *90*(5), 629.

The CNM has also worked with the College of Natural Sciences (CNS) at UT-Austin to achieve a large scale reinvention of its undergraduate research paradigm that was faculty initiated. This program was originally conceived in the Departments of Chemistry and Biochemistry and Molecular Biology (Stevenson, Ellington, Stephens) in response to a 2005 NSF Undergraduate Research Center solicitation. This program has now morphed into what is known as the "Freshman Research Initiative" (FRI) (www.cns.utexas.edu/fri) that addresses the following goals: 1) attract and retain students in STEM, 2) engage large numbers of students with diverse backgrounds in authentic research, 3) improve undergraduate retention and academic success (g.p.a. and graduation rates), 4) bridge the gap between education and research by using research as a vehicle for teaching, 5) create an environment in which the effects of research training can be assessed, 6) drive STEM curriculum reform, and 7) enhance interdisciplinary collaborations that promote education through undergraduate research.

This newly integrated research and teaching model has now been proven to increase the number and diversity of students participating in undergraduate research experiences by involving a large number of incoming freshmen in an intimate research experience over the course of their first two years on campus. Students are recruited during freshman summer orientation and are encouraged to participate because FRI program offers a research-based, smaller-class alternative to required freshman courses, is linked with other high-demand courses, and offers closer interaction with research faculty. Students begin by enrolling in Research Methods, then choose one of >25 Research Streams, and participate in research as part of their Stream through the subsequent Spring, Summer and Fall. Selected sophomores may remain in the program through the following Spring to mentor incoming freshmen. For example, as a founding faculty member of the FRI program, I have run a research stream since 2005 on "Nanomaterials for Chemical Catalysis" (https://sites.google.com/site/frinanostream), which now has trained and educated over 400 undergraduates of diversity (35% minority, 50% female) in the area of nanoscience and technology. This program has significantly improved retention (70% on track to graduate within 4-years) and graduation rates (a doubling) of at-risk, underrepresented students enrolled in CNS majors. This program has also expanded interactions with corporations, industry researchers, and local small businesses and provided new opportunities such as internships and jobs after graduation.

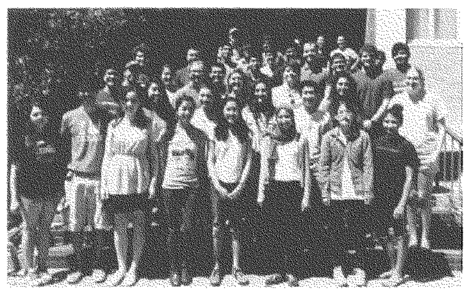


Photo of undergraduate students participating in the 2014 Nano-Stream at UT-Austin.

The CNM has also supported several large scale research centers funded by the NSF and DOE. For instance, currently the CNM provides administrative support, facilities training and management, and educational resources to support a $15M DOE funded Energy Frontier Research Center (EFRC) based on solar energy and electrochemical energy storage (www.efrc.nano.utexas.edu). Since 2009 this DOE program has trained and educated over 72 graduate students and postdocs that now have entered the energy workforce. This program is currently pending a five-year renewal.

Specific Examples of the Value Added to STEM and Workforce Needs:

CNM sponsored programs integrate education, research and training to increase students' competitiveness for fellowships, national awards, graduate school, postdoctoral fellowships and industrial positions

- Educational outreach increases the public's appreciation of scientific and engineering excellence in nanotechnology at UT-Austin
- Secondary school students are recruited to UT-Austin as science and engineering majors

- Undergraduates at other campuses are recruited to UT-Austin as graduate students
- CNM resources and programs are leveraged by CNM-affiliated faculty to initiate and sustain their own education and teaching efforts for federal grants
- CNM supports mechanisms for modernization of undergraduate education and training programs to increase students' competitiveness in the workforce
- CNM runs the Doctoral Portfolio Program in Nanoscience and Nanotechnology
    - 119 graduate students have earned credentials to date
    - Current enrollment of >60 students representing >10 disciplines
- CNM supported the Summer Nanoscience Academy aimed at educating HS students and Teachers
    - Originated as a NSF IGERT-funded educational outreach activity
    - More than 100 HS students and teachers have participated in the program since its inception in 2007
- CNM established a UT Pan Am Materials Partnership to increase minority participation
    - Funded UTPA undergraduates' trips to UT-Austin for training and data acquisition on CNM equipment
    - Pairs UTPA undergraduates with UT-Austin graduate students and faculty to consult on nanotechnology research
    - This program was leveraged in a past $1.5M NSF CCI Phase 1 proposal
- Supported the Partner University Fund (PUF) international student/faculty exchange
    - Funded student and faculty exchanges between CNM And Universite Joseph Fourier, Grenoble, France
    - Supports fellowships to attend Summer European School on Nanosciences and Nanotechnologies (ESONN) in Grenoble, France

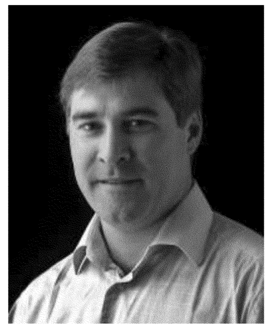
The CNM also provides training, management and maintenance of a suite of $28M in nanofabrication and analysis tools to a user base of more than 300 students, postdocs and faculty, annually. The CNM works with UT-Austin faculty and other Centers to identify instrumentation needs and acquire new instrumentation capabilities via federal and private funding. CNM staff technicians and facility managers consult with faculty to develop customized tools and techniques for their research needs. Other investments associated with the Microelectronics Research Center (former host of a National Nanotechnology Initiative Network site) and the Texas Materials Institute complement CNM's nanotechnology resources and infrastructure investments.

Specific Examples of the Value Added to STEM and Workforce Needs:

- Increased research productivity and training of students through well-managed and maintained nanotechnology facilities with minimal downtime

- Access to of state-of-the-art nanotechnology facilities on campus improves recruitment and retention of undergraduates and graduate students.
- Hands-on, state-of-the-art training provided to increase competitiveness in the STEM workforce

I would like to close by restating my sincere appreciation to this committee, Congress, and the American people for the continual support of fundamental core science areas that have facilitated tremendous advancement of nanoscience and nanotechnology in this country.



Stevenson is a well-established electrochemist, materials chemist and nanoscientist with over 145 refereed publications, six patents, and five book chapters. Recent awards include the Society of Electroanalytical Chemistry (SEAC) Young Investigator Award (2006) and 2012 Kavli Fellow. He is the Director of the $38M Center for Nano- and Molecular Science and Technology (CNM). He also is acting thrust leader on a $11.2M DOE Energy Frontiers Research Center at UT-Austin. His research interests are aimed at elucidating and controlling chemistry at solid/liquid interfaces vital to many emerging technologies and on advancing an array of important electrochemical materials applications including chemical sensing, energy conversion and storage, electrochromics, and electrocatalysis. Stevenson has also been extremely innovative in pursuing major educational initiatives. In addition to being the State Director of the Welch Foundation Summer Scholars Program (2008-present), he is one of the original founding faculty members of a program now known as the Freshman Research Initiative (FRI) at UT-Austin. The FRI program currently involves over 25 research faculty and >700 undergraduate researchers per year; and is transforming the way undergraduate research is conducted at large scale universities.

Chairman BUCSHON. Thank you very much, Dr. Stevenson.

Dr. Hersam, you are recognized for five minutes. By the way, I graduated from the University of Illinois, so welcome.

TESTIMONY OF DR. MARK HERSAM, PROFESSOR, DEPARTMENT OF MATERIALS SCIENCE & ENGINEERING, MCCORMICK SCHOOL OF ENGINEERING & APPLIED SCIENCE, NORTHWESTERN UNIVERSITY

Dr. HERSAM. Very glad to hear it.

On behalf of Northwestern University, I would like to thank Chairman Bucshon, Ranking Member Lipinski, Ranking Member Johnson, the entire Subcommittee on Research and Technology for the opportunity to participate in today's hearing.

I am currently Professor of Material Science and Engineering, Chemistry, and Medicine, and Director of the Materials Research Center at Northwestern University. My research group studies and develops nanomaterials for use in a wide range of technologies, including electronics, photovoltaics, batteries, catalysis, and bioimaging.

A significant portion of our research has been patented and commercialized, including our work on carbon nanomaterials that serve as the basis of a startup company that I cofounded called NanoIntegris. I have also been deeply involved in the development of education and outreach activities based on nanoscience and nanotechnology.

The vast majority of my research has been funded by the National Nanotechnology Initiative. While much of this research focuses on applied technologies, the systematic application developments have been punctuated by discontinuous unanticipated breakthroughs.

Therefore, while I strongly support the emergence of applied nanotechnology research funding, nanoscience remains an extremely fertile ground for discovery and therefore a diversified federal funding portfolio that includes strong support for fundamental research is critical to realize the full potential of nanotechnology. In particular, an expansion of the National Science Foundation Nanoscale Science and Engineering Centers would foster fundamental research, bring new discoveries, and accelerate innovation in nanotechnology education and outreach.

With its ability to impact diverse and interdisciplinary problems in medicine, health, environment, water, energy, catalysis, electronics, photonics, magnetics, and infrastructure, nanotechnology touches essentially all technological sectors and will continue to impact economic and job growth for the foreseeable future. In my role as Co-Chair of the National Science Foundation's sanctioned global study entitled, "Nanotechnology Research Directions for Societal Needs in 2020," it is apparent that this opinion is now widely held globally leading to substantial investments in nanotechnology by governments throughout the industrialized world.

Consequently, to maintain American global competitiveness and fully realize nanotechnology applications, sustained and predictable support of the National Science Foundation Nanosystems Engineering Research Centers and related applied research centers across all funded agencies would be required. In addition, the National

Nanotechnology Infrastructure Network should be reinstated to provide regional hubs and enable universal access to nanotechnology infrastructure.

The ultimate judge of the utility of any technology is its ability to succeed as a commercial product in the marketplace. Towards that end, the Nanoscale Science and Engineering Center at Northwestern University has launched 14 startup companies in diverse technologies ranging from biomedical diagnostics to nanoelectronic materials.

The company that spun out of my lab, NanoIntegris, is among those 14 startups. In its early stages, NanoIntegris benefited significantly from federal funding in the form of small business innovation research grants that supported the scale-up of our carbon nanomaterial technology. By accelerating our technical milestones, federal funding allowed NanoIntegris to more quickly focus on business development, ultimately growing revenue and creating jobs. Expansion of the Small Business Innovation Research program will thus enable more nanotechnology startup companies to negotiate the so-called Valley of Death.

Furthermore, reforms targeting improved efficiency of the United States Patent and Trademark Office, where I have consistently experienced waits of four to five years for a nanotechnology patent be issued, will allow valuable intellectual property to be secured quickly, thereby reducing commercialization risks and accelerating economic growth.

It is well documented that the United States is trailing many other industrialized nations in STEM education. While this problem is multifaceted with no simple solution, the situation is certainly improved when the most talented American students are inspired to pursue careers in science and engineering. In that regard, the incorporation of nanotechnology content into education and outreach efforts has been exceedingly successful.

For example, under the support of the National Science Foundation, I incorporated nanotechnology into our materials science and engineering curriculum, resulting in a doubling of our domestic undergraduate population. From the perspective of commercialization, the Small Business Evaluation and Entrepreneur Program has united science, engineering, and business students in the development of business plans that have helped spawn multiple startup companies from Northwestern University.

At the graduate level, the National Science Foundation, the National Defense Science and Engineering Graduate Fellowship Programs have been superlative at recruiting and retaining the top domestic science and engineering talent. Therefore, beyond its clear successes in producing significant discoveries and fostering innovation, the National Nanotechnology Initiative has proven to be one of the best federal programs for enhancing STEM education and thus American global competitiveness.

In conclusion, I would like to thank you again for this opportunity and your ongoing support of nanotechnology research, education, and commercialization. Thank you.

