S. HRG. 112–688

THE NATIONAL NANOTECHNOLOGY INVESTMENT: MANUFACTURING, COMMERCIALIZATION, AND JOB CREATION

HEARING

BEFORE THE

SUBCOMMITTEE ON SCIENCE AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

ONE HUNDRED TWELFTH CONGRESS

FIRST SESSION

JULY 14, 2011

Printed for the use of the Committee on Commerce, Science, and Transportation

U.S. GOVERNMENT PRINTING OFFICE

78–182 PDF WASHINGTON : 2013

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

SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED TWELFTH CONGRESS

FIRST SESSION

JOHN D. ROCKEFELLER IV, West Virginia, *Chairman*

DANIEL K. INOUYE, Hawaii
JOHN F. KERRY, Massachusetts
BARBARA BOXER, California
BILL NELSON, Florida
MARIA CANTWELL, Washington
FRANK R. LAUTENBERG, New Jersey
MARK PRYOR, Arkansas
CLAIRE McCASKILL, Missouri
AMY KLOBUCHAR, Minnesota
TOM UDALL, New Mexico
MARK WARNER, Virginia
MARK BEGICH, Alaska

KAY BAILEY HUTCHISON, Texas, *Ranking*
OLYMPIA J. SNOWE, Maine
JIM DeMINT, South Carolina
JOHN THUNE, South Dakota
ROGER F. WICKER, Mississippi
JOHNNY ISAKSON, Georgia
ROY BLUNT, Missouri
JOHN BOOZMAN, Arkansas
PATRICK J. TOOMEY, Pennsylvania
MARCO RUBIO, Florida
KELLY AYOTTE, New Hampshire
DEAN HELLER, Nevada

ELLEN L. DONESKI, *Staff Director*
JAMES REID, *Deputy Staff Director*
BRUCE H. ANDREWS, *General Counsel*
TODD BERTOSON, *Republican Staff Director*
JARROD THOMPSON, *epublican Deputy Staff Director*
REBECCA SEIDEL, *Republican General Counsel and Chief Investigator*

SUBCOMMITTEE ON SCIENCE AND SPACE

BILL NELSON, Florida, *Chairman*
DANIEL K. INOUYE, Hawaii
JOHN F. KERRY, Massachusetts
MARIA CANTWELL, Washington
MARK PRYOR, Arkansas
MARK WARNER, Virginia

JOHN BOOZMAN, Arkansas, *Ranking*
JOHN ENSIGN, Nevada
ROGER F. WICKER, Mississippi
MARCO RUBIO, Florida
KELLY AYOTTE, New Hampshire

CONTENTS

THE NATIONAL NANOTECHNOLOGY INVESTMENT: MANUFACTURING, COMMERCIALIZATION, AND JOB CREATION

THURSDAY, JULY 14, 2011

U.S. SENATE,
SUBCOMMITTEE ON SCIENCE AND SPACE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Subcommittee met, pursuant to notice, at 10:05 a.m. in room SR–253, Russell Senate Office Building, Hon. Bill Nelson, Chairman of the Subcommittee, presiding.

OPENING STATEMENT OF HON. BILL NELSON, U.S. SENATOR FROM FLORIDA

Senator NELSON. Good morning. We are really looking forward to this hearing. Senator Boozman and I are quite honored to have the senior leadership of the full Commerce Committee here with us. And so I want to turn it over first to the Chairman of the Committee, Chairman Rockefeller, and then recognize the Ranking Member, Senator Hutchison.

Mr. Chairman?

STATEMENT OF HON. JOHN D. ROCKEFELLER IV, U.S. SENATOR FROM WEST VIRGINIA

The CHAIRMAN. A most courteous gesture. I want to repeat what Senator Nelson said. I think the depth of knowledge that you have—I prepared for this hearing, and it was brilliantly prepared for me by a woman sitting behind me, and it was one of the best briefings I've ever gotten. And what it basically does is—because we were doing this 12 years ago, if you can remember. We had little demonstrations out here on the floor, and we didn't know what we were looking at. And the people who were explaining it didn't know how to explain it. And then here you come absolutely brilliant, top people in the country.

So we're at a place today where big advances in technology are happening at a very small level, stunningly small. Everything from biotechnology tools to detect early stage Alzheimer's disease, which is extraordinarily interesting, to soon reducing your computer's entire memory to the size of a single tiny chip. I can't believe that.

And, Dr. Mirkin, you're going to tell me why it's true.

Just over ten years ago, the government created the National Nanotechnology Initiative to focus on this issue, and that was a very wise move. That early and sustained commitment has translated into U.S. global leadership in nanotechnology research, for the moment, and development and commercialization. So there are very significant economic incentives to maintain our lead in this field. We have had lots of leads in lots of areas, math and science and all kinds of things. But we don't have it any longer, and we don't want this to follow that path.

Others are very aggressive on their own projections for commercialization of this technology. It was about $200 billion in 2009. You're projecting a trillion dollars by 2015. That's actually just two and a half years from now, maybe a little bit more than that.

Nanotechnology has the potential to revolutionize such areas as health care, which is incredibly important to me, information technology; energy, also important; homeland security; food safety; and transportation.

At a time when Americans and American businesses are struggling financially, we've got to do whatever we can. And all of a sudden, we're presented with this enormous gift which could employ millions of people, if they were trained to so do.

Now, if Dow Chemical is telling me that they can't—because their engineers are retiring and that they can't replace them, in a chemical company, then that makes me really worry about nanotechnology and what we're actually doing about that in this era of budget cuts. And I want us to talk about that.

Germany and Japan are hot after all of this. So are China and South Korea. They're commercializing investments to take advantage of this growing nanotechnology product market.

I really look forward to hearing from you. I always say that every time I chair a hearing. But I really mean it. You're extraordinary people in your backgrounds and in the knowledge that you have.

I have to put a plug, obviously, in for West Virginia, and I can do that very easily through Dr. Diandra Leslie-Pelecky, who is here, and has a whole group of researchers all over the state of West Virginia helping her on this subject. And she leads something called the West Virginia Nanotechnology Initiative, WVNano, which started back in 2004. It was started back in 2004, and the program focus is on stimulating research in nanoscience. I couldn't be more pleased to welcome the new director with us here today.

She's an expert in the use of magnetic nanoparticles for medical diagnosis, treatment, and drug delivery. And one of the things which perks my imagination— she's also known for making science accessible to everybody and, therefore, has even written a book called "The Physics of NASCAR," which has to do with nanotechnology, I assume.

In any event, I'm really proud that you're here representing our state.

Mr. Chairman, I thank you for your more than good courtesy.

[The prepared statement of Senator Rockefeller follows:]

PREPARED STATEMENT OF HON. JOHN D. ROCKEFELLER IV, U.S. SENATOR FROM WEST VIRGINIA

I want to thank you all for being here today to discuss what some have referred to as "the next industrial revolution." We are at a place today where big advances on technology are happening at a very small level—everything from bio-technology tools to detect early stage Alzheimer's disease, to soon reducing your computer's entire memory to the size of a single tiny chip.

Just over 10 years ago, the government created a National Nanotechnology Initiative to focus on this issue. That early and sustained commitment has translated into U.S. global leadership in nanotechnology research and development and commercialization.

There are significant economic and societal incentives to maintain our lead in this field. The global market for nanotechnology-related products was more than $200 billion in 2009, and projections suggesting that it will reach $1 trillion by 2015. With this growth, comes demand for workers with nanotechnology-related skills.

Nanotechnology has the potential to revolutionize such areas as health care, information technology, energy, homeland security, food safety, and transportation.

At a time when Americans and American businesses are struggling financially, we must do whatever we can to stimulate the economy. This Committee has spent a lot of time this Congress focusing on job creation and manufacturing. I believe nanotechnology plays a key role in boosting the economy and creating jobs.

Like all science and technology efforts, however, our international competitors are catching up and increasing their investments in this area. China, South Korea, Germany, Japan and others are commercializing their investments to take advantage of the growing nanotechnology product market. If we wait too long, these countries will surpass us.

I look forward to hearing from our witnesses on the best ways to turn our nation's early research lead into successful commercialization to create businesses and jobs here in the United States.

Realizing the potential of nanotechnology, my own state of West Virginia established the West Virginia Nanotechnology Initiative—or WVNano—back in 2004. The program focuses on stimulating research in nanoscience, and I couldn't be more pleased to welcome the new director here with us today.

Dr. Diandra Leslie-Pelecky is an expert in the use of magnetic nanoparticles for medical diagnosis, treatment, and drug delivery. In her role as director of WVNano, she works with about 40 researchers throughout the state at West Virginia University, Marshall University, and West Virginia State University to advance nanoscale science, engineering, and education.

Dr. Leslie-Pelecky is also known for making science accessible everyone—including explaining physics through a book she authored titled, *The Physics of NASCAR*. As I'm sure you know, not every student is found in a classroom, and I think you will find my colleagues and I ready to learn from you today.

I'd like to thank you all again for being here today and look forward to your testimony.

Senator NELSON. My pleasure.

Senator Hutchison?

STATEMENT OF HON. KAY BAILEY HUTCHISON, U.S. SENATOR FROM TEXAS

Senator HUTCHISON. Well, thank you very much, Mr. Chairman, for recognizing Chairman Rockefeller and me. And I hope you realize that holding this hearing means we think it is a real priority for this Committee to reauthorize the National Nanotechnology Initiative.

Nanotechnology is one of the few growing sectors of the economy. And the United States must do more to take advantage of this great growth and our own leadership in this field. For example, the Nobel Laureates who discovered the buckyball molecule, which is a building block of nanotechnology, were Rice University professors Dr. Richard Smalley and Dr. Bob Curl.

And so I am very pleased that we have with us today the Provost of Rice University, Dr. George McLendon. And thank you, Mr. Chairman, for granting my request to have him come and testify, because I do feel like Texas has taken a leadership role in this field.

I hope that we can go forward and reauthorize the National Nanotechnology Initiative with the same spirit that we have had in Texas. We must share information and collaborate with the different centers of excellence to go into the many different fields of nanotechnology. And if we prioritize the consortia and the collaboration, that's how we will really keep our preeminence in this vital field.

Just as an example, Rice University houses the Consortium for Nanomaterials for Aerospace Commerce Technology which includes other universities such as the University of Texas. And it is developing nanotechnology applications to recharge personal digital assistants and to power unmanned aerial vehicles, which are increasingly used by our military. And so these are some of the outgrowths of this nanotechnology research that have come about through a consortium of engineers as well as scientists coming together to make the products with the research.

But as we are going forward on the National Nanotechnology Initiative, we've got to realize that America led because of our pro-innovation incentives. We started the R&D tax credit that has really put America in the forefront. But other countries have now adopted our successful formula, and the R&D tax credits in other countries are now stronger and better than America's. Ours is more incremental and is not permanent. So every couple of years, we have to come back and reauthorize the R&D tax credit. One of the things that we should recommend out of this committee is that we make the R&D tax credit permanent, because it has been a foundation of our innovation and has helped us so much. So I look forward to working with all of you on this.