[The prepared statement of Dr. Hersam follows:]

TESTIMONY

of

Professor Mark C. Hersam
Northwestern University
Evanston, Illinois

to the

Committee on Science, Space, and Technology
Subcommittee on Research and Technology
U.S. House of Representatives
20 May 2014

Introduction

On behalf of Northwestern University, I would like to thank Chairman Buchson, Ranking Member Lipinski, and the entire Subcommittee on Research and Technology for the opportunity to participate in today's hearing entitled "Nanotechnology: From Laboratories to Commercial Products." I am currently the Bette and Neison Harris Chair in Teaching Excellence, Professor of Materials Science and Engineering, Chemistry, and Medicine, and Director of the Materials Research Center at Northwestern University. My research group studies and develops nanomaterials for use in a wide range of technologies including electronics, optoelectronics, photovoltaics, batteries, catalysis, and bioimaging. A significant portion of our research has been or is in the process of being patented and commercialized, including our work on carbon nanomaterials that has served as the basis of a startup company that I cofounded called Nanolntegris. I have also been deeply involved in the development of education and outreach activities based on nanoscience and nanotechnology. I greatly appreciate the opportunity today to share my experiences and perspectives on several topics related to nanotechnology policy including fundamental research, application development, commercialization, intellectual property, education, and global competitiveness.

Importance of Fundamental Research

In many ways, I am a product of the National Nanotechnology Initiative. When I entered college in the mid-1990s, I initially intended to pursue an undergraduate degree in engineering as a stepping stone to an MBA and a career on Wall Street. However, these plans abruptly changed following a fundamental research seminar where I was introduced to the scanning tunneling microscope. Not only does the scanning tunneling microscope allow the atomic structure of matter to be visualized, but it can also be used as a tool to manipulate materials with atomic precision. I was immediately enthralled by the possibilities for nanofabrication at the nanometer-length scale, including the evidently attainable goal of constructing electronic devices and circuits with unprecedented computational power. Foreseeing a future that included ubiquitous portable electronics that would revolutionize how individuals would interact with each other and technology, I decided to abandon the MBA plan and instead enroll in graduate school where I could pursue fundamental research on nanoelectronic materials. Since countless other practicing scientists and engineers have similar stories, I am confident that one of the most significant benefits of federally funded fundamental research is its ability to inspire and motivate young people to pursue careers in science and engineering and thus become the drivers of technological and economic growth.

My career decision was subsequently validated when President Bill Clinton announced the National Nanotechnology Initiative during the final year of my PhD studies. In my independent faculty career at Northwestern University, the vast majority of my research has been funded by the National Nanotechnology Initiative. While much of this research has become increasingly applied as elements of the nanotechnology field have matured, these systematic application developments have been punctuated by discontinuous, unanticipated breakthroughs. For example, when the National Nanotechnology Initiative was announced in 2000, no one was talking about the material graphene (a one-atom thick sheet of carbon). However, this material was later discovered in 2004, rapidly advanced over the next 5 years, and ultimately won the Nobel Prize in Physics by the year 2010. More recently, a diverse range of additional atomically thin materials have emerged out of fundamental research laboratories. These nanomaterials are now poised to impact high value applications in information technology, energy technology, and biotechnology. Therefore, while I strongly support the emergence of applied nanotechnology research funding in recent years such as the Nanosystems Engineering Research Centers from the National Science Foundation, nanoscience remains an extremely fertile ground for discovery and therefore a diversified federal funding portfolio that includes sustained support for fundamental research is critical to realize the full potential of nanotechnology. For example, an expansion of the National Science Foundation Nanoscale Science and Engineering Centers, which have a significant focus on fundamental research, would effectively complement the more applied Nanosystems Engineering Research Centers.

Sustained Commitment to Application Development

Over the past decade, nanotechnology has proven to have broad, interdisciplinary impact in virtually all fields of science and engineering. As the co-chair of the National Science Foundation sanctioned global study entitled "Nanotechnology Research Directions for Societal Needs in 2020: Retrospective and Outlook," I had the opportunity to meet with global nanotechnology leaders and observe diverse prototype nanotechnologies that positively address problems in medicine, health, environment, water, energy conversion/storage, catalysis, electronics, photonics, magnetics, and structural materials.[1-3] While some of these prototypes have begun the transition to the marketplace, others remain at a nascent stage. It should also be noted that most of the early nanotechnology application developments have exploited one specific nanoscale device or material, which suggests that significantly more innovation will emerge as multiple materials and functions are integrated into unified platforms.

In this regard, the historical development of related technologies can provide insight into the likely future for nanotechnology application development. Since nanotechnology by definition focuses on short length scales, it is particularly relevant to look at the historical development of other technologies that gained performance through miniaturization. Specifically, the microelectronics revolution is a poignant example of how the relentless reduction in size of the solid-state transistor has driven ever-improving performance of integrated circuits, computers, and portable electronics. While the invention of the transistor was immediately recognized as a means of replacing the vacuum tube and thus could dramatically reduce the size and improve the effectiveness of computer technology, it took another 14 years of sustained effort to solve all of the materials compatibility and systems-level issues before the first integrated circuit was realized. Similarly, many of the early successes of nanotechnology are now in the midst of analogous sustained efforts to solve the reliability, reproducibility, integration, and systems-level problems that will maximize their potential. Consequently, sustained federal support in these areas will ensure that the full technological and economic impact of nanotechnology applications will be achieved.

As noted above, the National Science Foundation Nanosystems Engineering Research Centers are providing such support in a select number of application areas. However, broader investments of this type across all funding agencies (e.g., Department of Energy, Department of Defense, National Institutes of Health, and National Institutes of Standards and Technology) will be necessary to achieve the full range of nanotechnology applications. In addition, both fundamental and applied research requires universal access to nanotechnology infrastructure. Historically, the National Nanotechnology Infrastructure Network provided such infrastructure, but its future is currently in doubt. Renewal and expansion of this program will undoubtedly accelerate the timescales for nanotechnology innovation. In all cases, researchers will be able to plan and execute their application development most efficiently when funding is sustainable and predictable. Therefore, it is highly desirable for federal budgets to be announced and approved in a timely manner without the uncertainties and unpredictability that result from brinkmanship, government shutdowns, and unanticipated sequestrations.

Commercialization and Intellectual Property

The ultimate judge of the utility of any technology is its ability to succeed as a commercial product in the marketplace. Towards that end, many nanotechnologies that were originally supported by federal research grants have spun out of university research laboratories into startup companies. For example, during its 10 years of funding from the National Science Foundation, the Nanoscale Science and Engineering Center at Northwestern University launched 14 startup companies in diverse technologies ranging from biomedical diagnostics and therapeutics to nanoelectronic materials. The company that spun out of my lab, NanoIntegris, is among those 14 startups. In its early stages, NanoIntegris benefited significantly from federal funding in the form of Small Business Innovation Research grants that supported the scale-up of our carbon nanomaterial purification technology. By accelerating our technical milestones, the Small Business Innovation Research program allowed NanoIntegris to more quickly focus on business development, ultimately growing revenue and creating jobs. Expansion of the Small Business Innovation Research program, especially at the Phase II level, will thus enable more nanotechnology startup companies to negotiate the so-called valley of death, resulting in sustainable economic and job growth. Furthermore, early-stage proof-of-concept funding will enable more research laboratory concepts to reach the prototype level, which is often a prerequisite for successful commercialization.

While the NanoIntegris story is largely positive, its ultimate success was nearly compromised by issues surrounding intellectual property. The key patent application for NanoIntegris, which consisted of both method and composition of matter claims, was filed in early 2005. However, the initial office action response from the United States Patent and Trademark Office did not occur for nearly 4 years, and the initial patent, which only allowed the method claims, was not issued until early 2010. To this date nearly 10 years later, the composition of matter claims remain pending. While the 10 year timeframe on the composition of matter claims is exceptional, a wait of 4 to 5 years for a nanotechnology patent to be issued has been commonplace in my experience. Indeed, I currently have 28 nanotechnology patents pending, which implies that my commercialization attempts have largely occurred without formal patent protection. In the case of NanoIntegris, the absence of issued patents likely contributed to our technology being blatantly copied by multiple companies in Asia, which created stress on our emerging business that could have been minimized with more expeditious patent protection. Therefore, I strongly believe that policies that improve the efficiency of the United States Patent and Trademark Office are critical for advancing and protecting nanotechnology commercialization.

Education and Global Competitiveness

It is well documented that the United States is trailing many other industrialized nations in science, technology, engineering, and math (STEM) education at all levels including K-12, undergraduate, and graduate students.[4] While this problem is multi-faceted with no easy solution, the situation is certainly improved when the most talented American students are inspired to pursue careers in science and engineering. Towards this end, the incorporation of nanotechnology content into education and outreach efforts has been exceeding successful at Northwestern University. For example, under the support of the National Science Foundation, I incorporated nanotechnology into our undergraduate materials science and engineering curriculum, resulting in a doubling of our domestic undergraduate population. Similarly, efforts targeting undergraduate research, such as the Research Experience for Undergraduates program, have been successful at inspiring domestic students to pursue graduate study in this field. From the perspective of entrepreneurship, the Small Business Evaluation and Entrepreneur program and the NUvention program have successfully united science, engineering, and business students in the development of business plans based on nanotechnology research that have helped spawn the aforementioned 14 nanotechnology startup companies from Northwestern University.

At the K-12 level, the Research Experience for Teachers program brings K-12 STEM teachers onto campus in the summer, allowing them to be exposed to the latest nanotechnology research that then inform their curricula and thus impact their K-12 students. Similarly, the Materials World Modules program reaches thousands of K-12 students by developing teaching modules that can be seamlessly incorporated into K-12 STEM curricula. Partnerships with local museums, such as the Chicago Museum of Science and Industry, allow the excitement of nanotechnology innovations to be disseminated to the general public. These education and outreach efforts were pioneered and directed in a coordinated fashion under the support of the National Science Foundation Nanoscale Science and Engineering Center. An expansion of these centers will therefore not only facilitate nanotechnology research but also provide tangible benefits to STEM education and American global competitiveness.

At the graduate level, the National Science Foundation and National Defense Science and Engineering Graduate Fellowship programs have been exceedingly successful in recruiting and retaining the top domestic science and engineering talent. While these fellowships do provide a modest financial incentive to prospective graduate students, their true value is in the intellectual freedom that is provided to fellowship recipients. By combining the top talent with the freedom to pursue creative research solutions, federally funded graduate fellowship programs consistently produce significant discoveries, innovation, and domestic graduate students with a high propensity to remain in science and engineering in their subsequent careers. Consequently, an expansion of the National Science Foundation and National Defense Science and Engineering Graduate Fellowship programs would have immediate impact on graduate education and American global competitiveness.

Conclusions

In conclusion, the National Nanotechnology Initiative has successfully fueled fundamental discoveries, application development, commercialized technologies, educational innovation, and global competitiveness over the past 14 years. With its ability to impact diverse and interdisciplinary problems in medicine, health, environment, water, energy conversion/storage, catalysis, electronics, photonics, magnetics, and structural materials, nanotechnology touches essentially all technological sectors and will continue to impact economic and job growth for the foreseeable future. This opinion is now widely held globally, leading to substantial investments in nanotechnology by governments throughout the industrialized world. Consequently, coordinated, predictable, and sustained federal funding by the United States in both applied technology development and fundamental research will be critical to maintaining our global competitive advantage. In addition to continued growth of the National Nanotechnology Initiative, specific recommendations include expansion of the Nanoscale Science and Engineering Centers and Nanosystems Engineering Research Centers, reinstatement of the National Nanotechnology Infrastructure Network, expanded support of the Small Business Innovation Research program, reforms targeting improved efficiency of the United States Patent and Trademark Office, and growth of the National Science Foundation and National Defense Science and Engineering Graduate Fellowship programs.

References

[1] M. C. Roco, C. A. Mirkin, and M. C. Hersam, "Nanotechnology research directions for societal needs in 2020: Summary of international study," *Journal of Nanoparticle Research*, **13**, 897 (2011).

[2] *Nanotechnology Research Directions for Societal Needs in 2020*, M. C. Roco, C. A. Mirkin, and M. C. Hersam, eds., Springer, 2011, ISBN: 978-94-007-1167-9.

[3] http://www.wtec.org/nano2/Nanotechnology_Research_Directions_to_2020/

[4] E. T. Foley and M. C. Hersam, "Assessing the need for nanotechnology education reform in the United States," *Nanotechnology Law and Business*, **3**, 467 (2006).

Executive Summary of Testimony

The National Nanotechnology Initiative has successfully fueled fundamental discoveries, application development, commercialized technologies, educational innovation, and global competitiveness over the past 14 years. With its ability to impact diverse and interdisciplinary problems in medicine, health, environment, water, energy conversion/storage, catalysis, electronics, photonics, magnetics, and structural materials, nanotechnology touches essentially all technological sectors and will continue to impact economic and job growth for the foreseeable future. This opinion is now widely held globally, leading to substantial investments in nanotechnology by governments throughout the industrialized world. Consequently, coordinated, predictable, and sustained federal funding by the United States in both applied technology development and fundamental research will be critical to maintaining our global competitive advantage. In addition to continued growth of the National Nanotechnology Initiative, specific recommendations include:

(1) Expansion of the National Science Foundation Nanoscale Science and Engineering Centers due to their success in fostering fundamental research, breeding new discoveries, and accelerating innovation in nanotechnology education and outreach.

(2) Sustained support of the National Science Foundation Nanosystems Engineering Research Centers and related applied research centers across all funding agencies (e.g., Department of Energy, Department of Defense, National Institutes of Health, and National Institutes of Standards and Technology) to ensure that the full range of nanotechnology applications are realized.

(3) Reinstatement of the National Nanotechnology Infrastructure Network to provide regional hubs and ultimately universal access to nanotechnology infrastructure for fundamental research, applied technology development, and commercialization activities.

(4) Expanded support of the Small Business Innovation Research program both at Phase I for proof-of-concept demonstrations and at Phase II to help nanotechnology startup companies negotiate the so-called valley of death, resulting in sustainable economic and job growth.

(5) Reforms targeting improved efficiency of the United States Patent and Trademark Office so that valuable nanotechnology intellectual property can be secured quickly, thereby reducing commercialization risks and improving American global competitiveness.

(6) Growth of the National Science Foundation and National Defense Science and Engineering Graduate Fellowship programs due to their proven success at producing significant discoveries, fostering innovation, and attracting the top domestic students with a high propensity to remain in science and engineering in their subsequent careers.

Professional Biography of Mark C. Hersam

Materials Science and Engineering, Northwestern University
2220 Campus Drive, Evanston, IL 60208-3108 USA
Tel: 847-491-2696; Fax: 847-491-7820
E-mail: m-hersam@northwestern.edu
WWW: http://www.hersam-group.northwestern.edu/

Mark C. Hersam is the Bette and Neison Harris Chair in Teaching Excellence, Professor of Materials Science and Engineering, Chemistry, and Medicine, and Director of the Materials Research Center at Northwestern University. He earned a B.S. in Electrical Engineering from the University of Illinois at Urbana-Champaign (UIUC) in 1996, M.Phil. in Physics from the University of Cambridge in 1997, and a Ph.D. in Electrical Engineering from UIUC in 2000. As a faculty member, Dr. Hersam has received several awards including the NSF CAREER, Sloan Fellowship, Presidential Early Career Award for Scientists and Engineers, AVS Peter Mark Award, MRS Outstanding Young Investigator, and six Teacher of the Year Awards. Dr. Hersam is the co-founder of NanoIntegris, which is a commercial supplier of carbon nanomaterials. Dr. Hersam is a Fellow of MRS, AVS, APS, and SPIE, and serves as Associate Editor of *ACS Nano*.

Chairman BUCSHON. Thank you, Dr. Hersam.

I now recognize Mr. Ivie for five minutes to present his testimony.

TESTIMONY OF MR. LES IVIE, PRESIDENT & CEO, F CUBED, LLC

Mr. IVIE. Chairman Bucshon, Ranking Member Lipinski, and honorable Members of the Subcommittee, my name is Les Ivie and I am President and CEO of F Cubed, a company engaged in the commercialization of molecular detection technology for the rapid identification of pathogenic bacteria such as MRSA in wounds, Listeria in food—in contaminated foods, and E. coli in water samples. Our particular technology rests on exclusive of licenses obtained from the University of Notre Dame in South Bend, Indiana, as well as the Israel Institute of technology in Haifa, as well as several inhouse patented inventions.

Our investors have been extremely generous. However, we would not exist today if the underlying science behind our technology had not found support from the National Science Foundation or the National Nanotechnology Initiative.

F Cubed is not a direct recipient of any federal funding. However, the University of Notre Dame has received approximately $3.9 million in federal grants that were specifically used to develop our technology. I would respectfully suggest that funding basic research in an academic environment it is a good social and financial investment. Entrepreneurs will pursue and fund these technologies assuming that the economic environment is supportive, human resources are available, and regulatory obstacles remain manageable.

With regard to human resources, STEM education is of critical importance to F Cubed. In the field of nanotechnology, the availability of well-educated employees is critical to every company. STEM graduates come in at least two varieties. The typical STEM graduate is an individual with a bachelor, master, or doctoral degree.

However, there is another type of STEM graduate that is important and often forgotten in this educational debate. In the area of nanotechnology there are valuable two-year programs that produce individuals with associate degrees. The NSF-supported Nanotechnology Applications and Career Knowledge network, or NACK, is a good example of such a program. These two-year programs are important because they graduate individuals that have knowledge and capability to operate and prepare robotic and electronic equipment that is used to manufacture nanotechnology products.

STEM education is not monolithic. It is critical to support both traditional four-year and advanced degree programs, as well as two-year programs that produce the technicians that actually operate production lines for nanotechnology products.

F Cubed is an advisory member of NSF NACK and is fortunate enough to have a two-year nanotechnology program offered by Ivy Tech Community College in South Bend, Indiana. It is the only such program in Indiana. Many states have no comparable programs whatsoever. This deficiency is absolutely worth correcting.

F Cubed has exclusive licenses with two prestigious academic institutions and significant experience in identifying technologies and negotiating contracts with technology transfer offices. As an experienced licensee, we can state that the most challenging barrier to technology transfer is the time consumed in concluding negotiations. It is undeniable that startups are the engine that converts intellectual property into commercially interesting products. Startups license and commercialize new ideas and de-risk emerging technologies.

With a few adjustments in the enabling language of grants, the federal government could reduce a major obstacle associated with technology transfer, thus ensuring that recipients are incentivized to quickly commercialize intellectual property and get it into the hands of companies willing to make a development risk benefiting the licensor and licensee, benefiting taxpayers who will see a greater and faster return on their tax dollars, and bolstering the economy at large.

With regard to regulations, the materials used in nanotechnology are often new and exotic. Nanomaterials are used in minute quantities and are often so expensive the companies are economically incentivized to use as little as possible and absolutely minimize waste. Life science community benefits from an existing array of laboratory material safety practices, as well as good manufacturing practices that are not only customary within the industry but required by federal agencies such as the U.S. Food and Drug Administration and the U.S. Environmental Protection Agency.

F Cubed strongly supports objective and thoroughly peer-reviewed scientific investigations into the potential impact that nanomaterials may have on health and the environment under the guidance of the National Science Foundation or programs such as the Unregulated Contaminant Monitoring Rule process established by the U.S. Environmental Protection Agency. It maybe that the quantity of nanomaterials in the environment is so low that additional regulation is unnecessary beyond current industry safety practices.

The United States is a worldwide leader in nanotechnology. Our national approach to regulation must be rational and objective, not driven by misunderstanding of the materials in question or unsubstantiated fears.

In conclusion, nanotechnology is important to our universities, businesses, and consumers, many of whom will advance—will benefit from advances in medicine, food safety, and a cleaner environment. Federal funding is a large component of basic research and translation of such research into products by privately financed companies must be faster and more deliberate if we are to maintain our worldwide lead. It is critical that qualified technicians, engineers, and scientists emerge from STEM programs, and finally, regulation must be informed and intelligent. Safety is paramount.

Thank you for your support of nanotechnology.

[The prepared statement of Mr. Ivie follows:]

Written Testimony of
Leslie T. Ivie
President and CEO, F Cubed, LLC

Submitted to the
Subcommittee on Research and Technology
Committee on Science, Space, and Technology
For the hearing entitled
Nanotechnology: From Laboratories to Commercial Products

U. S House of Representatives
Washington, D.C.

May 20, 2014

Chairman Bucshon, Ranking Member Lipinski, and honorable members of the Subcommittee, my name is Leslie T. Ivie, and I am President and CEO of F Cubed, LLC, a company engaged in the commercialization of molecular detection technology for the rapid identification of pathogenic bacteria in medical diagnostic, food safety, and environmental science applications. Thank you for the opportunity to discuss nanotechnology. In my testimony I will describe:

- The ways in which companies such as F Cubed, LLC have benefitted from Federal funding in nanotechnology research.
- The importance of science, technology, engineering and mathematics (STEM) education in the development of the nanotechnology workforce and the ways in which F Cubed, LLC, is working to address the relevant STEM education and workforce needs associated with nanotechnology research and development and the manufacture of nanotechnology enabled products.
- The time, expense and complexity of the technology transfer process are significant barriers to nanotechnology commercialization and market success.
- Current and future Federal regulation of nanotechnology and the possible impacts on F Cubed, LLC and other participants in the industry.

A brief summary of the key points covered in my testimony is provided at the end of this document.

My testimony today is informed by my experiences as an executive with several international corporations, as well as my background as the founder of three start-up companies in the US and Europe. At the present time, US academic institutions and companies are the unquestioned world leaders in the field of nanotechnology. We operate in an economic environment that rewards innovation and we have access to human and financial resources that allow the development of highly differentiated and innovative technologies. Our ability to maintain or increase this lead requires the assurance of funding for the institutions that cultivate creative minds and develop individuals with the training and passion to innovate new technologies in a safe and productive environment.

F Cubed, LLC, has developed a portable device for the rapid identification of molecules (for example, DNA) outside of laboratories and for use by lay people with minimal training. The product is designed to permit immediate medical diagnosis of potential MRSA[i] (Methicillin-resistant Staphylococcus aureus) infection in abscesses, set the stage for easy and increased surveillance of fruits and vegetables to prevent distribution of contaminated foodstuffs, and allow for the rapid testing of polluted recreational and drinking water. Our technology rests on exclusive licenses obtained from the University of Notre Dame in South Bend, Indiana and the Israel Institute of Technology (Technion) in Haifa, as well as several in-house patented inventions.

The core technology underlying our product is built upon the complex combination of nano-scale electrodes and microfluidic structures that contain a matrix of carbon nanotubes characterized to hybridize with very specific DNA molecules. The hardware that we produce, a disposable biochip, is always the same. The matrix of carbon nanotubes varies by DNA target and is injected by robotic devices into to each biochip assembly in our facility in South Bend. This permits us to offer a wide variety of detectable targets.

F Cubed, LLC works closely with a wide variety of academic institutions and regulatory bodies, including Purdue University, the US Environmental Protection Agency and the US Food and Drug Administration. We have a Cooperative Research and Development Agreement (CRADA) with the US Environmental Protection Agency that is focused on the identification of the pathogenic bacteria Enterococcus in fresh and marine recreational waters. In addition, the US Food and Drug Administration has recently authorized us to begin human clinical trials for our MRSA diagnostic product.

In 2008, the founders of F Cubed, LLC, selected a very difficult technology to develop, at a very challenging time. Like all other new companies we worked diligently to identify and attract investors, all of whom are private individuals with the means to support us, but also with a passion for our mission to create tools to improve health and productivity. We recruited the best employees available, attracting individuals from Pennsylvania, North Carolina, Texas, California, and New York, to our facility in South Bend. All of our employees have classic STEM backgrounds from two-year nanotechnology degrees (technicians managing our production processes) to four-year and advanced degrees needed to conduct our life sciences and research and development efforts.

Benefits Of Federal Funding

Without question, the investors that have underwritten F Cubed, LLC, have been very generous. However, we would not exist today if the underlying science behind our technology had not found support from institutions such as the National Science Foundation and the National Nanotechnology Initiative (NNI)[ii]. F Cubed, LLC, is not a direct recipient of any Federal funding. The inventor of our core technology and Chief Science Advisor, Dr. Hsueh-Chia Chang, is the Bayer Professor of Chemical Engineering at the University of Notre Dame. Dr. Chang and his team have received approximately $3.9 million in Federal grants that were specifically used to develop our technology[iii].

This model will be familiar to the Committee: it works well. Groundbreaking developments in nanotechnology often emerge from academic research and are refined through subsequent attempts to demonstrate applications in specific areas such as medicine or environmental science. In those cases where the related intellectual property is strong, patents are filed, and the technology is transferred to commercial firms, a large percentage of which are start-ups like F Cubed, LLC. These start-ups then begin the process of raising private funds to more thoroughly demonstrate the technology, define the market and potential customers, build prototypes, establish manufacturing capability, and eventually start selling product.