I thank you, Senator Nelson, for making it a priority for your Subcommittee to hold this hearing so we can gain the knowledge from the researchers on the ground to know how better to utilize our resources and what the future promises.

Thank you.

Senator NELSON. Senator Boozman?

STATEMENT OF HON. JOHN BOOZMAN, U.S. SENATOR FROM ARKANSAS

Senator BOOZMAN. Thank you, Mr. Chairman, and I am very much looking forward to hearing from these witnesses and working with you on this important issue of nanotechnology research and development.

There's no doubt that advances in science and engineering are essential for ensuring America's economic growth and global competitiveness. Amongst these advances, the Federal investment in basic research in nanotechnology has been a striking success story. From its original beginnings as a niche science, nanotechnology R&D now spans across disciplines and has a burgeoning global market.

The field continues to have great potential in addressing some of the grand challenges facing our Nation in energy, defense, healthcare, water, and agriculture. Both industry and academia have acknowledged the effectiveness of the National Nanotechnology Initiative. And over time, the NNI has established a track record and reputation as a successful and cooperative organization. A great part of that success is that the NNI has leveraged the strengths of our scientific agencies, focusing primarily on the development of fundamental scientific knowledge through basic research while at the same time interfacing with industry and universities.

The NNI's effectiveness is increasingly necessary. Analysts have forecast that by 2014, products incorporating nanotechnology will rise to 15 percent of all global manufacturing, worth $2.6 trillion. All states, big and small, should be able to supply the growing market for nano-enabled products. And while nanotechnology R&D is more broadly distributed geographically than other scientific disciplines, the growth in nanotechnology R&D in EPSCoR states should be, and could be, greater.

Fortunately, my home state of Arkansas has laid the groundwork of research infrastructure to take advantage of market growth. The University of Arkansas system now has a nationally recognized Nanotechnology Center and Institute for Nanoscience and Engineering. And the university system has committed to build a regional institute for nanoscale material science and engineering in the near future.

The university system helped to develop NanoMech, whose primary products, TuffTek, which allows tools to last three times longer, and NanoGlide, which makes oil 30 to 50 times more efficient, are part of the $20 billion market Arkansas will now have access to. Furthermore, considering that Arkansas is home to major business entities, corporate, agriculture, and retail that would be excellent customers for nanotechnology businesses, it becomes clear that any state, regardless of their size, should be capable of building their innovation infrastructure to be able to conduct cutting edge nanotechnology R&D.

The President's proposed signature initiatives in solar energy, nanomanufacturing and nanoelectronics should not become bicoastal research and commercialization consortia. The very interdisciplinary nature of the nanotechnology research suggests that signature initiatives should be national collaborations involving a wide variety of research institutions. In fact, in the report on the NNI, the President's Council of Advisors on Science and Technology acknowledged the need for the NNI to improve its outreach to states, stating the need for engaging in closer and more frequent interactions with states which could provide important leverage of resources for the NNI.

As competition for leadership in nanotechnology has intensified with Brazil, Russia, India, China, and the EU all matching U.S. investments in nanotechnology research, we must align nanotechnology R&D stakeholders and use our Federal dollars efficiently and effectively. Ultimately, we all want the U.S. to continue to be a nanotechnology leader and a place where talented people engage in cutting edge research, where companies can develop products, and where graduate students can learn.

I very much look forward to hearing from the witnesses. We appreciate you being here. We appreciate the hard work and the fact that today we truly are going to hear about a success story.

Thank you. And with that, I yield back, Mr. Chairman.

Senator NELSON. It's my understanding that Senator Ayotte wants to make a comment.

Please.

STATEMENT OF HON. KELLY AYOTTE, U.S. SENATOR FROM NEW HAMPSHIRE

Senator AYOTTE. Thank you Mr. Chairman for calling this hearing. In my state of New Hampshire, we are fortunate to have two companies doing innovative work in the nanotechnology field. Nanocomp Technologies in Concord is the nation's leading manufacturers of advanced carbon nanotube materials. They are leveraging Federal and private dollars to build the Nation's leading center for the manufacturing of 21st century products.

In the next 2 years, the company expects its workforce to increase by a factor of seven. For the past 14 years, Swanzey, New Hampshire has been the home of Moore Nanotech, which has quickly become a leader in state-of-the-art, ultra-precision manufacturing systems and advanced optics.

With so much innovation in my state and across the country, I'm excited about this hearing today. I want to drill down on this rapidly growing field and have a discussion about how our Federal research dollars are being invested, so that we can help continue to foster a positive climate to create jobs in this exciting field. I also want to align myself with the comments of Ranking Member Hutchison regarding the R&D tax credit. I firmly believe we should make them permanent and would further encourage investment not only in this field but in other fields of manufacturing across this country.

So thank you for being here today. I look forward to hearing the witnesses.

Senator NELSON. Senator Blunt?

STATEMENT OF HON. ROY BLUNT, U.S. SENATOR FROM MISSOURI

Senator BLUNT. Thank you, Chairman. I'm glad to be here. I'm looking forward to the witnesses.

We do have a significant nanotech effort in Missouri at Missouri State University in Springfield, where I live, and, in fact, at the Jordan Valley Innovation Center, lots of nanotech work focused on seeing what we can do to harden our satellites and other things that may be able to replace big equipment that would be really hard to replace, square inch for square inch, with equipment that does the same job that's much more resistant to electro pulse, magnetic pulse attacks and things like that.

This is an important hearing, and I'm glad to be here to listen and learn. And thanks for holding it.

Senator NELSON. Thank you, Senators. And I've reserved my comments, mainly to introduce our very distinguished panel.

But this is quite extraordinary. We're talking about gold nanoparticles that can detect prostate cancer. We're talking about "buckypaper" that can end up being 250 times the strength of steel and 10 times lighter. We're talking about carbon nanotubes put directly on a metal surface that results in much longer life batteries and powerful energy storage devices.

And so what we want to do is examine—now that we have this interagency initiative called the National Nanotechnology Initiative—what we need to do to keep this going so that the genius of America can blossom to continue this research, and then so the genius of America can be encouraged to take that research and development and get it out into the commercial sector. And we want to look at things like international standards, understanding that the absence of standards could also be a hindrance to commercialization, because if venture capitalists don't have something that they consider to be certain, then that could delay the commercialization of these products.

This is a distinguished panel. I'll take the parochial privilege of pointing out Dr. Tom O'Neal from my home area of central Florida, from our university there, that heads up the business incubation program, and they're just doing great things there.

We also have the jurisdiction under this subcommittee of America's space program. We know that the space program is transitioning, and we're going from one set of rockets that have been so reliable for us called the Space Shuttle for 30 years, not without tragedy. Now we're going to two new different lines of rockets, one to and from the Space Station, and another, the big rocket. But in the process, we're going to be more efficient, and what we need to do is diversify.

This subject area of nanotechnology is another opportunity, Dr. O'Neal, of taking your expertise in your incubator and expanding a lot of the role in and around the Kennedy Space Center with the extraordinary talent that is available to put them to use on this.

Dr. Chad Mirkin is the Director of the International Institute for Nanotechnology at Northwestern and a member of the President's Council of Advisors on Science and Technology. He's the founder of three nanotechnology companies that are commercializing the fruits of his research.

Dr. Charles Romine is the Acting Associate Director for Laboratory Programs and the Principal Deputy in the Office of the Director of the National Institute of Standards and Technology.

And we want you to talk about those standards, Dr. Romine.

And he's going to discuss the work of the NIST Center for Nanoscale Science and Technology and NIST's broader role. And then Dr. Diandra Leslie-Pelecky who Senator Rockefeller has already introduced—she is the Director of the West Virginia Nanotechnology Initiative and a professor of physics.

We're looking forward to your testimony.

Dr. George McLendon is the Hughes Provost and Professor of Chemistry at Rice. His testimony will discuss how nanotechnology can help address our nation's challenges in energy independence—does that sound familiar?—healthcare—does that sound familiar?—economic growth—does that sound especially sound familiar?—and, of course, keeping America competitive in a changing global marketplace.

So we welcome all of you here. I thank the chairman and the ranking member for their presence. And shall we just start from that side of the table and just go right on down?

Instead of just sitting there and reading a speech, as much as you can, talk it. And then keep it about 5 minutes so that we can really get into some good give-and-take.

Dr. Mirkin?

STATEMENT OF CHAD A. MIRKIN, DIRECTOR, NORTHWESTERN UNIVERSITY INTERNATIONAL INSTITUTE FOR NANOTECHNOLOGY, RATHMANN PROFESSOR OF CHEMISTRY, PROFESSOR OF MEDICINE, PROFESSOR OF MATERIALS SCIENCE AND ENGINEERING, PROFESSOR OF BIOMEDICAL ENGINEERING, PROFESSOR OF CHEMICAL AND BIOLOGICAL ENGINEERING

Dr. MIRKIN. Thank you. Chairman Nelson, Ranking Member Boozman, and members of the Committee, thanks for the privilege and honor to provide testimony today regarding the NNI.

As Chairman Nelson said, I come from Northwestern University, where I run one of the largest institutes for nanotechnology in the country. We have hundreds of students and post-docs working in this area and contributing to the development of the field.

In addition, I have been involved in two of the largest policy reports that evaluated the NNI and also the U.S.'s position in the world in nanotechnology. We just finished a very large study where we traveled all over the world—to four different countries, where we brought together 35 different countries, or representatives from 35 different countries, to tell us about what they've been doing, some of the strategies they've been taking, and we learned a lot from that. And we learned a lot about where we stand compared to them and how far we have to go and some of the great things that are happening not only in the U.S. but also in the rest of the world.

I've also been involved in starting three companies, one of which has gone public—it's traded on the NASDAQ—called NanoSphere. The other two are private companies, AuraSense and NanoInk. They employ hundreds of people and, hopefully, 1 day soon, thousands of people. And they represent, I think, some of the first real dividends from the early investments in the NNI, and I'm very proud to be a part of them.

Consequently, I have a pretty broad view of the field and an understanding of some of the issues facing it. If we step back and look at what's happened over the last decade, I don't think anybody would argue that the first 10 years of the NNI has been an overwhelming success. The visibility and societal importance of nanoscale science and engineering and technology have been confirmed, while extreme predictions—and I'm sure you remember in the early days, they were extreme, both pro and con—they've receded. And so we've gotten down to the serious business of real science, finding out what we can really do with this field and making real advances in the development of important technologies.

The field has been recognized as revolutionary and comparable with the introduction of the biotechnology and digital information revolutions. And the U.S. is positioned to make extraordinary strides over the next 10 years. But, as I said, it's clear the rest of the world now understands the importance of the field, and many countries are building efforts that rival what has been established by the NNI. This includes dozens of institutes throughout Asia, the Mideast, and Europe.