If the process is successful, the start-up grows and becomes financially viable, the university and inventor benefit from royalties that may fund additional research and infrastructure. Recent programs such as the National Nanotechnology Initiative (NNI) have returned US science programs to their creative and application-oriented Edisonian roots. We hope that this model will continue to give US university researchers and US start-up companies a global edge in introducing new technology and solving previously intractable problems.

Federal funds are well placed in an academic environment that can be focused on creative and differentiated research. These institutions have processes in place to encourage and cultivate such research, administer the needed controls to ensure compliance with Federal guidelines, and ensure that funding is properly allocated, expended, and tracked through project completion. Start-up companies, indeed most mid-sized companies, are not always equipped to manage the needed paperwork and processes associated with Federal grants and monitoring programs. Nevertheless, the need for such basic research is great: it fuels start-ups and other companies that look to develop and commercialize technologies.

The current model works well and has resulted in an environment in which companies such as F Cubed, LLC can find exciting technologies to commercialize. We can focus on what we do best: prepare the market place for our products, commercialize the product, and sell solutions to customers in need of them. We can also find like-minded investors who are willing to risk their capital in the hope that they can earn an acceptable financial return.

I would respectfully suggest that funding for basic research in an academic environment is a good social and financial investment. This is especially true for application-oriented research in nanotechnology. Entrepreneurs will find and pursue these opportunities, assuming that the economic environment is supportive, human resources are available, and regulatory obstacles remain manageable.

Importance Of STEM Education

Science, Technology, Engineering, and Mathematics (STEM) education is of critical importance to F Cubed, LLC. In the field of nanotechnology, the availability of well-educated employees is critical. Furthermore, many start-ups choose recent graduates with less experience because they are extremely motivated and enthusiastic as they start a new career and are less expensive in terms of salary and benefits. Nanotechnology as a discipline is new enough that candidates with deep experience simply are not available.

In the field of nanotechnology, STEM graduates come in at least two varieties, and both are of critical importance. The typical STEM graduate would be an individual with a Bachelor of Science, Master of Science, or Doctorate in Chemical Engineering, Mechanical Engineering, Biology, or Physics. These individuals are critical for life sciences work and for research and development activities associated with designing and manufacturing a nanotechnology product.

However, there is another type of STEM graduate that is important and often forgotten in this educational debate. In the area of nanotechnology there are active two-year programs that produce individuals with Associate degrees. The Nanotechnology Applications and Career Knowledge (NACK[iv], a National Science Foundation National ATE Center for Nanotechnology Workforce Development program) Network is a good example of an organization that promotes education in the area and specifically delivers graduates with two-year degrees.

These two-year programs are important because they graduate individuals that have the knowledge and capability to operate and repair the robotic and electronic equipment that is used to manufacture nanotechnology products. Students are trained in environments and with equipment that is specifically used in nanotechnology; indeed, they are able to operate and repair equipment that most four-year and advanced degree STEM graduates would have had little or no exposure to in their educational experience. This is an important distinction: graduates with four-year and advanced STEM degrees expect to work in research and development environments in which they design devices, tooling, and processes. They do not expect to actually work on the factory floor, and are often incapable of doing so or find it to be less stimulating and less challenging. NACK-type two-year graduates are trained to work on the factory floor and, in our experience, have proven to be ideal employees for this work.

The ongoing discussion concerning the need to attract a diverse population of students into STEM disciplines is critical. Companies involved in nanotechnology and other high technology areas will find success and continue to lead the worldwide market place in direct proportion to the availability of such graduates. However, we may endanger our current position and potential for future success if we do not recognize the need for technicians in nanotechnology emerging from two-year NACK-like programs. It is important to ensure that such programs are available, are promoted to potential students, and that graduates are connected to companies in need of these skills.

STEM education is not monolithic. It is critical to support both traditional four-year and advanced degree programs, as well as two-year programs that produce the technicians that actually operate the production lines for nanotechnology products. Successful companies will select the right combination of candidates from each group and find themselves in a much more competitive position. F Cubed, LLC, is a member of NACK and is fortunate enough to have a two-year nanotechnology program offered by Ivy Tech Community College in South Bend. It is the only such program in Indiana, and many states have no comparable programs whatsoever. This deficiency is absolutely worth correcting.

Technology Transfer Challenges And Successes

Technology transfer is a complex process. F Cubed, LLC has exclusive licenses with two prestigious academic institutions and significant experience in identifying technologies and negotiating contracts with technology transfer offices. Such negotiations are like any other large purchase: the buyer wishes to pay the lowest possible price for the most exclusive and flexible license; the seller wishes to receive the highest price possible, limit the scope of the intellectual property offered, and reserve the option to offer similar licenses to other parties in adjacent areas of application.

The hopeful licensee is often a start-up with very limited funding, little or no legal advice, and very little time; the technology transfer office has a wealth of resources, a good deal of time, and abundant legal representation. In addition, intellectual property is the only asset that a start-up has available to use in discussions with potential financial backers; the longer the license discussions continue, the more difficult it becomes to raise funding to begin actual commercialization activities. As a licensee, the most significant barrier to technology transfer is the time consumed in concluding negotiations.

Technology transfer offices try to operate as de facto profit centers for universities, attempting to transform original research into potential cash flow streams for future research or other university projects[v]. Based on our experience, technology transfer offices would prefer to work with established companies, but often find start-ups to be the most interested parties. However, license negotiations proceed in many cases in such a manner that would be expected between two large, equally experienced, and well financed organizations: start-ups are often forced to agree to terms that are less advantageous than desired because they cannot afford to drag out negotiations or continue to fund the ongoing participation of their legal counsel.

It is undeniable that start-ups are the engine that converts such intellectual property into commercially interesting products. Large corporations continue to reduce research and development expenditures[vi] in favor of acquisitions of start-ups that have licensed and commercialized a new technology and, in effect, de-risked the emerging technology. The benefit in the technology transfer process is that when these successful start-ups (which are likely producing a stream of royalty revenue for the licensor) are acquired, the large corporation will use its much greater production and distribution capacity to exponentially increase royalty revenues to the licensor.

Licenses are linked to intellectual property such as patents, and patents are generated with grant funding, often from the Federal government. The difficult dance between offices of technology transfer and start-ups could be made considerably easier by linking the granted funds and concomitant intellectual property with a preference for a reasonably rapid commercialization and licensing processes. That would help remove time as an element of negotiation and lower a significant barrier in the technology transfer process. This would not require a preference for start-ups over established companies; rather it would merely speed up the process and result in benefits for all of the core participants, speed products to potential customers in the market place, provide the tax payers with a quicker return on their investment, and enhance the US economy at large.

It should also be acknowledged that the engine of US economic growth is small business and start-ups are a significant component. Start-ups by definition must hire new employees to commercialize technology. F Cubed, LLC, is still a small company, but we have become one of the fastest growing companies in South Bend. The more technology that is transferred into the hands of small companies, the more new jobs will be created, and the majority of these jobs will be for well-paid STEM graduates who will be able to contribute to their respective communities. Large corporations simply cannot match this process: they typically will roll such technology into existing research and development organizations and rarely enable the type of multiplier effect that start-ups can create.

Success in terms of technology transfer and licensing first requires a definition of success: the most common definition is the ability to raise sufficient funding for the development venture. Investors are attracted to highly differentiated technology, freedom to practice and implement the technology in the broadest possible sense, and creation of a business team with experience and a plan to achieve success in a reasonable amount of time.

F Cubed, LLC, methodically examined more than 100 technologies available from a variety of public and private institutions. We interviewed the inventors and examined the commercialization terms offered by the technology transfer offices. Of course, we examined our own development capabilities and matched technologies with potential investors with passions and interests in certain technology fields. Eventually we selected the University of Notre Dame and started the negotiation process.

The inventor of the technology, Dr. Hsueh-Chia Chang, was anxious to see his work commercialized. We also learned that the US Environmental Protection Agency was very interested in using this type of technology for recreational water testing. Finally, we had connections with potential investors very interested in the area of rapid molecular diagnostics. Through a combination of luck, good negotiating skills, and selling capability, we were able to conclude our first license and raise our first round of funding during the same week.

Our second license with the Israel Institute of Technology was considerably easier to manage because we had funding, an established reputation as an innovator in the area of molecular diagnostics, and influential board members that could help us sway the office of technology transfer. The entire licensing process was concluded in a few months. Time was still important: while we had more money, we also had very expensive legal representation, so concluding the negotiations in a timely manner was vital.

Federal funding is critical for academic research and for technology transfer to companies like F Cubed, LLC. With a few adjustments in the enabling language of the granting process, the Federal government could lower the major obstacle associated with technology transfer: ensure that the institutional beneficiaries of Federal funding are incentivized to quickly commercialize technology and get it into the hands of companies willing to take a development risk that benefits the licensor, the licensee, tax payers who will see a greater and faster return on their tax dollars, and the economy at large.

Nanotechnology Regulation

The materials used in nanotechnology are new and often exotic. These include plastics, ceramics, and metallic nano-scale substrates, as well as a variety of nano-sized particles fabricated from a nearly uncountable number of materials. These particles range from well-known carbon nanotubes, to nano wires, and a variety of particles fabricated from mundane materials such as latex to exotic metal alloys.

Nano materials are used in minute quantities and often are so expensive that companies such as F Cubed, LLC, are economically incentivized to use as little as possible and absolutely minimize waste. As a participant in the life sciences industry, F Cubed, LLC, benefits from an existing array of laboratory and materials safety practices, as well as Good Manufacturing Practices[vii] that are not only customary within the industry, but also required by Federal agencies such as the US Food and Drug Administration and the US Environmental Protection Agency.

For example, raw materials such as carbon nanotubes and related functionalizing chemicals are accompanied by MSDS (Material Safety Data Sheets)[viii] that describe required handling and disposal processes. F Cubed, LLC, like all companies in our space, administer this process through our laboratory safety manager. The state of Indiana, the Occupational Safety and Health Administration, and our lessor / landlord (the University of Notre Dame) periodically review our processes and facilities. While our waste streams are measured in grams and milliliters, they are disposed of through accredited scientific disposal companies.

Each one of our disposable biochips contains micrograms of nano-particles. As the biochip is used, the nano-particles are transported through the biochip and trapped in a hermetically sealed waste reservoir. This permits disposal of the entire biochip through regular hazardous waste channels, ensuring safety and customer convenience.

Our market research indicates that our approach is similar to features found in most life science products containing nano-particles or other nano-materials.

Our experience indicates that research organizations and companies using nano materials handle them with great care. As noted above, these materials are quite expensive, are used in minute quantities, and are often modified through combination with other materials into literally thousands of final forms. While it may theoretically be possible that these materials could be discarded in common solid or water waste streams, this is rare.

Concerns have been expressed that nano materials may have deleterious human health effects. F Cubed, LLC, has no reliable scientific information from our suppliers or academic research colleagues to indicate that there is significant risk. Nevertheless, as a responsible member of our community, we understand that individuals and public entities might have questions about nano materials. For example, concerns have been raised about micro-beads[ix] used in consumer products (toothpaste and other hygiene products) passing through water treatment facilities and entering the environment, where they may disrupt the feeding habits of aquatic animals and result in other unknown impacts.

Micro-bead use is measured in hundreds of thousands of kilograms of homogeneous waste each year. Heterogeneous nano materials are used in quantities that can be measured in tens of kilograms per year and are not discarded in such a way that they can measurably pollute public waters or landfills. That does not mean that nano-materials should be excluded from Federal regulatory efforts, however.

F Cubed, LLC, strongly supports objective and thoroughly peer-reviewed scientific investigations into the potential impact that nano materials may have on health and the environment under the guidance of organizations such as the National Science Foundation or programs such as the Unregulated Contaminant Monitor Rule (UMCR)[x] process established by the US Environmental Protection Agency. Such studies first determine how much nano-material is injected into solid and liquid waste streams. It may be that the quantity at issue is so low that additional regulation is unnecessary, beyond current laboratory safety practices, materials safety practices, and Good Manufacturing Practices. Of course, should such studies indicate the presence of a risk, then the next step would include in vitro testing and epidemiological reviews which are likely to be quite complex given the heterogeneous nature of nano materials.

The US is the worldwide leader in nanotechnology. Our national approach to regulation of nanotechnology must be rational and objective and not driven by misunderstanding of the materials in question or by unsubstantiated fear.

Concluding Thoughts

Nanotechnology is important to our universities, businesses, and consumers, many of whom will benefit from advances in medicine, food safety, and a cleaner environment. Federal funding is a large component of basic research, but the translation of such research into products by privately financed companies must be faster and more deliberate if we our to maintain our worldwide lead. Regulation must be informed and intelligent: safety is paramount and must be focused on the applications at hand. Finally, it is critical that human resources emerge from STEM programs at technician, engineer, and scientist levels because the development and commercialization of nanotechnology products require broad design and production expertise.

Thank you for your support of nanotechnology. I would be pleased to answer your questions.

Summary Of Testimony

- US academic institutions and companies are the unquestioned leaders in the field of nanotechnology, due in large part to an environment that rewards innovation and provides access to the appropriate human and financial resources. We strongly support an investment model in which Federal funding fuels targeted university research and private funding supports entrepreneurs who develop and de-risk technology. Start-ups in this area are an engine of economic growth supplying much-needed products and creating new jobs for recent STEM graduates.

- STEM programs are critical to the development and commercialization of nanotechnology, but they are not monolithic: It is important to encourage continued growth in four-year and advanced degree programs. However, this cannot be done at the expense of two-year programs that have proven to be critical in the education of technicians who are able to operate the equipment and tools that produce nanotechnology devices. NACK (Nanotechnology Applications and Career Knowledge) is a good example of a successful and much needed two-year program.

- Technology transfer is often a battle between highly resourced universities and barely resourced start-up companies. Both parties wish to commercialize technology and solve intractable problems, however the process of licensing is very slow and financially draining. Enabling language in the granting process that incentivizes speed could be highly beneficial in turbo charging this process and permitting start-ups to do what they do best: create new jobs and de-risk technology that can be passed on to larger corporations in the future.

- Creating technologies with new and exotic materials is exciting for those who understand the process and perhaps frightening to others who have witnessed miracle applications turn into health and safety problems. It must be understood that nanotechnology was born into an environment of laboratory and materials safety and Good Manufacturing Practices that were created to limit health and environmental risks. Also, the minute quantity and heterogeneity of nanotechnology materials further reduces their potential risk. Nevertheless, it is incumbent on regulatory bodies and nanotechnology companies to undertake an effort to determine if nanotechnology waste streams are significant in volume (perhaps through something similar to the Unregulated Contaminant Monitor Rule process) and propose regulations that are in line with the associated risk.

Witness Biography

Leslie T. Ivie, F Cubed, LLC

Leslie T. Ivie is President, CEO, and a founding member of F Cubed, LLC ("F3"), an Indiana corporation. He was also founder and Chief Operating Officer of Gas Clip Technologies, Inc. Prior to founding F3, he was Chief Technology Officer at Honeywell International.

Mr. Ivie was instrumental in selling Zurich-based Zellweger Analytics AG to Honeywell international and the later purchase of First Technologies Plc. by Honeywell International. He was also Senior Vice President and Chief Operating Officer of Zellweger Luwa AG in Switzerland after serving as Executive Vice President for Research and Development at Zellweger Uster AG in Switzerland.

He was a founder, board member, and later Chairman of the Board for Textillio AG, an Internet company based in Zurich, Switzerland. Mr. Ivie held a variety of positions at United Technologies Corporation, including Director of the Escalator Business Unit for Otis Elevator Company. In addition to residing abroad in Switzerland, he has lived in Japan, Brazil, and Germany.

Mr. Ivie is a member of the National Advisory Council for the NSF Nanotechnology Applications and Career Knowledge (NACK) Network.

Mr. Ivie graduated from Portland State University with a Bachelor of Science in Mathematics and a Bachelor of Science in Economics and from the University of Denver with a Master of Business Administration. Mr. Ivie holds patents for gas analyzer apparatus and methods of analyzing gases and is an inventor of several pending patents in the area of DNA sample preparation and molecular detection.

End Notes

i More information about MRSA can be found at: https://en.wikipedia.org/wiki/Mrsa.

ii More information about the National Nanotechnology Initiative can be found at http://nano.gov.

iii Electromagnetically Controlled Self-Assembly of Nano and Micro Colloids for Miniature Medical Diagnostic Kits, Notre Dame-Argonne Frontiers in Material Science Grant, 2003-2005, $200,000 (with I. Aronson).

"Faradaic Micro-fluidic Devices for Complex Fluids", National Science Foundation, 2005-2007, $100,000.

"Risk assessment and management of the Great Lakes species", Great Lakes Protection Fund, 2006-2009, $1,090,000 (with D. Lodge, J. Feder).

"Developing and Applying a Portable Real-Time Genetic Probe for Detecting Aquatic Invasive Species in Ship's Ballast, Great Lake Protection Fund, 2007-2010, $805,000 (with D. M. Lodge and J. Feder).

"Collaborative Research: Development of a Biofluid Transport, Separation and Molecular Analysis System using Microfluidics and a Miniature Mass Spectrometer", National Science Foundation, 2009-2012, $1,500,000 (with P. Bohn, G. Cooke and Z. Ou-yang) joint Purdue-ND project.

"Dielectrophoresis of Nanocolloids: A New Technique for Capturing Biomolecules and Biomarkers", United States-Israel Binational Science Foundation, 2010-2014, $156,975 (with G. Yossifon and T. Miloh)

iv The Nanotechnology Applications and Career Knowledge (NACK) Network is the NSF National ATE Center for Nanotechnology Workforce Development. Through resource sharing, providing course materials, and stressing broad student preparation, we will help create and sustain economically viable nanotechnology education across the U.S. More information about NACK can be found at http://nano4me.org.

v "University Start-Ups: Critical For Improving Technology Transfer", Brookings Institution, November 20, 2013. http://www.brookings.edu/research/papers/2013/11/university-start-ups-technology-transfer-valdivia

vi More information about life science R&D spending can be found here: http://medcitynews.com/2012/12/analysis-healthcare-will-spend-more-on-r-globalization-collaboration-will-rule/.

vii For more information concerning Good Manufacturing Practices, please see: https://en.wikipedia.org/wiki/Good_Manufacturing_Practice.

viii More information about MSDS can be found at: https://en.wikipedia.org/wiki/Material_safety_data_sheet.

ix More information about micro-beads in the environment can be found here: http://www.motherjones.com/environment/2013/09/microbeads-cleanser-ocean-pollution.

x More information concerning UCMR can be found at: http://water.epa.gov/lawsregs/rulesregs/sdwa/ucmr/ucmr3/index.cfm.

Chairman BUCSHON. Thank you, Mr. Ivie, for your testimony and all of the witnesses for their fascinating testimony.

I want to remind the Members that the Committee rules limit questioning to five minutes and the Chair at this point will open the round of questions. I recognize myself for five minutes.

First, Dr. Whitman, according to the President's 2015 National Nanotechnology Initiative supplement, the proposed Fiscal Year 2015 NNI budget is $1.537 billion, which is $1 million less than the estimated Fiscal Year 2014 spend amount and $13 million less than what was spent in Fiscal Year 2013. How can we remain competitive with flat or decreased funding?

Dr. WHITMAN. So, first, let me comment that historically the actual budgets when they are reported are—can be quite a bit larger than that in the request. Many of the agencies, including the Department of Defense and even many programs within NIH and NSF and DOE aren't specifically—aren't nano-specific solicitations such that at the end of the process nano tends to be very competitive in competing for funds so that when the cross cut is done, it may in fact turn out that the nanotechnology budget may even have increased.

So generally my comment would be that nanotechnology has continued to be quite competitive in solving problems and leading to funding in the current very tight budget environment.

Chairman BUCSHON. Yes, that makes sense.

Mr. Ivie, in your written testimony you write that our national approach to regulation of nanotechnology must be rational and objective and not driven by misunderstanding of materials in question or by unsubstantiated fear. What type of leadership and priorities should be coming from the federal government regarding research on the environmental and safety impacts of nanotechnology?

Mr. IVIE. I think the—excuse me, the U.S. Environmental Protection Agency has a process which I refer to in my written testimony as UMCR, the Unregulated Contaminant Monitoring Rule, which has been very effective in identifying potential contaminants in the environment and has been very deliberate in the way they approach this problem, much as they do with some of the things we look for such as E. coli, Listeria, and terracoccus. That is a good starting place for regulation of the materials that we use I think. It has been very deliberate and they relied on scientific processes and scientific contribution to that so I think that is probably the best place to start.

Chairman BUCSHON. Thank you.

And as a physician, anyone want to comment? I was really interested in reading in the press about the gold nano particles you mentioned Dr. Whitman—being attached and used for anticancer therapy. I was really excited about the possibility of micro-targeting cancer because, as a cardiovascular surgeon, we macro-targeted it by removing it. But obviously that doesn't cure cancer in many aspects; for example, lung cancer, even in earlier stages, there is still a percentage of people that eventually do not survive their cancer even though there is no detectable cancer in the body at the time. Does anyone want to comment about the future of that?

Dr. Hersam, I see you—I mean I—that is an exciting area. And, Dr. Persons.

Dr. HERSAM. Yes. I think the opportunity for nanomaterials in this regard is the fact that in one particular material you can control multiple properties concurrently, so we can functionalize nanoparticles with a particular therapeutic agent. You can also functionalize it with a species that will direct where the agent will be delivered, and then you can have an external trigger such as an optical trigger, which can tell you exactly when the drug will be released. And I think it is that temporal control or time control of the release which gives you the opportunity to give clinicians a new knob to turn to realize new therapies, more effective therapies.

Chairman BUCSHON. So in cancer cells is there a surface protein or something that you target? Is that how it works?

Dr. HERSAM. You can do it in that way. You can take advantage of differences in the pH or the local acidity of the environment. It doesn't mean it is a triggering release. Or you can have an external trigger, which would be dictated by the clinician.

Chairman BUCSHON. Dr. Persons.

Dr. PERSONS. Yes, Mr. Chairman. We did do a profile on nanotherapeutics as part of our study and we did look at one particular group, but I would just add to what Dr. Hersam was saying. There is some exciting work on functionalizing these nanoparticles. First of all, we will be able to just make them with pristine accuracy down to that scale and even design them so that they do have sort of a Trojan horse effect if you will uptake into the cancer or the malignant cells. So the highly targeted nature of that is very exciting.

Thank you.

Chairman BUCSHON. Anybody else have any comments on that?

If not, then I yield to Mr. Lipinski for five minutes for his line of listening. Thank you.

Mr. LIPINSKI. Thank you.

I just wanted to start out by talking about a potential reauthorization of NNI, which, as I mentioned in my opening statement, we haven't done since 2003. I just want to start by asking any recommendations that anyone has of—starting with Dr. Whitman, anything you would like to see in a reauthorization of NNI?

Dr. WHITMAN. So as I commented in general, we think that the 2003 act is fairly good. We have I think discussed in the past with a number of the Members one of the peculiar aspects of it is that there are actually multiple assessments called for in that act on different timescales and on different timescales than our other reporting. So we are—we have both a National Nanotechnology Assessment Panel and a National Research Council Panel on different timescales plus annual budget supplements and triennial strategic plans. So as the director of the office responsible for all of that, it is somewhat of a perpetual cycle of preparing for a review, responding for a review, and so having a somewhat more efficient schedule for those and perhaps not as much redundancy would be helpful.

Mr. LIPINSKI. Thank you.

Does anyone else have any recommendations?

Dr. HERSAM. Yes. I mean what I would say is if we look at the maturity of nanotechnology, it is tempting to say there are winners and we should invest in those winners and really develop technologies to a higher level and I think that that should happen. However, nanoscience itself remains a fertile area for breakthroughs, unanticipated new technologies. And so I think a diversified portfolio both on the fundamental research side and on the applied side is critical to take advantage of the full potential of this field.

Mr. LIPINSKI. Thank you.

Dr. Stevenson?

Dr. STEVENSON. Yes. I would like to comment.

We had an NNI site, one of these infrastructure nanotechnology network sites at our Pickle Research Campus that is home of the Materials Research and Engineering Center, and they were part of the NSF last round of funding and they decided not to fund any of the new NNI sites. And this had quite an impact on our local campus just being able to bridge the gap so that we have a lot of facilities that need care and feeding, and also there is a lot of large user base with dedicated staff scientists. And without that continued funding, then there is bridge funds essentially that are needed in order to keep that operational.