If the United States does not act now and aggressively pursue development of nanoscience and nanotechnology, we will lose our position as a global leader in this transformative field. Moreover, and maybe more importantly, we will lose the opportunities it can afford us to build our economy and new manufacturing base.

So why is there so much interest in nanotechnology? The reason is simple and we've heard allusions to it: it really has the potential to transform almost every aspect of our lives by providing rapid routes to addressing some of the most pressing problems in healthcare, electronics, energy, and the environment, just to name a few. Anywhere where materials are important, nanotechnology is going to play a big role.

Take, for example, a technology like gene regulation. A few decades ago, this technology held the promise of treating and potentially curing some of the most debilitating diseases, including cardiovascular disease, neurological disorders like Alzheimer's disease, and many forms of cancer. As scientists and doctors, we have learned that it is not an easy technology to implement and requires materials that can deliver the genetic drugs effectively and without toxicity.

The good news is that researchers are now discovering all sorts of nanomaterials through NNI funded efforts, like the National Cancer Institute's Centers of Cancer Nanotechnology Excellence, that show extraordinary promise for the effective use of such therapies in humans. I'm convinced that nanotechnology will play a lead role in finding the cures to many of these diseases and not just in the long term—but in the short term. I think there are real major inroads that have been made in the last decade that will contribute to that goal.

On the diagnostic side, meaning medical diagnostics, the NNI funded efforts like the NSF's Science and Engineering Centers have discovered powerful new ways of detecting and tracking disease markers at very early stages, stages that cannot be detected with conventional tools and when therapeutics can be more effective. Several of these technologies are FDA cleared and commercialized. And after only a decade, it is just simply remarkable to see what scientists would call basic science, the early stages of science, already transitioned into meaningful commercial successes.

That is an incredible feat, to do that in only 10 years. If you follow technological development and commercialization, it usually takes much longer. Innovation and the related job creation will likely continue at an accelerated rate if we maintain a well coordinated and implemented NNI.

What are the challenges going forward? In my opinion, we should not be discussing the renewal of the NNI but rather its expansion. That's a tough but critical decision in troubled economic times. The United States simply cannot afford to lose its competitive edge in nanotechnology over the next decade.

There are three primary areas which need to be addressed over the next decade, and they pertain to management of the NNI, which is a big beast to navigate and steer, and to do it effectively; developing strategies for future investment in both research and education and training—that's really the core; and then dealing with environment, health, and safety (EHS) issues potentially posed by nanotechnology. I'm going to only share my recommendations with respect to one of these. We have other experts that are going to talk about the EHS issues, and I've testified in my written testimony on some of the management issues.

With regard to strategies for future investments, the NNI should maintain a parallel focus on basic research, the discovery part of research, and its translation into commercializable products and processes. You can't have the latter without the former. So it would be crazy to not invest heavily in basic research while we begin to translate the early fruits of that basic research into commercializable technologies that can lead to companies that will create jobs and build our economy.

With a budget planning process coordinated by OSTP, each agency should continuously reevaluate its NNI balance of investments among the program component areas. There are several program component areas if you look at the reports. Each area should enhance its focus on commercialization and—this is key—double its investment in nanomanufacturing over the next 5 years, while maintaining the current level of investment in basic research. So, again, we harvest what we initially planted a decade ago.

The NNI should have a focus on signature initiatives in areas such as nanomedicine, advanced nanomanufacturing, nanoelectronics and photonics, nanomaterials for energy applications, and environmental monitoring and remediation. Each signature initiative's lead agency should develop coordinated milestones, promote strong educational components, and create public-private partnerships to leverage the outcomes of the initiatives.

The opportunities in this field are immense, but we need a way to identify and coordinate national centers of excellence to act as international hubs to attract and keep the best and the brightest in the field and train the next generation of workers and leaders in nanomanufacturing in the U.S. That's central here, taking advantage of the whole pool, in this case.

In conclusion, advances in nanotechnology will continue to play a critical part on the world economic stage. And it is imperative that the U.S. continue to support, strengthen, and expand the NNI in order to maintain its competitive edge.

I thank you for your time, attention, and service to the country, and I'm happy to answer any questions that you may have.

The prepared statement of Dr. Mirkin follows:]

PREPARED STATEMENT OF CHAD A. MIRKIN, DIRECTOR, NORTHWESTERN UNIVERSITY INTERNATIONAL INSTITUTE FOR NANOTECHNOLOGY, RATHMANN PROFESSOR OF CHEMISTRY, PROFESSOR OF MEDICINE, PROFESSOR OF MATERIALS SCIENCE AND ENGINEERING, PROFESSOR OF BIOMEDICAL ENGINEERING, PROFESSOR OF CHEMICAL AND BIOLOGICAL ENGINEERING

Chairman Nelson, Ranking Member Boozman, and Members of the Committee, Thank you for the privilege and honor to provide testimony today regarding the National Nanotechnology Initiative (NNI). This testimony provides my personal perspective on the issue that is the subject of this hearing, and does not necessarily reflect that of any organizations with which I affiliated.

I am Chad Mirkin, a Professor at Northwestern University and Director of the Northwestern University International Institute for Nanotechnology, one of the largest university nanotechnology centers in the world. I also am a member of the President's Council of Advisors on Science and Technology (PCAST) and contributed to their report titled, "*Report to the President and Congress on the Third Assessment of the National Nanotechnology Initiative.*" In addition, I served as a co-chair on the science policy report committee, coordinated by the World Technology Evaluation Center, which produced "*Nanotechnology Research Directions for Societal Needs in*

2020," an analysis of world accomplishments in nanotechnology during the first ten years of the NNI and an assessment of the prospects for the next ten years. This report had input from leading experts from academia, industry, and government from over 35 countries in forums held in four different countries last year. In addition, I have started three nanotech companies, Nanosphere, NanoInk, and AuraSense, which have commercialized NNI-sponsored university-based inventions, generated hundreds of new jobs, and begun to build a new economic and manufacturing base for the Nation. Consequently, I have a fairly broad view of the field and an understanding of some of the issues facing the United States as it tries to maintain a leadership position within it.

The first ten years of the NNI have been an overwhelming success. The visibility and societal importance of nanoscale science, engineering, and technology have been confirmed, while extreme predictions, both pro and con, have receded. The field has been recognized as revolutionary and comparable to the introduction of the biotechnology and digital information revolutions. The worldwide market for products incorporating nanotechnology is significant and reached about a quarter of a trillion dollars in 2009. This is just the "tip of the iceberg", and the U.S. is positioned to make extraordinary strides over the next ten years. However, the rest of the world now understands the importance of this field, and many countries are building efforts that rival what has been established by the NNI. This includes dozens of institutes throughout China, Japan, Singapore, Taiwan, Saudi Arabia, and many countries in Europe, including Germany, Switzerland, and Great Britain. If the United States does not act now and aggressively pursue the development of nanoscience and nanotechnology, we will lose our position as the global leader in this transformative field; moreover, we will lose the opportunities it can afford us to build our economy and new manufacturing base.

Why is there so much interest in nanotechnology? The reason is simple; it has the potential to transform almost every aspect of our lives by providing rapid routes to addressing some of the most pressing problems in health care, electronics, energy, and the environment. One of the lessons learned over the first ten years is that every material, when miniaturized, has new properties, and many of these properties can be used to create applications and technologies that solve these problems.

Take for example, a technology like gene-regulation—a few decades ago, this technology held the promise of treating and potentially curing some of the most debilitating diseases, including cardiovascular disease, neurological disorders like Alzheimer's disease, and many forms of cancer. As scientists and doctors, we have learned that it is not an easy technology to implement and requires materials that can deliver the genetic drugs effectively and without toxicity. The fastest way to new materials is through the miniaturization of existing materials (a tenet of nanotechnology). Researchers are now discovering all sorts of nanomaterials (through NNI-funded efforts like the National Cancer Institute's Centers of Cancer Nanotechnology Excellence) that show extraordinary promise for the effective use of such therapies in humans. I am convinced that nanotechnology will play a lead role in finding cures for these diseases.

On the diagnostic side, NNI-funded efforts like the National Science Foundation's Nanoscale Science and Engineering Centers have discovered powerful new ways of detecting and tracking disease markers at very early stages—stages that cannot be detected with conventional tools and when therapeutics can be more effective. They have created ways of differentiating patient populations to determine which ones will respond to a given therapeutic and which ones will not. This not only improves patient care but also substantially lowers the cost of healthcare, since many costly therapeutics are now often broadly (and needlessly) distributed to the American population, when their effectiveness is in question for a significant portion of it.

In the area of energy, we need new advances in solar energy technologies, batteries, and biofuels. Meaningful advances in these areas have been hampered over the last decade because existing materials do not offer the properties required for a given application. Again, nanotechnology is leading the way to solving these problems. New plants are being built and jobs are being created. Companies like A123 have used nanotechnological approaches to create powerful new batteries that are being built in Michigan and will go into some of the current and future lines of electric cars and commercial vehicles. After only a decade, it is simply remarkable to see basic science already transition into meaningful commercial successes. Innovation and the related job creation will likely continue at an accelerated rate if we maintain a well-coordinated, and implemented NNI.

What are the challenges going forward? Based upon my personal observations and the Committee that wrote the world overview report, we should not be discussing the *renewal* of the NNI but rather its *expansion*—a tough but critical decision in troubled economic times. The United States cannot afford to lose its competitive edge in nanotechnology over the next decade, and an expanded, well-coordinated and targeted NNI is the only effective way to accomplish this objective.

There are three primary areas, which need to be addressed, including:

1. Strengthening the NNI management structure,
2. Developing strategies for future investment in both research and education/training, and
3. Dealing with environment, health, and safety (EHS) issues potentially posed by nanotechnology.

I would like to share with you my recommendations in two of these three areas. I will not focus on EHS since we have other experts providing testimony on this topic.

In the management area, the National Nanotechnology Coordination Office (or NNCO) should broaden its impact and efficacy and improve its ability to coordinate and develop NNI programs and policies related to those programs. The OSTP should facilitate these improvements by taking the following actions:

- First, require each agency in the NNI to have senior representatives with decision-making authority participate in coordination activities of the NNI.
- Second, strengthen the NNCO to enhance its ability to act as the coordinating entity for the NNI.
- Third, mandate that the NNCO develop metrics for nanotechnology-specific program outputs and that it work with the Bureau of Economic Analysis to develop meaningful metrics and to collect data on the economic impacts of the NNI. PCAST estimated that 0.3 percent of NNI funding should be dedicated to the NNCO in order to ensure the appropriate staffing and budget to effectively develop, monitor, and assess NNI programs.

With regard to strategies for future investments, the NNI should maintain a parallel focus on basic research and its translation into commercializable products and processes. We cannot have the latter without the former.

With a budget planning process coordinated by OSTP, each agency would continually re-evaluate its NNI balance of investments among the Program Component Areas. Each area should enhance its focus on commercialization and double its investment in nanomanufacturing over the next five years, while maintaining the current level of investment in basic research.