The other thing to recognize is that a lot of this infrastructure that has—like these networks that have been built up, now there are several other new initiatives that actually are intertwined with the development and discoveries made in nanotechnology such as materials genome, the BRAIN Initiative, and a few others, mesoscale science in particular with the Department of Energy. Those types of new initiatives actually rely on a lot of the infrastructure and resources that were established by the NNI over the last 13 years.

Mr. LIPINSKI. Thank you.

Dr. Persons?

Dr. PERSONS. Thank you, sir. I just would follow up. GAO in past work in looking at the NNI of course encourages a risk management-based approach on nano environment, health, and safety issues, so just would encourage based on our past work focus on that, although again in the same mode that Mr. Ivie was talking about in terms of a reasonable regulation type domain.

I would also just echo what our study found, one of the large emphases on the need for international standards on these things as it moves into the commercial sector. Thank you.

Mr. LIPINSKI. Thank you.

I want to move on to technology transfer that I think is critical. I know, Dr. Hersam, when you were starting your company NanoIntegris that you applied and received SBIR grants, which you talked about. Can you talk about the importance of the SBIR program? And I will start with you and see if anyone else has any comments about what can be done to improve technology transfer when it comes to nanotech.

Dr. HERSAM. Yeah. So I would say that the SBIR program has been absolutely critical. In the very early stages it allows prototype developments. I think that is key in order to get additional private capital injected into nanotech companies. The Phase 2 funding is especially important for going to the next level, which is often the scale-up level. The scale-up is critical if you want to get your product to a larger market.

I think there is an opportunity to reassess the Phase 3 program. Often when you are entering into Phase 3 you approach this valley of death where if the company doesn't get a significant injection of capital, it can perish at that stage, and I think there is a lot of companies that are suffering at that moment. A little bit more investment from the federal government there would bring those to a profitable level and that of course would lead to economic growth.

Mr. LIPINSKI. Anyone else want to—okay.

I will yield back.

Chairman BUCSHON. Thank you.

I now recognize Mr. Collins for five minutes for his line of questioning.

Mr. COLLINS. Thank you, Chairman Bucshon.

Dr. Whitman, I am from western New York. Cornell University has been a big participant in the NNIN, and recently their funding has come to an end, as we have—now looking at the next gen. I just wonder could you help the Committee understand a little bit more about where the next generation NNIN stands? And I believe there was some proposals you were asking, you got a couple of groups that submitted but neither one was selected.

And I know our big concern in New York is the State matches the funds that come out of the NNIN. And as Dr. Stevenson said, there is infrastructure there and you just can't cut it off and then expect it to reappear if there is even a six month delay. And so, you know, on behalf of Cornell University and others, I would like to better understand where that initiative stands and is there a basic understanding you can't just turn the spigot off and expect to turn it back on six months later.

Dr. WHITMAN. So, unfortunately, although the NNCO is hosted by NSF, I am actually not part of the NSF organization so that is really a question that you would have to ask NSF leadership. I can briefly comment on what they have stated publicly, which is that the program is important and they are, actually recently had a "Dear Colleague" letter soliciting advice on how best to proceed with the program, so it is not—I think the intention from NSF appears to be to continue the program in some form. So, you know, I would be happy to take the question for the record to NSF and get a response but——

Mr. COLLINS. Yeah, maybe if you could.

Dr. Stevenson, do you have any other comment as you have witnessed this firsthand?

Dr. STEVENSON. Yeah. I mean it is a little bit—with all the pressure with the cuts and the deficit, especially with new centers, like there was encouragement to actually diversify and create other nanoscale research and engineering centers. Maybe that is not going to be the best way to go if we already have these established networks because these are serious investments. The—so there needs to be some pushback, I think a little bit to some of these agencies to say, hey, you already invested in this. You need to continue to do so. You can't just leave these people hanging.

Mr. COLLINS. Well, and right now I think, you know, time is of the essence.

Dr. STEVENSON. Yeah, it—and this is really impacting our UT campus, our resources as well.

Mr. COLLINS. So is there anything you could suggest that we could do on this Committee or in Congress to try to expedite this black hole that appears to be there?

Dr. STEVENSON. Just to recognize that these resources just can't be cut off and that there are people behind them that actually enable science, other funded initiatives and the growth of the technology base. So at the NNIN site in Texas they are—have several companies, over 50 that use this facility on a daily basis, and those companies need that access, too, especially the small companies.

Mr. COLLINS. Well, you know, again, Cornell shares that concern and so do I, so, you know, we will have to see what we might do to at least ask more questions and understand this is a resource that just can't be turned off and then turned back on.

With that, Chairman, I yield back.

Chairman BUCSHON. Thank you.

I now recognize Ms. Johnson for her five minutes for her line of questioning.

Ms. JOHNSON. Thank you very much, Mr. Chairman.

Dr. Whitman, the National Nanotechnology Initiative has had a workforce development component since it was established. Could you please speak to the efforts on education and workforce development and also talk a little bit about the education outreach activities at the elementary or secondary level and how the NNI agencies such as the National Science Foundation is providing resources for teachers or informal STEM educators so they can effectively integrate nanotechnology concepts into the classrooms and activities?

Dr. WHITMAN. I will do my best.

So this is not an area I have deep personal expertise, but I can tell you that nanotechnology—the federal government has worked hard to make nanotechnology a part of the federal-wide K–12 and postsecondary STEM education strategy. The NSF and the Department of Education have had a number of programs to do that. We in the NNCO do outreach at a variety of places. I actually personally attended the booth at the Science and Engineering Festival, which was a lot of fun.

And there is also—NSF and other agencies support the National Nanomanufacturing Network, which also supports education, and there is also EHS-related work encouraging people to learn about the safe use of nanoparticles.

Again, if you want to take that question for the record and I can provide additional information.

Ms. JOHNSON. Okay. Thank you.

I am concerned about the turning off and on, as just been mentioned, and also in any kind of sustainability of how we can make sure there is a workforce, a research group in the future. Does anybody else on the panel have any comments?

Dr. HERSAM. Yeah. I am happy to comment on that.

So the National Science Foundation Nanoscale Science and Engineering Centers would devote about, you know 1/4 to 1/3 of their budget to precisely STEM education and outreach. These programs were outstanding because you would have the latest in research impacting work being done at K–12 level, general public outreach, undergraduate level. And these centers were designed to run for ten years, and the problem is after those ten years you have all this momentum and then, as you mentioned, the spigot is turned off and that gap in funding really decimates those programs.

And consequently, having sustained and predictable funding will not only influence the fundamental research but perhaps more importantly STEM education and therefore American competitiveness.

Ms. JOHNSON. Thank you.

What about the gentleman, Mr. Ivie, the Notre Dame graduate, do you see any deficit in your work in the future for talent?

Mr. IVIE. Yes. We see deficits in a couple of areas. One of them is in my written testimony and in my spoken testimony I highlighted the impact that people with associate's degrees have on our business. For us this is important because these are the people that actually operate our production lines and these people are hard to come by right now, and that is primarily because the NSF program, NACK, the Nanotechnology Applications and Career Knowledge Network is just starting to take off.

Typically in our business we hire people with bachelor's degrees, master's degrees, Ph.D.'s, and while they may be interested in—for working on a production line with a robot that is applying nanomaterials to our product for a few weeks, this isn't something they want to make a career out of. So this is one thing we are particularly concerned about.

I think the other thing we are concerned about in general is the issue that I am sort of hearing from some of the other testimonies, which is spreading federal government money over too much territory. As an entrepreneur, we view our business responsibility as taking this technology and commercializing it. We don't see it as the university's responsibility to do that for us. That is why we go out and find private individuals with a lot of money. Now, of course, Uncle Sam has a lot of money as well but that probably should be used somewhere else and I think that is also something that needs to be dealt with on the technology transfer side.

Ms. JOHNSON. Thank you very much, Mr. Chairman.

Chairman BUCSHON. Thank you.

I now recognize Mr. Johnson from Ohio for his line of questioning.

Mr. JOHNSON. Thank you, Mr. Chairman, and thank you for having this hearing today.

Dr. Whitman, in your written testimony on the NNI you write, "there is always room for improvement, as also suggested by the National Nanotechnology Advisory Panel and the National Academies." Could you please give us an idea of which specific areas you think need improvement and why they are necessary? Can you expand on that, please?

Dr. WHITMAN. Sure. So one of the areas, you know, we have been working hard at is improving our interface to the business community, both to provide resources to them and so that we can hear them as stakeholders. So, for example, we heard mention about the availability of things like the SBIR program so we have in our office a full-time industrial liaison person now and we have taken a number of steps to try to make our website a better resource for industry and interface with groups like the Nanotechnology Business Commercialization Alliance to make sure they know who they need to talk to, bring people together, and support their needs as an industry community. That is one example.

Mr. JOHNSON. Okay. All right. Thank you.

Dr. Hersam, in your testimony you write that you "have 28 nanotechnology patents pending, which implies that my commercialization attempts have largely occurred without formal patent protection." So is this mainly due to the delays at the United States Patent and Trademark Office?

Dr. HERSAM. That is correct. So the time from filing a patent to getting initial office action in my experience has typically been about three years, and then after the office action you are looking at another year or more before the patent is issued. This field moves so quickly that if you are going to commercialize, you have to go to market before your patent is issued, and therefore you are assuming risk because there is little legal recourse if your patent is not yet issued.

So any effort that can streamline the operation or improve the efficiency of the U.S. Patent and Trademark Office I think will improve the ability to commercialize nanotechnologies because you reduce risk that will allow easier time gaining investments and protecting IP, which was developed in the United States.

Mr. JOHNSON. How many patents team you have with the Patent and Trademark Office now?

Dr. HERSAM. Issued?

Mr. JOHNSON. No. How many do you have waiting?

Dr. HERSAM. The 28 that you mentioned.

Mr. JOHNSON. The 28 are still waiting?

Dr. HERSAM. That is right.

Mr. JOHNSON. Okay. And how long have they been there?

Dr. HERSAM. It depends on the——

Mr. JOHNSON. Give me the oldest one.

Dr. HERSAM. I have one that was filed in 2005 that is still pending.

Mr. JOHNSON. Okay. Good grief, nine years.

Dr. HERSAM. That is correct.

Mr. JOHNSON. How in your mind could the process be reformed at the Patent and Trademark Office and what specific policies do you think should be fixed and addressed, especially in this area that we are talking about, nanotechnology commercialization?

Dr. HERSAM. You know, it is hard to know exactly why thing get delayed, but presumably it is not enough patent examiners in this field. I mean that is what I would anticipate as a limiting factor. It just takes—there is a large stack on the desk and it takes a long time to get through those. So getting them on the desk of the examiner more quickly presumably would be more examiners would help significantly.

Mr. JOHNSON. But nine years. You think—I mean nanotechnology, I can't imagine that there is—I mean maybe there are and maybe I am wrong, but I can't imagine that there are that many people flooding the desk of the nanotechnology department at the Patent and Trademark Office.

Dr. HERSAM. Yes. So in that regard I guess I am as mystified as you are and it is not transparent or obvious to me why it takes so long.

Mr. JOHNSON. Okay. All right.

Well, Mr. Chairman, that—those are all the questions I have. I yield back the remaining balance of my time. Thank you, gentlemen.

Chairman BUCSHON. Thank you.

I now recognize Ms. Kelly for five minutes for her line of questioning.

Ms. KELLY. Thank you, Mr. Chair.

Several of you mentioned successful public-private partnerships, including the College for Nanoscience and Engineering in New York. Are there lessons we can learn from public-private partnerships in nanotechnology, in particular partnerships that involve significant leveraging of private funds? And whoever cares to answer can answer, which I hope someone cares to answer.

Mr. IVIE. I will take a stab at it.

Ms. KELLY. Okay.

Mr. IVIE. The University of Notre Dame has a program called ESTEEM, which is a graduate one-year program for establishing science and entrepreneurship amongst STEM graduates. I think we have seen that as becoming successful because, number one, they implant interns into our organization. That is people with degrees that are useful, help us develop our products, and also to turn these students into entrepreneurs themselves.

I think most four-year graduates, while they like the idea of becoming a business owner, what they don't like is the idea of becoming impoverished in the process of doing that. However, what we have tried to explain to them is that if you are going to risk something, risk something before you have a home, several car payments, and children to support.

So we have seen that partnership between us and them and other small businesses in our community become very successful.

Ms. KELLY. That is great. I am sure they are worried about all the student loan debt.

Mr. IVIE. They are, believe me.

Ms. KELLY. Anyone else?

Dr. WHITMAN. So it certainly works best when you have a combination of strong technology pull from the industry where they see a market and a need that can be met and a good technology push with a new technology. That is what you will see in something like the Nanoelectronics Research Initiative. It also works well when the nature of that public-private partnership involves a lot of—a significant amount of precompetitive work such that industries feel they can work together at that stage, so that certainly is the case there. And then the other one—there is one actually with the forest products related to nanocellulose. In fact, there is a workshop going on today about that field and the challenges and opportunities for commercialization, but there is already a public-private partnership in the area as well so you need those kind of combination of things that make it work.

Dr. PERSONS. Yes, ma'am. And I would just add on to Dr. Whitman's statement on—emphasizing the precompetitive research and development sort of environment that is set up there. It is also—and seeing as each case is co-located with universities so you have this nice ecosystem of training, as has been mentioned a number of times. And there are strong involvement in integration with industry needs overall, so there is lots of industries coordination on that side and there is coordination on the STEM or the educational side.

Ms. KELLY. Thank you.

Dr. STEVENSON. I would add one specific example that Texas—is that—is part of the establishment of the NNIN site. They worked with a local company that was founded at University of Texas, Molecular Imprints. It has now been sold to Canon. And with that agreement the Molecular Imprints gave them a significant discount on the state-of-the-art lithographic capabilities that then helped facilitate the training from people from local companies to use this technology at the NNIN site. And this was only enabled because of the partnership between the federal investments to establish the NNIN capabilities Texas but also the fact that this company is really innovating in that particular area a totally different way of doing nanofabrication than what is currently done in the commercial sense.

So this partnership really had led not only the training of people at different companies but also students and graduate students in this area, so it was a very emerging cutting-edge technology that was enabled from that.

Ms. KELLY. Thank you. I yield back.

Chairman BUCSHON. Thank you.

I now recognize Mr. Stockman, five minutes.

Mr. STOCKMAN. I am from Texas so I am glad to hear so much about Texas, and I think University of Houston also had some nanotechnology, so I don't want to—representing Houston, I don't want to leave that out.

I have a friend up in Dallas who spent I think close to $100 million of his own money—I wish I could say I spent that—but—and one of the things he found out is he developed a nanotechnology. The people in the government, particularly the EPA, were not as familiar with what he was doing and they came in there and—in a way that prohibited him from doing things and research, which I don't—there is a gap between government regulations and what they know and what they are proposing. And then the DOD told him he can't sell his product to pay for his research because they said it is classified, so DOD won't buy it. And so what happens now—he is looking at going to—in transferring his entire company to Abu Dhabi, and I am wondering if we can't get feedback from you on how we could make sure that we don't lose private corporations because they feel restricted either through the EPA or the DOD. So feel free to answer.

Dr. STEVENSON. I am happy to answer at least one aspect of that question. First of all, EPA seems to be bifurcated in their behavior towards certain materials. For example, contaminants that you would find in water such as Lake Michigan, they might spend 20 to 25 years examining the problem, coming up with a prescription for the solution to the problem, and then implementing the solution. What we have seen in nanotechnology is there already are a huge number of regulations we are required to comply with, whether that is laboratory safety, material safety, OSHA requirements, in Indiana, the Indiana Department of Safety and Health and then the University of Notre Dame, so there is already a very large contingent of regulations that we have to comply with.

I think part of what we are seeing is probably a political reaction, number one, and secondly, a misunderstanding of what it is we are dealing with. They don't understand the characteristics of the materials and many of their laboratories that they have in places like Cincinnati have not dealt with these things before.

So the solution to what EPA is doing I am not sure what the solution is, but one thing I am certain is not a solution is not talking about it and that seems to be what is on the agenda right now. There isn't a lot of public disclosure about what they are going to do.

Mr. STOCKMAN. Given that you are in the private sector, is there any way you can get to this Committee some of the problems you are seeing? Because I think for us we make laws for you to make and facilitate your productivity and we want to see you succeed, but if we don't know the problems, we can't correct that. And to me it was alarming because here is a guy who put in a lot of his own money and now is forced to leave because the people—given the rules and regulations, a lot of them don't have a clue. I mean they don't have a clue about what you are doing and so they just shoot in the dark at regulations saying, well, I hope this regulation is going to help. We don't really know. There is no case study to prove our regulation is going to help and it is driving people out even before this industry takes off.

And for me to see America's competitiveness being driven down by people that don't know what is going on is pretty alarming to me.

Mr. IVIE. Well, I think in my opinion what I would rather see happen instead of giving F Cubed a grant, for example, or a small business loan, what I would refer to see is something like a program at the U.S. EPA for the Unregulated Contaminant Monitoring Rules that they already have in place to examine these things over a period of time with the NSF or an organization like that. We already know this has worked with other contaminants such as hexavalent chromium or hormones that are being injected into the water system through waste streams. That is probably the most important thing. I just don't think they are being pressured to do that. That is where their true scientific capability lies.

With regard to your friend who is going to Abu Dhabi, one thing I can say, we experience this on a daily basis. Many organizations in places, not so much the Middle East but in Asia, are spending a huge amount of money trying to do what we are doing. That is they are trying to develop entrepreneurs to take over nanotechnology. The difference is that so far from a cultural point of view they have not succeeded in doing that. It is not because they are not just spending the money to try, however.

Mr. STOCKMAN. Well, they don't even make the distinction between friable and un-friable or in suspension. They just use a shotgun.

But I appreciate your feedback. If you can get us ways that we can improve the efficiency, I would appreciate that.

Mr. IVIE. Certainly.

Mr. STOCKMAN. Thank you, Mr. Chairman. Thank you for having the hearing.

Chairman BUCSHON. Thank you. And—excuse me. At this point I would like to thank the witnesses for their valuable testimony, very fascinating subject, and the Members for their questions. The record will remain open for two weeks for additional comments and written questions from Members.

The witnesses are excused and the hearing is adjourned.

[Whereupon, at 11:21 a.m., the Subcommittee was adjourned.]

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Lloyd Whitman

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY

"Nanotechnology: From Laboratories to Commercial Products"

Questions for the Record, Dr. Lloyd Whitman, Interim Director of the National Nanotechnology Coordination Office and Deputy Director of the Center for Nanoscale Science and Technology, National Institute of Standards and Technology

Questions submitted by Rep. Larry Bucshon, Chairman, Subcommittee on Research and Technology

1. 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 NNI. Given that NNI is "functioning" without any recent Congressional reauthorization, why should Congress reauthorize NNI? Could each of you comment on any areas that you see room for improvement or changes in a potential NNI reauthorization bill? Please explain.

   By reauthorizing the NNI, Congress would demonstrate a commitment to the field, which is important to the Nation for a number of reasons. First, that commitment sends a strong signal to scientists and engineers—especially students and young professionals—that resources will be available for research and development and that there is a future in the field, thereby ensuring a full pipeline of new talent and ideas. Second, a national commitment to the NNI is critical to maintaining strong private-sector investments in commercializing nanotechnology-based products. By reauthorizing the NNI, Congress will help sustain vital support for fundamental, ground-breaking research, development, infrastructure, and education and training programs that collectively constitute a major U.S. innovation enterprise.

   The 21st Century Nanotechnology Research and Development Act of 2003 calls for a biennial review of the NNI by the National Nanotechnology Advisory Panel in addition to a triennial review by the National Research Council of the National Academy of Sciences. While these external assessments provide critical expert input, the frequency and overlap of these two periodic reviews create a significant burden and expense to the NNI agencies. Streamlining these requirements by consolidating to a single external review, perhaps every four or five years, with a broadly-defined scope that is flexible enough to allow tailoring the topics to be covered in each review to the circumstances at hand, would be a more economical approach to informing the NNI and Congress. Similarly, the timeline for the NNI strategic planning process could then be adjusted to match the period of the external review, but with due dates that are staggered from those of the external review to allow time for the plan to respond to review recommendations, and for the review to assess the most recent plan. Ideally the external body performing the review could also be flexible, rather than being specified in legislative language as a "sole-source" provider, since a number of organizations might be qualified to assess different aspects of the NNI.

2. Within the NNI budget, could you recommend where significant savings can be achieved within the nanotechnology portfolio? Please explain.

   The NNI is a coordinated multi-agency initiative driven by bottom-up innovation, not a distinctly funded "program" with a centralized budget and management. One of the distinct advantages of such an initiative is that it is inherently efficient at supporting only programs and projects that most effectively meet each agency's needs among competing priorities within the appropriated budgets. The competitiveness of nanotechnology among competing priorities is evident in the relatively stable overall support annually provided by the NNI participating agencies, in total, even in the current budget environment.

Question for the Record from Representative Lipinski (D IL)
For Dr. Lloyd Whitman
May 20 Hearing "Nanotechnology: From Laboratories to Commercial Products"

At the hearing, Representative Collins (R NY) asked you about the funding for the National Nanotechnology Infrastructure Network (NNIN) that is supported by the National Science Foundation (NSF). I wanted to give you an opportunity to expand on your answer. Specifically, has the funding for NNIN stopped? Further, please explain the future of the NNIN, how NSF is working with the nanotechnology community, and how the next generation NNIN would continue NSF's investmentin nanotechnology and the NNIN's user facilities?

As Interim Director of the National Nanotechnology Coordination Office, I am not involved in the administration of the NSF's NNIN program nor in NSF's consideration of options for future, related programs. I would refer you to NSF for more information about this topic.

Question for the Record from Ranking Member Johnson (D-TX)
For Dr. Lloyd Whitman
May 20 Hearing "Nanotechnology: From Laboratories to Commercial Products"

At the hearing, I asked you about the workforce development component of the National Nanotechnology Initiative (NNI). I was hoping that you could elaborate on the NNI's broad efforts on education and workforce development. What are the workforce development activities of the NNI? What are the education and outreach activities of the NNI at the elementary and secondary level? How are the NNI agencies, such as the National Science Foundation and the Department of Education, providing resources to teachers and informal STEM educators so they can effectively integrate nanoscale science and engineering concepts into their classrooms and activities?

Education and a skilled workforce are fundamental to the successful development of nanotechnology. Both are primary components of Goal 3 as defined in the 2014 NNI Strategic Plan. The NNI agencies have a broad array of activities that support education and workforce development. These activities include internships; support for undergraduate, graduate, and postdoctoral researchers; programs focused on mentored, laboratory-based training; and professional development seminars, workshops, and short courses. Education is among the chief objectives of all NNI-funded university research. In addition, there are specific programs targeting K–16 education to improve nanotechnology curricula in U.S. schools and universities and to educate the public about nanotechnology. Some specific examples are described below, with more detailed information reported in the annual NNI Supplement to the President's Budget and on nano.gov.

The NCI Alliance for Nanotechnology in Cancer supports Cancer Nanotechnology Training Centers that are establishing innovative research education programs supporting the development of a cadre of investigators capable of pursuing cancer nanotechnology research. The training programs are focused on mentored, laboratory-based training in multidisciplinary research projects. Each training center also develops seminars, workshops, and short courses to teach the cross-cutting skills and knowledge necessary for successful research in cancer nanotechnology. The training centers have trained 125 graduate students and postdoctoral researchers in multidisciplinary research, with a focus on cross-training in medical and physical sciences and engineering. More than 800 people, ranging from undergraduates to mid-career researchers, have participated in symposia, workshops, and conferences organized or hosted by the training centers.

NIST and NSF are conducting a joint program that provides extended internships at NIST for community college students being trained in semiconductor manufacturing technology. The program is providing students with hands-on, practical experience in nanofabrication, processing, characterization, and tool maintenance in areas specifically targeted to meet the needs of U.S. manufacturers for skilled technicians.