The NNI should have a focus on *signature* initiatives such as the development of nanomaterials to enable the development of nanomedicine, advanced nanomanufacturing, and nanomaterials for environmental monitoring and remediation. Each Signature Initiative's lead agency should develop coordinated milestones, promote strong educational components, and create public-private partnerships to leverage the outcomes of the Initiatives. Each lead agency also should develop strategies for monitoring, evaluating, and disseminating outcomes. The opportunities in this field are immense, but we need a way to identify and coordinate *national centers of excellence* that act as international hubs to attract the best and the brightest in the field, and train the next generation of workers and leaders in nanomanufacturing.

In the area of *education,* the agencies of the NNI should continue making investments in innovative and effective education, and the NNCO should consider commissioning a comprehensive evaluation of the outcomes of the overall investment in NNI education. As products are being commercialized and nanotech industries are being built, we must have a parallel effort in student training and education. These are the folks who will become the workers and leaders in these new companies. I just visited one of our companies, NanoInk, and they are producing products that are very important to the pharmaceutical industry for high throughput drug screening applications. Pharmaceutical companies want to use these tools in-house immediately, but they do not have a competent workforce available to handle them. Universities need to train a new workforce and retrain an old one, so that these positions can be filled with highly qualified individuals at the pace of the nanotechnology industry development. The NNI should play an important role in making this happen for the field at large.

In conclusion, I strongly believe that advances in nanotechnology will continue to play a critical part on the world economic stage and that it is imperative that the U.S. continue to support, strengthen, and expand the NNI in order to maintain its competitive edge. I thank you for your time, attention, and service to the country, and am happy to answer any questions that you may have.

Senator NELSON. Thank you. Dr. Romine?

STATEMENT OF DR. CHARLES H. ROMINE, ACTING ASSOCIATE DIRECTOR, LABORATORY PROGRAMS, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, U.S. DEPARTMENT OF COMMERCE

Dr. ROMINE. Chairman Nelson, Ranking Member Boozman, and members of the Subcommittee, thanks for the opportunity to appear before you today to testify about NIST's role in nanotechnology and nanomanufacturing.

The administration has aggressively worked to promote the growth of basic and applied nanotechnology. In February 2011, the National Science and Technology Council released the National Nanotechnology Initiative Strategic Plan. NIST has a key role in this initiative. As the benefits of the NNI continue to accrue, the role of NIST and the breadth of its innovation-related programs will become even more important in ensuring that the end results match the promise in terms of new jobs and revolutionary technologies that benefit the Nation's economy and the American people.

NIST is uniquely equipped to develop the improvements in measurements and standards that are essential for the adoption of advanced technologies needed by U.S. manufacturers to compete more effectively in the global technology-intensive products market. The nanotechnology-related research conducted in NIST's laboratories and user facilities develops measurements, standards, and data crucial to a wide range of industries and Federal agencies.

NIST has a history of serving the needs of manufacturing sectors. One high-profile area of current support is in the measurements of a nanoscale material, graphene. Graphene, the subject of the 2010 Nobel Prize in Physics, is one of the most promising materials for the next generation of semiconductor devices needed to make electronic devices ever smaller and faster.

Working closely with academic and industrial partners, NIST has recently completed the most advanced ultra-low temperature scanning probe microscope in the world, allowing an international team of researchers to measure key properties of graphene. As a result of NIST research, multiple components of this microscope are now products being sold by U.S. companies.

NIST has a history of working with industry through public-private partnerships and other consortia. For example, NIST's partnership with the Nanoelectronics Research Initiative, the NRI, a consortium that brings together the semiconductor electronics industry, government agencies, and universities, has leveraged a modest NIST investment, $2.75 million per year, by $5 million per year from industry partners and $15 million per year from states to support projects at 30 universities to work in 4 regional centers. The partnership has attracted state and private funding to support business development and commercialization. NIST–NRI interactions are currently supporting over 100 graduate students and have produced scientific publications as well as patented technologies.

The President's 2012 budget request outlines nanomanufacturing research priorities at NIST that include developing measurement capabilities for large-scale nanomanufacturing and the manufacture of cost-competitive solar technologies that incorporate nanoscale structures. As part of the Materials Genome Initiative announced recently by the President, NIST will work together with other agencies to develop the design tools needed to accelerate materials development for industry.

NIST will also continue close and targeted interaction with other agencies in NNI's signature initiative, Sustainable Manufacturing. In February 2011, NIST hosted a workshop in support of this initiative on the topic of technical challenges to the commercial development of high-performance carbon-based nanomaterials.

Nanotechnology standards foster greater industry and consumer confidence, resulting in accelerated deployment of new products. NIST actively leads the development of international nanotechnology standards and guidelines. An understanding of the environmental, health, and safety of nanomaterials and nanotechnology-based products, known as NanoEHS, is critical for the responsible development and oversight of nanotechnology. NIST research in NanoEHS provides the underpinning science and measurement needed for a science-based approach to risk management. In Fiscal Year 2012, NIST plans to further develop validated measurement methods, tools, standards, and protocols that help to enhance understanding of the safety of nanomaterials.

NIST's Center for Nanoscale Science and Technology is the nation's only nanotechnology user facility established with a focus on commerce. An important goal of the NIST's CNST is to reduce measurement barriers to innovation by providing access to world-class nanoscale measurement and fabrication methods and technologies. Industry access to these resources will help accelerate nanotechnology transfer to the marketplace. The number of commercial users has roughly doubled on an annual basis over the past three years.

The nanofabrication facility at the CNST is a world-class shared resource, home to major commercial measurement and processing tools. The NanoFab has streamlined the process to obtain access to the facility. In Fiscal Year 2010, the CNST hosted nearly a thousand researchers, including a small company whose entrepreneur needed the tools to turn an invention into a working prototype, to a large company, using the CNST resources to develop future supercomputing technologies.

The President's 2012 budget request includes $5.18 million to replace and update the equipment in the CNST so that it can continue to meet the needs of growing numbers of industry customers and other stakeholders.

In conclusion, the breadth of the programmatic activities uniquely positions NIST to provide the underpinnings that will foster the transfer of new technologies into products for commercial and public benefit.

Thank you for the opportunity to discuss NIST's nanomanufacturing activities, and I'm happy to answer any questions you may have.

[The prepared statement of Dr. Romine follows:]

PREPARED STATEMENT OF DR. CHARLES H. ROMINE, ACTING ASSOCIATE DIRECTOR, LABORATORY PROGRAMS, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, U.S. DEPARTMENT OF COMMERCE

Introduction

Chairman Nelson, Ranking Member Boozman, and members of the Subcommittee, thank you for the opportunity to appear before you today to testify about the Department of Commerce's National Institute of Standards and Technology's (NIST) role in nanotechnology and nanomanufacturing.

The Administration has aggressively worked to promote the growth of basic and applied nanotechnology. In February 2011, the National Science and Technology Council (NSTC) released the National Nanotechnology Initiative (NNI) Strategic Plan. The goals of this plan are to advance a world-class nanotechnology research and development program, move nanotechnology discoveries from the laboratory into new products for commercial and public benefit, encourage more students and teachers to become involved in nanotechnology education, create a skilled workforce and the supporting infrastructure and tools to advance nanotechnology and to support the responsible development of nanotechnology.

NIST has a key role in this initiative, consistent with its mission to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.

Specifically, in the area of nanotechnology, NIST has a number of existing and planned programs that support the development, adoption, manufacture, commercialization, and use of nanotechnology-based innovations and products. Furthermore, the NIST efforts in the area of nanotechnology have been a key element of the NNI, of which NIST is one of 25 participating agencies. As the benefits of the NNI continue to accrue, the role of NIST and breadth of its innovation-related programs will become even more important in ensuring that the end results match the promise in terms of new jobs and revolutionary technologies that benefit the Nation's economy and the American people.

Providing Industry with the Measurements and Technology to Support Innovation

NIST is uniquely equipped to develop the improvements in measurements and standards that are essential for the adoption of advanced technologies needed by U.S. manufacturers to compete more effectively in the global technology-intensive products market. The nanotechnology-related research conducted in NIST's laboratories and user facilities develops measurements, standards, and data crucial to a wide range of industries and Federal agencies.

NIST has a history of serving the needs of manufacturing sectors. NIST's work with the semiconductor electronics industry provides one compelling example. The 2007 "Economic Impact of Measurement in the Semiconductor Industry" report estimated that the $12 billion spent on advancing measurement capabilities during the decade beginning in 1996 will have saved that sector more than $51 billion in scrap and rework costs by 2011—a net benefit of $39 billion [1].

One high-profile area of current support to this industry is in measurements of the nanoscale material graphene. Graphene, the subject of the 2010 Nobel Prize in Physics, is one of the most promising materials for the next generation of semiconductor devices needed to make electronic devices ever smaller and faster. Working closely with academic and industrial partners, NIST has recently completed the most advanced ultra-low temperature scanning probe microscope in the world, allowing an international team of researchers to measure key properties of graphene with unprecedented resolution. This unique instrument includes multiple components developed jointly with NIST that are now products being sold by U.S. companies.

Measurements and modeling by NIST researchers are helping electronics industry manufacturers to develop improved and new processes for the nanofabrication of electronics components like microprocessors and memory chips. For example, following on a semiconductor industry roadmap determination that copper interconnects would be needed to manufacture smaller and faster devices, NIST researchers identified critical technical barriers and developed a new predictive modeling tool. The model helped lower the cost of R&D and reduced the time to production, resulting in an estimated NIST benefit-to-cost ratio of 5.8 and a net benefit for industry of over $9 million, according to a NIST 2008 economic analysis.[2]

[1] *http://www.nist.gov/director/planning/upload/report07–2.pdf*
[2] *http://www.nist.gov/director/planning/upload/report08–1.pdf*

NIST employs a number of tools to enable technology and knowledge transfer from NIST to promote U.S. competitiveness, including cooperative R&D agreements, facility use agreements, and intellectual property tools such as NIST inventions, patents, and licenses. NIST is home to a significant number of Associates and Guest Researchers, including summer undergraduate students and postdoctoral researchers, who develop technical expertise at NIST before continuing in their scientific careers.

NIST has a history of working with industry through public-private partnerships and other consortia. These groups help drive manufacturing research priorities and leverage investments. For example, NIST's partnership with the Nanoelectronics Research Initiative (NRI), a consortium that brings together the semiconductor electronics industry, government agencies, and universities, has leveraged a modest NIST investment ($2.75 million per year) by $5 million per year from industry partners and $15 million per year from states to support projects at 30 universities to work in 4 regional centers. The partnership has attracted $110 million over 5 years in state and private funding to support business development and commercialization. NIST/NRI interactions are currently supporting 111 graduate students and have produced 159 scientific publications as well as patented technologies (3 issued and 2 filed). NIST is also engaged with industry consortia in the areas of flexible electronics and neutron-based measurements for the manufacture of soft materials such as chemicals, petroleum products, and pharmaceuticals.

The President's 2012 budget request outlines research priorities at NIST that are specific to needs in nanomanufacturing. This includes developing the measurement knowledge and capabilities to enable cost-effective in-line measurement techniques for closed-loop process control, thereby overcoming a major obstacle to large-scale nanomanufacturing. In addition, NIST researchers are planning to develop and demonstrate measurement capabilities required to overcome barriers to the manufacture of cost-competitive third-generation solar technologies, which incorporate molecular films, quantum dots, nanoscale crystals, and other nanoscale structures. As part of the Materials Genome Initiative announced recently by the President, NIST will work together with other agencies to develop the computational and design tools needed to accelerate materials development for industry.

Also in Fiscal Year 2012, NIST will continue close and targeted interaction with other agencies in the three NNI Nanotechnology Signature Initiatives: Sustainable Nanomanufacturing, Nanotechnology for Solar Energy Collection and Conversion, and Nanoelectronics for 2020 and Beyond. In February 2011, NIST organized and hosted a workshop in support of the Sustainable Nanomanufacturing initiative, on the topic of carbon nanostructured materials. This event brought together stakeholders from industry, academia, and government to identify the technical challenges to the commercial development of high-performance, carbon-based nanomaterials, and discuss potential pathways to establishing a public-private consortium to address these challenges.

Providing the Scientific Basis to Support the Safe and Responsible Deployment of Nanotechnology

Nanotechnology standards foster greater industry and consumer confidence, resulting in accelerated deployment of new products. NIST staff members actively lead the development of international nanotechnology standards and guidelines conducted through international fora and coordinated with other agencies through the NSTC. Altogether these activities create favorable conditions for the responsible transfer of nanotechnologies into products for commercial and public benefit.

An understanding of the environmental, health and safety aspects of nanomaterials and nanotechnology-based products (NanoEHS) is critical for the responsible development and oversight of nanotechnology. NIST research in NanoEHS provides the underpinning science and measurement needed for a science-based approach to risk management. Policymakers and regulators can use the information to ensure that the U.S. is supporting innovation, encouraging new technologies, and not creating trade barriers.

NIST's NanoEHS activities provide information and data for research institutions, regulatory agencies, the public, and industry. NIST activities include the development of reference materials for widely produced nanomaterials used in a broad range of applications, including electronics, personal care products, and construction materials. Examples include the first gold nanoparticle standard reference material; providing technical support and help to lead development of documentary standards that enable consistent and reproducible measurements of nanomaterial properties; and developing instruments and transferable methods to measure key properties of nanomaterials as needed by industry and regulatory agencies to make sound, science-based risk assessments.

NIST's Fiscal Year 2012 request will increase NIST's ability to further develop validated measurement methods, tools, standards, and protocols that help to enhance understanding of the safety of nanomaterials and their mechanisms of interaction with the environment and humans with a focus on nanomaterials of greatest concern based on such factors as production volume, widespread use in products, and the potential for hazard or likelihood of exposure.

NIST will continue to coordinate its NanoEHS program with other Federal agencies' activities through the nanotechnology subcommittee of the NSTC, using the 2011 *NNI Environmental, Health and Safety Research Strategy*[3] as a framing document.

Providing Industry and Academia Access to Advanced Nanofabrication Facilities

NIST's Center for Nanoscale Science and Technology (CNST), is the Nation's only nanotechnology user facility established with a focus on commerce. An important goal of the NIST CNST is to reduce measurement barriers to innovation, by providing industry, academia, and other government agencies with access to world-class nanoscale measurement and fabrication methods and technology. NIST has undertaken a sustained effort to reach out to industrial researchers whose access to these resources will help accelerate nanotechnology transfer to the marketplace; the number of industry users has roughly doubled on an annual basis since Fiscal Year 2008.

The NIST CNST mission is guided by an understanding that rapid commercial development of nanotechnology—in particular, the speed with which industry can bring a specific new nanotechnology from discovery to production—depends critically on the availability and efficacy of applicable metrology tools and processes at each stage of the transition. Developing these tools and processes will have an immediate and significant impact on the commercial viability of nanotechnologies in a diverse array of fields, such as electronics, computation, information storage, medical diagnostics and therapeutics, and national security and defense.

The Nanofabrication facility (NanoFab) at the NIST CNST is a world-class, 60,000 square foot shared resource for nanofabrication and measurement—with over 19,000 square feet of cleanroom laboratory space and over 90 major commercial measurement and processing tools. To meet specific needs of industry, the NIST NanoFab has created a rapid, easy process for users to obtain equitable access to the facility, whether or not they are doing proprietary research. Research at the NIST NanoFab can be done by individual users or alongside a technical expert from the NIST NanoFab staff, imparting flexibility to industry users depending on the nature of the research and individual competencies.

In the few years since its inception, the NIST CNST has become a major national resource for nanoscale science and the development of nanotechnology. Having now completed its initial ramp up in staff, equipment, facilities, and processes, the NIST CNST is continuing to expand on its strategic relationships and collaborations with industrial and academic partners.

In Fiscal Year 2010 the NIST CNST hosted nearly 1,000 researchers from companies, government institutions, and universities from across 39 states and the District of Columbia; during the same period NIST NanoFab tool use increased by 90 percent. Corporate researchers ranged from a small company, needing the tools to turn an invention into a working prototype, to a large company, using the NIST CNST resources to reduce the development cycle time of future supercomputer technologies.

The President's Fiscal Year 2012 Budget Request includes $5.18 million for the recapitalization of the NIST CNST. This funding is needed to replace and update the equipment and instrumentation in the NIST CNST so that it can continue to meet the nanoscale measurement and fabrication needs of growing numbers of industry customers and other stakeholders.

Accelerating the Development of Transformational Technologies

NIST external partnership programs provide a coordinated set of activities to meet manufacturing challenges. The Technology Innovation Program (TIP) funds small companies and joint ventures comprised of businesses, institutions of higher education and other organizations such as national laboratories or nonprofit research institutes to support high-risk transformational R&D. The 2010 TIP competition focused on manufacturing technologies, resulting in awards to small companies and joint ventures producing a range of nanotechnology-enabled products in areas including flexible liquid crystal displays, organic photovoltaics, and lithium-ion batteries.

[3] Draft publicly available; awaiting final clearance.

In its Fiscal Year 2012 budget request, the Administration proposed the creation of the Advanced Manufacturing Technology Consortia Program (AMTech) at NIST. AMTech was also included in the President's recent Advanced Manufacturing Partnership (AMP) initiative that is aimed at strengthening support for U.S. manufacturing. The AMTech program will address a critical need for early stage technology development by providing incentives for the formation of, and providing resources to, industry-led consortia that will support precompetitive R&D, thereby enabling technology development and creating the infrastructure necessary for more efficient transfer of technology. AMTech builds on lessons learned from NIST's partnership with the NRI, which I mentioned previously. In addition, although similar to TIP in the pursuit of high-risk, high-reward research, the AMTech program brings together multiple players in the innovation cycle, under a single consortium, to accelerate the pace of innovation in a particular industry sector. This strategy has the potential to drive economic growth, enhance competitiveness and spur the creation of jobs in high-value sectors of the U.S. economy.

Finally, the nationwide network of Hollings Manufacturing Extension Partnership (MEP) centers helps small and medium manufacturers strengthen their competitive positions. The MEP system does this by accelerating the adoption of technological innovations, facilitating the adoption of environmentally sustainable business practices, providing training and assistance to increase exports, promoting renewable energy initiatives, fostering market diversification, and connecting domestic suppliers to manufacturers. All of these services are to assist manufacturers in successfully competing over the long term in today's complex global manufacturing environment.

Conclusion

In conclusion, there is a breadth of programmatic activities at NIST covering scientific discovery, measurement science, standards development, and technology transfer relating to nanomanufacturing. NIST programs span all stages of the innovation ecosystem that enable the development and implementation of advanced technologies. These programs will help U.S. industry become more efficient and competitive. NIST is uniquely positioned to provide the scientific underpinnings for these emerging technologies that will foster the transfer of new technologies into products for commercial and public benefit.

I thank the Subcommittee for allowing me to discuss NIST's nanomanufacturing activities and I welcome the opportunity to answer any questions you may have.

Dr. Charles (Chuck) H. Romine

Dr. Charles (Chuck) H. Romine serves as the Acting Associate Director for NIST Laboratory Programs. He is responsible for oversight and direction of NIST's six laboratory programs and is the principal deputy to the NIST Director. The position of Associate Director for Laboratory Programs was created in October 2010 as part of the first major realignment of NIST programs in 20 years.

NIST's six laboratories include the Physical Measurement Laboratory, Material Measurement Laboratory, Engineering Laboratory, Information Technology Laboratory, the Center for Nanoscale Science and Technology, and the NIST Center for Neutron Research. The NIST Laboratories collaborate with U.S. industry and universities to conduct measurement, standards, and technology research that advances the Nation's R&D infrastructure. The overarching goal of the NIST laboratory programs is to accelerate U.S. innovation, which is a major driver of economic growth and job creation.

Prior to his appointment as the Acting Associate Director for Laboratory Programs, Romine served as the Senior Policy Advisor to the NIST Director and as the Associate Director for Program Implementation within the NIST Information Technology Laboratory. He joined NIST in 2009 after serving for 5 years in the White House Office of Science and Technology Policy as the Senior Policy Analyst responsible for providing expert technical and policy advice to the President's Science Advisor for all areas related to information technology.

Romine began his career in 1986 with the Department of Energy after receiving a Ph.D. in applied mathematics and a B.A. in mathematics, both from the University of Virginia. He spent 15 years conducting research at Oak Ridge National Laboratory on advanced algorithms for supercomputers and 4 years at the Department of Energy Office of Science as program manager for the Office of Advanced Scientific Computing Research.

Senator NELSON. Thank you.

Dr. Leslie-Pelecky?

STATEMENT OF DIANDRA L. LESLIE-PELECKY, PH.D., DIRECTOR, WEST VIRGINIA NANO INITIATIVE; PROFESSOR OF PHYSICS, WEST VIRGINIA UNIVERSITY

Dr. LESLIE-PELECKY. Thank you very much. I'd like to echo my colleagues' thanks for the invitation to testify here today. And I want to emphasize this really isn't an abstract thanks, because the NNI has had a huge impact on moving my own research from very fundamental to more applied.

Just to give you an idea of what I do, I think most of you in the room are old enough to remember a toy called Wooly Willy. It's a picture of a guy's face with iron filings. You use a magnet to make a beard and hair and things. I do the same thing with magnetic nanoparticles.

What we do is we attach chemotherapy drugs to the magnetic nanoparticles. We inject them, and then I use a magnet to hold them where I want them, which is near cancer tumors. By doing this, we concentrate the chemotherapy drugs. That allows them to be more efficacious and also decreases side effects.

Now, our work has been funded by the National Science Foundation and the National Institutes of Health. We've also run into situations where our work is too disease-focused for NSF but not quite disease-focused enough for NIH. Funding agencies have started having coordinated funding—calls for funding, but more coordination is necessary to ensure that these ideas that are sort of out of the funding box don't get lost and they can move from that eureka moment to actual applications.