The NSF Nanotechnology Applications and Career Knowledge (NACK) Network, centered at Pennsylvania State University, is a nation-wide network that builds partnerships in nanotechnology education among research universities, 2-year community and technical colleges, and 4-year colleges/universities through resource sharing and creation of educational pathways for student development. An on-line portal (nano4me.org) enables broad access to resources for students, educators, and industry personnel with nearly 40,000 downloads since January 2009. In addition to coursework and hands-on laboratory experiences for student and technician training, NACK provides hands-on introductory workshops for educators and industry personnel with a focus on how to implement and teach courses. Over 1200 educators have attended these programs.

In addition to the training and resources made available through the NACK Network, NSF supports Research Experience for Teacher (RET) programs at universities across the country, many of which involve nanotechnology. For example, the Center for Diversity in Engineering at the University of Virginia has hosted a series of RET programs and made the resources developed available online. Furthermore, these resources consider implementation within the Virginia State Science Standards of Learning (SOLs), the first in the country to include nanotechnology.

The NSF Nanotechnology Center for Learning and Teaching, supported from 2004 through 2011, developed a vast array of resources available at the NanoEd Resource Portal that are now in daily use by teachers and students nation-wide. These resources, many of which are mapped to state education standards, include lessons and courses; seminars and lectures; and online lessons, simulations and games.

In addition to teacher training and nanoeducation resources targeting the primary and secondary school levels, there are significant efforts underway to support outreach to students and the public at large. The NSF Nanoscale Informal Science Education (NISE) Network, led by the Museum of Science, Boston, has established an annual, nationwide, week-long NanoDays event and provides demonstrations for use across the country. The NISE Network has developed 121 educational products and distributed 1400 hands-on demonstration kits to all 50 states, resulting in 3 million encounters during NanoDays events. The actual reach is much broader — 100% of the participants report use of the kits throughout the year. In addition, in 2013, the NISE Network supported 90 mini-exhibitions on nanotechnology reaching 9 million people.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY

"Nanotechnology: From Laboratories to Commercial Products"

Questions for the Record, Dr. Lloyd Whitman, Interim Director of the National Nanotechnology Coordination Office and Deputy Director of the Center for Nanoscale Science and Technology, National Institute of Standards and Technology

Question submitted by Rep. Bill Johnson

It is crucial for both the economy of the United States - and Ohio in particular - that we continue to find ways to encourage the development and use of nanotechnology – considering that its use will help spur breakthroughs in other important sectors of our economy, such as manufacturing, health care, and energy production. To that end, what strategic investment changes should the United States make, in order to encourage the growth of revolutionary nanotech products?

A current priority of the NNI is to foster the transfer of new technologies into products for commercial and public benefit, and to ensure that those products are safe. As enumerated in the 2014 NNI Strategic Plan, to achieve these goals we should:

1. Assist the nanotechnology-based business community in understanding the Federal Government's R&D funding and regulatory environment.
2. Increase focus on nanotechnology-based commercialization and related support for public–private partnerships.
3. Promote broader accessibility and utilization of user facilities, cooperative research centers, and regional initiatives to accelerate the transfer of nanoscale science from lab to market.
4. Actively engage in international activities integral to the development and responsible commercialization of nanotechnology-enabled products and processes.
5. Support the creation of a comprehensive knowledge base for evaluation of the potential risks and benefits of nanotechnology to the environment and to human health and safety.
6. Create and employ means for timely dissemination, evaluation, and incorporation of relevant environmental, health, and safety (EHS) knowledge and best practices.
7. Develop the national capacity to identify, define, and responsibly address concepts and challenges specific to the ethical, legal, and societal implications (ELSI) of nanotechnology.
8. Incorporate sustainability in the responsible development of nanotechnology.

One mechanism by which the development of select technologies is currently being accelerated is through the new NNI Signature Initiatives. These initiatives are designed to accelerate innovation in areas of national priority through enhanced interagency coordination and focused investment. They are intended to be dynamic, with topical areas rotating and evolving over time along with agencies' strategic investment priorities. The current topics are as follows (with additional topics under development):

- Nanotechnology for Solar Energy Collection and Conversion
- Sustainable Nanomanufacturing

- Nanoelectronics for 2020 and Beyond
- Nanotechnology Knowledge Infrastructure (NKI)
- Nanotechnology for Sensors and Sensors for Nanotechnology

NNI agencies are also participating in the President's Advanced Manufacturing initiatives, which are complementary and synergistic with the NNI, particularly with the NNI's efforts to promote commercialization and nanomanufacturing.

Responses by Mr. Les Ivie

1441 North Michigan Street, Suite 2000, South Bend, Indiana 46617 USA

June 26, 2014

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY

"Nanotechnology: From Laboratories to Commercial Products"

Questions for the Record, Mr. Les Ivie, President and CEO, F Cubed, LLC

Questions submitted by Rep. Larry Bucshon, Chairman, Subcommittee on Research and Technology

It is important to improve our understanding of any environmental, health, and safety issues associated with nanotechnology and to resolve uncertainties in the regulatory regime governing 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? Are current federal and private research efforts adequate to address concerns about environmental, health, and safety impacts of nanotechnology? What impact have regulatory and environmental uncertainties had on how the semiconductor and medical industries approach nanotechnology research, product manufacturing, and business/job creation?

Response:

In terms of prioritization of nanotechnology materials with regard to environmental, health, and safety issues, the most sensible first step is to quantify the presence of such materials in the environment. Determining public exposure levels will provide a key metric in later decisions regarding regulation.

The US Environmental Protection Agency ("US EPA") has conducted a number of detailed studies as part of the Unregulated Contaminant Monitoring Program that has resulted in Unregulated Contaminant Monitoring Rules ("UCMR"). UCMR 1 (2001 - 2005) examined 25 contaminants. UCMR 2 (2007 - 2011) examined 25 additional contaminants. UCMR 3 (2012 - 2016) is examining an additional 30 contaminants. The purpose of this program is to determine the presence of specific contaminates in the environment and then determine the regulation needed for those materials. The program administration and investigative methods are quite robust and the well respected by industry and academia.

The Unregulated Contaminant Monitoring Program should be used to examine and measure the presence of nanotechnology materials in the environment. The program processes are well understood, and academia and industry are well practiced in

1441 North Michigan Street, Suite 2000, South Bend, Indiana 46617 USA

participating in the program and providing comments when the opportunity is provided.

The nanotechnology industry is present nationwide. The Federal Government should take the lead in examining the materials in question and ensuring that the approach is scientific, objective, and not overburdened by emotional and non-scientific scare tactics. Recent state regulatory efforts to control or eliminate the use of plastic microbeads (which are certainly not a nanotechnology material - please see the following citation:) have demonstrated what can happen when unscientific scare tactics and poor science are applied to a potential environmental problem. Such responses will do little to positively impact public health and safety, and will significantly and negatively impact research, manufacturing, and job creation.

The United States is a leader in nanotechnology, but we participate in a worldwide scientific and business environment. In the absence of specific UCMR data with regard to nanotechnology materials, we risk restricting the use of such materials or compromising their utility for little or no improvement in public health and safety. Our academic and business competitors outside of the United States are actively supported by their national governments to develop nanotechnology materials, optimize production of such materials to reduce costs, incorporate those materials into finish products, and export them to the United States. They support programs to develop entrepreneurs and ensure they can compete against US-based companies. Such countries have a track record of paying little attention to public health and safety, and certainly are uninterested in business and job creation in the United States. For example, the People's Republic of China is now the world's leading supplier of basic pharmaceutical compounds and also the leader in semiconductor manufacturing. It would be unfortunate to witness the United States give up its leadership of nanotechnology. The negative impact on industries from medicine to aerospace is almost to terrifying to imagine.

We value the environment, health, and safety. We have a history of efficiency and effectiveness in research and manufacturing that demonstrates that we can comply with sensible regulations and still win in the international marketplace. The key phrase is "sensible regulations". The Unregulated Contaminated Materials Program and concomitant UCMR rules provide a scientific, objective, and reasonable way to examine nanotechnology materials, and provide a regulatory framework, if needed.

Additional Responses to Questions Posed at the Hearing
Mr. Les Ivie, President and CEO, F Cubed, LLC

Question One: Rep. Kelly asked about public-private partnerships. I provided information concerning a program at the University of Notre Dame, ESTEEM (Engineering, Science, Technology Entrepreneur Excellence masters program). I would like to add the following information as well.

"F Cubed, LLC is an advisory board member of the National Science Foundation NACK (Nanotechnology Applications and Career Knowledge) program. The purpose of this program is equivalent to an trade apprenticeship program: students work towards an Associates Degree in Nanotechnology which includes internships at nanotechnology companies. Large companies such as Boeing and Corning participate in this program, as does F Cubed, LLC. Thus far we have had four interns in the last 12 months. We have offered full-time employment to three of the interns that graduated. We were pleased to see that the fourth intern was able to find a new career with Tenneco as a quality technician in one of their large automotive facilities. This summer, 2014, we have a new batch of interns, several of which we hope will join our company. There are dozens of NACK-associated community colleges around the USA that are trying to work with private companies with varying levels of success. One obstacle to success is the perception that two-year nanotechnology programs don't meet STEM requirements. This is not only untrue, it also damages the ability of USA-based companies to compete on an international basis. Such programs deserve more vocal support in both the nanotechnology discussion, and in the debate concerning STEM programs."

Question Two: Rep. Stockman asked about regulation of nanotechnology in terms of DOD-related applications and environmental regulations. I provided information concerning environmental regulations, regulations in general, and the impact on competitiveness in the USA. I would like to add the following information as well:

"In my written testimony I attempted to contrast unique and potentially important nanotechnology materials with such mundane materials as plastic microbeads used in toothpaste and personal care products. The US EPA and many state-based environmental regulators treat all such materials as pollutants, regardless of the quantity found in waste streams, the danger posed by the material in question, or the use of the material. It is absolutely critical that nanotechnology materials be treated with a much more care by regulators: they are used in minute quantities, offer incredible benefits in many applications, and absent studies to the contrary, are safe. Nevertheless, US EPA treats such materials with a broad brush and creates regulations that are burdensome, very difficult to manage, and have the effect of forcing certain manufacturing processes outside the USA. It would be very helpful if regulatory agencies were more thoughtful in their review of such materials. Perhaps legislation is required to ensure more detailed analysis by regulators, more extensive public comment periods, and more scrutiny of public interest groups who often drive regulatory discussions toward non-scientific and non-objective conclusions. A change to regulatory process is required, and required soon, or the USA will see its lead in nanotechnology erode even further."

Appendix II

Additional Material for the Record

SUBMITTED STATEMENT OF LAMAR S. SMITH, CHAIRMAN, COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY

Thank you Chairman Bucshon for holding today's hearing.

Many believe nanotechnology has the potential to usher in the next industrial revolution. Last February, the Government Accountability Office (GAO) released a report that the Committee's Chairman Emeritus, Mr. Hall, and I had requested, titled, "Nanomanufacturing: Emergence and Implications for U.S. Competitiveness, the Environment, and Human Health."

The report described nanomanufacturing as a future megatrend with societal and economic impacts that could surpass even the digital revolution. It also predicted further scientific breakthroughs in this area that will lead to new engineering developments and improvements in the manufacturing sector.

The report recommended that Congress update current innovation-related policies and programs and that we promote U.S. innovation in manufacturing through public-private partnerships. One such public-private partnership is the National Nanotechnology Infrastructure Network (NNIN). The NNIN is a partnership of user facilities, supported by the National Science Foundation (NSF), which serves the needs of nanoscale science, engineering and technology.

The University of Texas at Austin is home to one of these facilities called the Microelectronics Research Center (MRC). This center performs research to improve materials used in the integrated circuit industry and related industries.

The MRC is more than a clean room with open-access to advanced nano-fabrication equipment. It is a community of scientists who work together to share knowledge in order to ensure a more advanced and competitive America.

More importantly, MRC is leading the way in the instrumentation for manufacturing—precisely the area that was recommended for emphasis in the GAO report.

In 2013, NSF requested proposals for a Next Generation Nanotechnology Infrastructure Network (NG-NNIN). Two teams of universities responded to this call. Last March, NSF decided not to fund either of the NG-NNIN proposals under consideration.

Given the importance of nanotechnology research and the GAO report recommendation that the U.S. maintain and enhance competitiveness in this area, I don't know of a good explanation for NSF's decision.

I look forward to the witnesses' testimony on how we can ensure that the U.S. remains the world leader in nanotechnology research. I would especially like to thank Chemistry Professor Keith Stevenson, from the University of Texas at Austin, for his participation this morning.

○