One of those interesting concepts that I've been learning about is called bioactivity. And that characterizes how nanomaterials interact with living organisms in the environment. It should seem like bioactivity of a nanomaterial is something we really ought to be able to predict. But it turns out that the same surprising properties of nanomaterials that make them so useful often sometimes surprise us when we look at how they interact with the biological systems.

We can create new nanomaterials in a matter of days. It can take us up to months to really understand the bioactivity of those materials. We've developed an amazing ability to make new materials. Now we need to advance the understanding of bioactivity to catch up with our ability to make materials.

I moved to West Virginia recently in part because of the proximity of West Virginia University to the National Institutes of Occupational Safety and Health. Collaborations between our two organizations are making exciting progress on understanding the bioactivity of nanomaterials. One of those lines of research is developing microfluidic devices for real-time analyses. These devices could allow a researcher or a company to learn within minutes how a brand new nanomaterial would interact with different types of cells. These sensors could be used to monitor the presence of nanoparticles in the work environment. They could be used for homeland security purposes. There are really exciting opportunities for companies that are capable of doing rapid, accurate bioactivity screening.

This knowledge is extremely valuable for industries. Companies need the data to convince them to invest in new technologies. They want to know that their products are safe, and they want to know how to keep their workers safe. Even more importantly, those companies which are developing new nano-enabled products would benefit from better guidance as to the likely bioactivity of new materials.

Now, the situation of not being able to predict bioactivity greatly complicates regulation. It's basically like being asked to referee a game for which you didn't know all the rules. Consequently, nanomaterials have to be regulated on a case-by-case basis according to their actual properties, not some potentially superfluous characteristic such as size. That means the regulatory agencies must be nimble and able to adapt as our knowledge changes.

Let me conclude by briefly addressing a topic that sometimes gets lost in all of our excitement about the possibilities of nanomaterials, and that's the need for education. So when I was in graduate school, I studied physics. I worked with physicists. Now I study nanomedicine. I work with medical doctors, biologists, toxicologists, pathologists, not to mention chemists, engineers, and occasionally the odd physicist or two.

Nanomaterials transcends boundaries. It's a very different type of training than the discipline-based education that all of us went through. We need to invest in developing the most effective and efficient ways of educating the next generation of scientists and engineers who will lead the way.

But we also need to educate lawyers and business people, elected officials, regulatory officers, and venture capitalists about the realities of nanotechnology, especially as they pertain to specialized sectors of the economy, like energy, health, and the environment.

Most importantly perhaps, in my view, is educating all citizens to be able to make informed decisions about nanotechnology. Nanomaterials will eventually affect all facets of our lives, and some of them have been pointed out—everything from medical care to the cars we drive and the food we eat. Consumer understanding of nanomaterials is a prerequisite to their acceptance and thus realizing the huge potential of nanotechnology to improve our country, our economy, and our quality of life.

The NNI has facilitated the growth and development of this very important field. Reauthorization of the NNI must include coordination of effort among multiple government agencies; increasing understanding of nanomaterials bioactivity to facilitate safe and responsible use; and supporting infrastructure necessary for future research, development, and commercialization.

Finally, the NNI must promote education at all levels, from the future scientists and engineers that will enable us to maintain global leadership in nanotechnology to helping the public make informed decisions about the role nanotechnology will play in their lives.

Thank you again for the opportunity to address you about this very important issue.

[The prepared statement of Dr. Leslie-Pelecky follows:]

PREPARED STATEMENT OF DIANDRA L. LESLIE-PELECKY, PH.D., DIRECTOR, WEST VIRGINIA NANO INITIATIVE; PROFESSOR OF PHYSICS, WEST VIRGINIA UNIVERSITY

- The National Nanotechnology Initiative has had a tremendous impact in producing new materials for potential commercial applications, advancing fundamental knowledge, and developing a scientific and engineering workforce that has made the United States a global nanotechnology leader. Re-authorization of the NNI will ensure that the U.S. retains this leadership and will promote the transfer of basic knowledge to applications with important economic and societal impacts in energy, health and medicine, environmental monitoring and remediation, and homeland security.
- Nanotechnology is highly interdisciplinary and ranges from basic research to applications, making it critical for funding agencies to coordinate their efforts. Recent interagency calls for proposals in targeted areas involving nanotechnology must be continued and expanded upon to ensure that important research areas receive the necessary support.
- Realizing societal and economic benefits depends critically on establishing scientifically valid principles for responsibly developing and using nanotechnology.
  - We have much to learn about nanomaterial *bioactivity:* how a material interacts with biological organisms and the environment. In particular, we need to understand the relationships between physicochemical properties of nanomaterials and their bioactivity to enable "safety by design".
  - Regulation of nanomaterials is important to corporate and consumer adoption of this new technology. Companies need confidence that their products and manufacturing methods are safe for consumers and workers, while the development of new nanomaterials and nanotechnologies will benefit from being able to focus effort in the directions that are most likely to produce safe products.
  - Nanomaterials are a unique form of matter and we do not yet have all the knowledge we need to develop complete regulations for nanomaterials. Acquiring this knowledge must be a priority and nanomaterials regulation must remain flexible enough to adapt to our evolving understanding.
  - A potentially large market exists for products and services that determine nanomaterial bioactivity quickly and precisely. Sectors that would benefit include nanomanfacturing, homeland security, health and medicine, and a wide spectrum of basic and applied research.
- Nanotechnology research requires significant infrastructure for its continued development. Once-exotic instruments like electron microscopes are now basic tools for research and development. Funding opportunities to acquire these basic tools (some of which cost a half-million to a few million dollars) need to be developed. New state-of-the-art tools need to be invented and made available on a regional basis.
- Education is a priority to ensure our continuing world leadership in nanotechnology, to transfer basic discoveries to applications, and to ensure public acceptance of nanotechnology.
  - Educating the next generation of scientists and engineers requires new models at undergraduate and graduate levels that focus on integrating diverse fields without sacrificing depth of knowledge in core disciplines;
  - Lawyers, businesspersons, venture capitalists, elected officials, and government regulators need to acquire knowledge about specific nanomaterials and their applications to allow informed decision making;
  - Basic science and engineering education at the K–12 level is a pre-requisite for future scientists and engineers—but more importantly, it is critical for all citizens to develop fundamental scientific literacy so that they can make informed decisions about the roles nanomaterials will play in their lives.

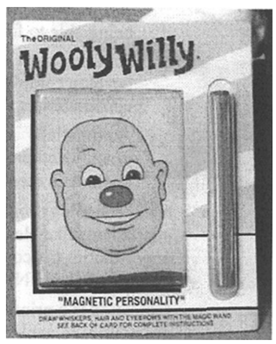
Mr. Chairman and Members of the Subcommittee, my name is Diandra Leslie-Pelecky and I am the Director of the West Virginia Nano Initiative and Professor of Physics at West Virginia University. Thank you for the opportunity to testify today regarding the impact of the National Nanotechnology Initiative (NNI) and its reauthorization.

This is not an abstract thanks, as I am one of literally thousands of scientists and engineers who have had the opportunity to contribute in some small way to the huge advances in our understanding of nanomaterials because of the government's commitment to nanotechnology and its potential impact on our country's future through the NNI. Reauthorization of the NNI will further our basic understanding of nanomaterials, and help transform that knowledge into products and services that will benefit the people of the United State and our economy.

The idea that one can change the basic properties of a material simply by changing its size introduced a major paradigm shift in science and engineering. The possibilities for using nanomaterials to solve some of the country's most important problems—like more efficiently transforming and storing energy, or detecting diseases like cancer when there are only a few cancerous cells present—are moving ideas from the realm of science fiction to reality.

Despite having worked in nanomaterials my entire career, I had a very traditional preparation to become a physicist. I started out studying the fundamental properties of magnetic nanoparticles—particles about a thousandth the width of a human hair—trying to understand how their magnetism changes as their size varies. About eight years ago, I was inspired to consider how these magnetic nanoparticles might be applied.

You may remember a toy called Woolly Willy—a drawing of a man's face in a container that also contained iron filings. You use a magnet to move the iron filings around to create a beard or hair. I do something analogous with magnetic nanoparticles. I attach chemotherapy drugs to the nanoparticles, inject them, and then use magnets outside the body to hold the nanoparticles where I want them—which is at cancer tumors. This magnetic targeting approach allows us to concentrate the chemotherapy drugs near the tumor, increasing efficacy and decreasing side effects.



This is how I entered the field of nanomedicine, which uses the unique properties of nanomaterials to detect and treat disease. Like many of the hybrid fields that have evolved from nanomaterials research, nanomedicine sometimes finds itself at the edges of two or more funding agency mandates. Our work has been funded by the National Science Foundation and the National Institutes of Health, but we've also found that some aspects of the research are too disease focused for NSF, but not focused enough for NIH. Funding agencies have started to issue joint calls for proposals in the last few years, but more coordination is necessary to ensure that ideas that don't fit neatly in a funding "box" can still move from the eureka moment to application. It is especially important to address the gap between the basic research pursued in most universities and the very applied work that immediately precedes commercialization.

As I continued working in nanomedicine, I've learned about a concept called 'bioactivity', which characterizes how nanomaterials interact with living organisms and the environment. My nanoparticles are designed to enter the body, locate near the tumor and release their chemotherapy drugs. After their mission is accomplished, the nanoparticles are metabolized by the body into oxygen and iron, both of which can be used or easily removed by the body. We do extensive tests to ensure that our nanoparticles' bioactivity is limited to cancer cells.

It might seem like the bioactivity of a material is something that we ought to be able to predict; however, the same surprising properties that we want to utilize to treat diseases and use energy more efficiently also sometimes surprise us when we look at how the materials interact with biological systems. Some materials have a threshold size, below which they start having undesired consequences. We can combine two materials that are fine on their own, but produce an undesired bioactivity when combined. Bioactivity has to be experimentally determined nanomaterial by nanomaterial.

We can create new nanomaterials in a matter of days; however, it takes several months for us to investigate and really understand the bioactivity of just one of those nanomaterials. Nanomaterials have turned the basic tenets of toxicology on their heads. We must support the basic research necessary to develop predictive capabilities for nanomaterials bioactivity. We have exceptional abilities in producing new nanomaterials of all kinds. Now, we need to advance our understanding of bioactivity to catch up with the rapid development of new nanomaterials.

I moved to West Virginia last year in part because of the proximity of West Virginia University to the National Institutes of Occupational Safety and Health (NIOSH). Collaborations between our organizations are producing some of the most exciting progress on understanding the bioactivity of naturally occurring and human-made nanomaterials. As the production of nanomaterials increases from lab quantities to nanomanufacturing-scale amounts, companies and regulatory agencies are going to need the type of information we collect on the intended and unintended environmental, health and safety impacts of nanomaterials.

Companies are uneasy about investing in new technologies that have so many unanswered questions. Companies need to know that their products are safe, and what steps they need to take to ensure that their workers have a safe environment. Even more importantly, companies developing new products would benefit significantly by being able to access a broad database of knowledge of environmental health and safety effects that could help predict the behavior of new nanomaterials and combinations of nanomaterials.

The ability to develop appropriate guidelines and regulations are hampered by lack of basic knowledge about nanomaterials bioactivity. Imagine being asked to referee a game for which you didn't know all the rules. The rules for nanomaterials are not likely to be simple, either. Nanomaterial bioactivity doesn't depend simply on size or shape or chemical composition. Nanomaterials must be regulated on a case-by-case basis according to their actual properties, not simple and possibly superfluous characteristics such as size. Regulatory agencies must be knowledgeable and nimble, willing to change as our knowledge increases.

There's an unfortunate perception that emphasis on understanding the environmental health and safety aspects of nanomaterials is a hindrance to using nanomaterials to drive the economy. Understanding nanomaterials bioactivity is a critical component of developing safe products and building consumer confidence in nanotechnology. It's also a potential business opportunity.

For example, researchers at West Virginia University and NIOSH are working on a microfluidic device that uses different types of cells as sensors to perform a realtime analysis of nanomaterials bioactivity. This device could allow a researcher or a company to learn within minutes how a new nanomaterial interacts with each different type of cell. There are industrial possibilities for developing sensors that monitor the presence of nanoparticles in the work environment or for homeland security purposes, and opportunities for companies capable of doing rapid, accurate bioactivity screening.

Realizing these opportunities requires advancing our basic understanding of nanomaterials bioactivity, which in turn requires infrastructure. The multifaceted nature of nanomaterials demands multiple characterization measurements, many of them pressing at the boundaries of what we are able to measure. The government has done an outstanding job making high-cost instrumentation available on a regional basis at national laboratories, such as the NSF-funded National Nanotechnology Infrastructure Network. These facilities make important contributions to research, but also provide unique educational opportunities for nanotechnology students.

Once-exotic instruments like electron microscopes are now basic tools that are required for nanomaterials research. There are a very limited number of funding opportunities for universities to acquire instruments in the half-million dollar to few million dollar range. These instruments do far more than facilitate research—they provide training opportunities for the next generations of nanotechnology researchers and developers.

Let me conclude by briefly addressing an aspect of nanotechnology that often gets lost: the need for education at many different levels. In graduate school, I studied physics and I worked with physicists. Now I study nanomedicine and I work with medical doctors, biologists, toxicologists, and pathologists—not to mention chemists, engineers and other physicists. I've learned almost an entirely new vocabulary in the last eight years. The undergraduate and graduate students working in my labs need to learn very different things than I learned when I went through school. Nanomaterials transcends disciplinary boundaries, requiring students to develop breadth of knowledge while still gaining expertise in their core discipline. Today's students won't be working in a small group of like-minded people in a single lab: they need to learn how to work with groups of people from very different backgrounds, on a wide spectrum of instrumentation. They need to learn about the importance of fundamental research, but they also need to learn about industrial applications of nanomaterials and entrepreneurship. This is a major departure from the discipline-based education most of us are used to and we need to invest in developing the most effective and efficient ways of educating the next generation of scientists and engineers.

Perhaps more importantly, we need to educate lawyers and businesspeople, elected officials, regulatory officers and venture capitalists about the realities of nanotechnology, especially as they pertain to specialized sectors of the economy like energy, health, and the environment. They need to utilize a principle of science that we often fail to communicate: cutting-edge scientific knowledge is dynamic and constantly evolving. Patent examiners, policy makers and the government scientists responsible for creating a stable and predictable regulatory climate will have learn how to adapt to our changing knowledge in a proactive and not reactive way.

Most importantly, in my view, is educating all citizens to make informed decisions about nanotechnology. This education starts in the K–12 system by building fundamental science and math literacy—something we are not doing very well at present. Our efforts need to be focused beyond developing curricula that define and explain nanomaterials. We need to emphasize the more fundamental objective of teaching people how to think critically. We need to switch the focus of education from memorizing information that any teenager can pull up in a microsecond from her phone to teaching that student how to synthesize and use that information to make valid decisions.

As the author of a science book written specifically for non-scientists, I have a lot more contact with the public than your average physics professor. What surprised me most was how hard the average person is willing to work to learn about science—if you can show them how it affects something they care about. Nanomaterials will eventually affect all facets of our lives, from our medical care to the cars we drive and the food we eat. Consumer understanding of nanomaterials is a prerequisite to realizing the huge potential of nanotechnology to improve our country, our economy and our quality of life.

The National Nanotechnology Initiative has facilitated the growth and development of this very important field. Re-authorization of the NNI must include coordination of effort among multiple government agencies, increasing understanding of the environmental health and safety impacts of nanomaterials to facilitate their safe and responsible use in consumer products, and supporting the infrastructure necessary for future research and development. Finally, the NNI must promote education at all levels, from the future scientists and engineers that will enable us to maintain global leadership in nanotechnology, to developing the scientific literacy of the public so that they can make informed decisions about the role of nanotechnology in their lives. Thank you again for the opportunity to provide input on this very important issue.

Senator NELSON. Thank you.

Dr. O'Neal?

STATEMENT OF DR. THOMAS O'NEAL, ASSOCIATE VICE PRESIDENT OF RESEARCH, OFFICE OF RESEARCH AND COMMERCIALIZATION, UNIVERSITY OF CENTRAL FLORIDA

Dr. O'NEAL. Let me echo my thanks for the opportunity to speak with you, Mr. Chairman, and the Committee about this very important issue. Again, I'll state from the start that I'm fully in support of renewing and expanding the National Nanotechnology Initiative. And I think that it has made us a global leader in the development of nanotechnology, and I really think we need to maintain that effort.

I'm from UCF. It's a growing university. If you're not familiar with it, we're actually the second largest university in the country now, just over 40 years old. So we're a new growing entity, if you will, and we've done a lot of experiments.

One thing we did was take a look at our ecosystem in terms of how to commercialize technologies and realized, in one sense, there were a lot of resources on land or air, but we're kind of like a sixth grade dance where all the girls and boys shut up and nobody's really dancing. So we try to figure out ways to bring people together.

And we created our incubator initially to commercialize technology. But we ended up doing a whole lot more than that. We ended up being the neutral site, if you will, for folks to come together and kind of act like a magnifying glass, if you will, to bring the community together to commercialize technologies.

I want to certainly say today that I think we need to continue this investment. It will keep us competitive and dominant in the world for years to come. And by that, I mean, you really need to almost consider doubling the university—the Federal investment in research.

We need to make sure we have the dominant supply of intellectually derived raw materials to supply our commercialization stuff. Then we need to create the commercialization stuff with the same kind of excitement we get about the science. And it really has the same challenges, if you will. There's tremendous scale-up properties that are problems that nano people face when they're taking things off the bench top, if you will, into commercial productivity.

So what can we do? I have some suggestions. Certainly, we need to really encourage universities and industry to partner more. Maybe we can increase the amount of the small—the STTR portion of the Small Business Innovative Research Program that requires universities and industry to partner before they can do Federal research. That would be an incentive for folks to start learning how to work together.

We could consider stipends, if you will, for really profound research that would go toward the commercialization and any kind of gap found of a really promising technology being developed in the research lab. We can also begin to think about an open call for the SBIR program, so we can do funding in real time, if you will, to companies that really have great discoveries they need to commercialize.

We have a matching grants program in Florida, High Tech Corridor, that provides additional money for when universities and industry do research together, and with the industry providing research, so we know it's something that's important to them—but additional money to help the faculty, incentivize them to work with things. I would consider creating proof of concept centers, where faculty and industry can come work together, share equipment, share space, share stuff with investors—really to figure out how we're going to get the commercialization out in the marketplace. They also need help with the manufacturing, and the scale-up issues we talked about earlier need to be addressed and, hopefully, some help to do that.

I'd offer that we provide help with compliance, too, for these entrepreneurs. Make it user friendly, you know. These—it's very daunting for faculty to start companies when they have to figure out all this compliance stuff and in real time. And it's a mine field, so, again, maybe a tour guide to help them get through that stuff would be great.

Industry can share space in each place. It can—when you think about ways to enhance university tech transfer, funding for university tech transfer offices and commercialization is sparse, usually taken out of the F&A recovery—cost recovery from the university—so ways to help them get the commercialization out of the technology, in supplements, maybe, again, from really exciting research to do the commercialization part, or they can go directly to a tech transfer office or incubators or the college of business and maybe even the company itself. That's where the money needs to go.

The last thing we really need to address is the capital problem—maybe a fund of funds for technology investment funds. Maybe we could create a fund like the CI did to help commercialize their technologies—figure out ways to incentivize angels to get off the sidelines and really start investing in these companies.

With that said, I'd like to conclude. Think about—we use the term ecosystem a lot—but think about ecosystem as a coral reef or a rain forest. Certainly, a coral reef and a rain forest are very different ecosystems, but they're both very complex in nature, and lots of things going on at the same time.

Communities and entrepreneurs and different areas of technology are also very different and they all need different support. So I really would include bringing, you know, city and industry and government and states together to solve their local community problems as well as addressing a national issue, if you will.

With that, certainly, I think that entrepreneurships need to be really considered. The last statistic I saw showed 90 percent of the companies in the United States have nine employees or less. So I think entrepreneurs and small businesses will be leading or have a major role in this effort.

And with that, I thank you for your time.

[The prepared statement of Dr. O'Neal follows:]

PREPARED STATEMENT OF DR. THOMAS O'NEAL, ASSOCIATE VICE PRESIDENT OF RESEARCH, OFFICE OF RESEARCH AND COMMERCIALIZATION, UNIVERSITY OF CENTRAL FLORIDA

Distinguished members of the Subcommittee on Science and Space of the Senate Committee on Commerce, Science, and Transportation: Please let me thank you for the opportunity to provide testimony related to an area that holds great potential to make a significant contribution to the U.S. economy. I wholeheartedly support the renewal and expansion of the National Nanotechnology Investment: Manufacturing, Commercialization, and Job Creation.

My testimony will focus on the commercialization aspects of nanotechnology:

- Industry potential
- Technology transfer
- University/Industry Interaction
- Economic Development

The Potential of NanoScience

Nanotechnology has been recognized as a revolutionary field of science and technology, comparable to the introduction of electricity, biotechnology, and digital information revolutions. Between 2001 and 2008, the numbers of discoveries, inventions, nanotechnology workers, R&D funding programs, and markets all increased by an average annual rate of 25 percent. The worldwide market for products incorporating nanotechnology reached about $254 billion in 2009. (Lux Research)

Nanoscience or Nanotechnology, the study and design of materials at the nanoscale (on the order of billionths of a meter) truly has the potential to address untold challenges and market opportunities because nanomaterials have fundamentally different chemical and physical properties than bulk materials. Understanding and exploiting these properties will allow scientists to tailor materials for specific uses that will create new market opportunities and commercial success.

In its comprehensive publication, *Societal Implications of Nanoscience and Nanotechnology,* the National Science Foundation (2001) suggested that among the expected breakthroughs [in nanoscience and nanotechnology] are orders-of-magnitude increases in computer efficiency, human organ restoration using engineered tissue, "designer" materials created from directed assembly of atoms and molecules, and the emergence of entirely new phenomena in chemistry and physics (p. iii). The authors added that the effect of nanotechnology on the health, wealth, and standard of living for people in this century could be at least as significant as the combined influences of microelectronics, medical imaging, computer-aided engineering, and man-made polymers developed in the past century (p. 2). This should not be ignored in terms of the economic development policy and practice in the U.S.

A report by Lux Research (2006) showed that the industries most impacted by nanotechnology will be Aerospace and Defense, Chemicals, Computer Peripherals, Computers, Office Equipment, Electronics, Energy, Medical Products & Equipment, Metals, Pharmaceuticals, Scientific, Photo, Control Equipment, Semiconductors and Other Electronic Components.

While the U.S. is a dominant player in the nanotechnology sector, Japan, Germany, and South Korea are also major players that are gaining ground.

There are things to consider when discussing the commercialization of nanotechnologies.

1. Nanoscience is an enabling, general purpose technology. It is a key building block for multiple applications across many sectors.
2. It represents a mixed bag of incremental improvements and disruptive technology breakthroughs.
3. Processes and products in the sector are key to the innovation process.

Things that affect the commercial potential include:

1. It is a new field and the average incubation time for a discovery to make it through the patent and licensing process is 7 years. Add to this the fact that the emphasis on nanoscience is relatively new and scientific research is often a slow hard road, especially in tight budget times.
2. We learned from microelectronics that the flip side of Moore's law is that the smaller the feature size the larger the machines that are often needed to make these features and the larger the increase in cost. For example, the initial printed circuits could be made with standard photographer's equipment available at any photo hobby store. Whereas now the light sources can cost up to a billion dollars and individual pieces of optics can easily exceed a million dollars in cost. This trend continues on the nano-scale.
3. As an enabling technology, nano often "disappears" from view as it is integrated into a system. Just one example, photonic band gap materials are nano devices that can enhance telecom but one does not think of the telecom device as either a nano device or a photonics device. Another specific example is photo-thermal-refractive (PTR) glass, which, at its heart, is a nano structure material. PTR glass is used to bend light at different angles by using nanoparticles and Bragg gratings.
4. In summary, nanoscience has already 'infiltrated' or enabled new devices or improvement in older devices, but their identity as nano enabled products disappears.

Commercialization Hurdles and Risks

The commercialization of nanotechnology has non trivial technical and business issues. Key problem areas are Manufacturing and Scale-up, FDA Issues, Business Investment Capital, and the decreasing Investments in Research.

Manufacturing and Scale-up phenomena runs rampant in nanoscale materials. For example, thin films/surface treatment deposition techniques, traditionally require expensive, large vacuum chambers that do not accommodate large scale production. Metallic and ceramic nanoparticles become non-uniform in high volume manufacturing. In other words, the physics of things change drastically at the nanoscale. Things don't do what they do in bulk.

FDA hurdles for nanoparticles are also a key issue. Dendrimers is the only FDA approved therapeutic in the market, and any non-dendrimer nanoparticle is susceptible to poor uniformity in bulk production. FDA scientists fear that sub-100 nm particles could interact with DNA or cause cell damage. The environmental, health, and safety issues associated with nanosocience must be examined and addressed in order to proceed with the technology in this arena.

Business capital must flow into this venue to ensure success in the market. Venture capitalists are investing in nanotech, but not aggressively due to the long cycles it takes from discovery to commercial viability. It should also be noted that U.S. investors are now putting more new money into international stock funds than into U.S. stock funds by a substantial margin. As recently as 6 years ago, only 8 percent of the money newly invested in U.S. stock funds went overseas; now the fraction has reached 77 percent. This hurts U.S. investment in nanoscience.

Commercialization of NanoTechnologies

To increase the commercialization of nanotechnology innovations, I submit for consideration the following:

1. Invest in research at a level that will make a difference.
2. Spur university and industry interactions.
3. Address the capital problem.

Investment in Research

Research results supply the raw materials for new emerging fields such as nanotechnology. To increase the commercial throughput, increase the supply of raw materials. Conversely, reducing the available innovative technologies available for commercialization reduces the amount of economic benefits available.

Norman Augustine in his National Academy of Science essay, "Is America Falling off the Flat Earth" makes the point that while "America remains extremely productive, ample warning signs are to be found in considering the future. For example,"

- In 2004, Federal funding of research in the physical sciences as a fraction of GDP was 54 percent less than in 1970. In engineering, it was 51 percent less.
- By the end of 2007, China and India will account for 31percent of the global R&D staff, up from 19 percent as recently as 2004.
- The share of U.S. post-doctoral scientists and engineers who are temporary residents has grown from 37 percent to 59 percent in two decades.
- In 2005, only four American companies were among the top 10 in receiving U.S. patents.
- The National Intelligence Council reports that in 2003 "foreigners contributed 37 percent of the research papers in Science, 55 percent in the Journal of Biological Chemistry, and 71 percent in the journals of the American Physical Society."
- For the first time, the world's most powerful particle accelerator does not reside in the United States; this virtually ensures that the next round of breakthroughs in this fundamental discipline will originate abroad.
- In the recent ranking by the Organisation for Economic Co-operation and Development (OECD), the United States is in 22nd place in the fraction of GDP devoted to nondefense research.
- Federal annual investment in research in the physical sciences, mathematics, and engineering combined is equal to the *increase* in U.S. health care costs experienced every 6 weeks.

These statistics are included in this testimony not to insinuate that the sky is falling but show a trend that needs to be reversed if the U.S. is to maintain the current dominant position it enjoys now and more. It is an undeniable fact that, in the foreseeable future, the U.S. will have to have the best scientists and engineers in sufficient supply. However, that alone will not ensure America's ability to compete in the 21st century. Funds must be available to underwrite the efforts of scientists and engineers who conduct the cutting edge research that creates business opportunities that in turn creates new jobs. The funds must provide for modern laboratories and instrumentation as well as the research enterprise itself. It is research that will keep the United States prosperous in the long term.

Recommendations

At a minimum, double the amount of Federal research expenditures overall within the next 5 years and consider an even higher increase in Nanotechnology. Simply put, we can't afford not to.

The Federal Government should also take steps to retain scientific and engineering talent trained in the United States by developing a program to provide U.S. Permanent Resident Cards for foreign individuals who receive an advanced degree in science or engineering at an accredited institution in the United States and for whom proof of permanent employment in that scientific or engineering discipline exists.

Spur University and Industry Interactions

Universities typically receive no funding for technology transfer or commercialization activities. Most are funded from Facilities and Administrative (F&A) cost (indirect cost) recovery. This is often problematic in that there is limited funding to pursue patent protection and even less resources to proactively commercialize technology developments. That means that most technology transfer offices protect a fraction of their technologies and then hope someone will discover it and take a license. Also as state budgets decline, universities must use the F&A cost recovery to fund facility construction, provide bridge funding for faculty competing for Federal grants, provide capitalization for labs, etc. This creates too much pressure on too little money!

A few home run hits have also created the notion that tech transfer activities are a source of income for universities. Truth is that less than 10 percent of tech transfer offices break even, much less generate income. The premise of income though often creates very adversarial license negotiations and can jeopardize fruitful, long term partnerships.

Lastly, resources for the commercialization activities are also difficult to obtain. Incubators and entrepreneurship centers are on the rise but often are office spaces, not suited for high tech ventures, operated on shoestring budgets, and are often not woven into an overall innovation ecosystem. Proof of Concept Centers that help move technologies from ideas to viable commercial product are needed for nanoscience as well as manufacturing centers that can help resolve the scale up problems that thwart technology exploitation.

Create a University Entrepreneurship and Technology Commercialization Initiative

It should be funded at a level comparable to the very successful SBIR program (2 percent of Federal R&D budget). Tasks to be undertaken include:

(1) Enhance the STTR Program to catalyze university and industry collaboration
- (a) Significantly increase the amount allocated
- (b) Provide supplements to projects for:
  - (i) Translation grants
  - (ii) Gap funds to move technology or venture forward
  - (iii) Provide matching grants to universities to further research efforts on company's behalf (company funding required and possibly university match)
- (c) Create open application deadline program option (SBIR and STTR)
  - (i) Updated as needed
  - (ii) Ability to make awards for promising opportunities quickly (weeks, not months)

(2) Create Proof of Concept and Manufacturing Centers
- (a) Provide shared facilities to bring technology to commercial viability
- (b) Enable industry and university partnerships
- (c) Access provided on a competitive basis
- (d) Scale-up assistance and manufacturing expertise to move technologies into production

(3) Enhance University Entrepreneurship Infrastructure
- (a) Support for University Affiliated Incubators and Accelerators
  - (i) Facility development and enhancement
  - (ii) Operational and program support
  - (iii) Client support
  - (iv) Support for networking events between startups, university personnel, investors
  - (v) Development of support infrastructure for second stage companies (10 + employees)
- (b) Student ventures and entrepreneurship support such as:
  - (i) Linking senior design classes to entrepreneurship and business classes
  - (ii) Business plan competitions support and promotion
  - (iii) Entrepreneurship curriculum development
  - (iv) Internships with startups
  - (v) Technology based entrepreneurship for technical students
- (c) Entrepreneur support

(i) Federal assistance for faculty/staff sabbaticals to start companies
(ii) Assistance with conflict of interest management
(iii) Market research support
(iv) University Presidents, Provosts, other senior staff, and faculty members should be rewarded in appropriate ways for entrepreneurial activities.

(4) Regulatory Support

(a) Relax faculty ownership regulations for SBIR and STTR programs
(b) Conflicts of Interest

(i) Need to allow faculty to start companies without fear. Current mechanisms create a mine field that is difficult to navigate. Clear guidance documents should be created and shared liberally. Assistance should be provided to help people stay in compliance while spinning off companies.

(c) Provide incentives that spur investment in new companies and relax rules and regulations that thwart it

Overall, a growing problem is increased 'compliance' demands that divert critical resources and destroys initiative (faculty are zapped for working extra hours, perhaps on the commercialization part of their work). It makes no sense to penalize a faculty member who put in their 40 hours and then some.

(5) Patent Reform

(a) Patents need to be issued quicker (months not years)
(b) Patent reform should not hurt small business

Entrepreneurs Should Be Celebrated

Universities and other government officials should recognize and reward entrepreneurs. Faculty should be given credit towards tenure and promotion, as well as help with compliance (COI). The system should create openness that encourages these activities, and sabbaticals to start companies should be accommodated. Take action to remove the barriers and confusion. University Presidents, Provosts, senior staff, and faculty should be rewarded in appropriate ways for entrepreneurial activities.

Address the Capital Problem

The lack of access to capital is a huge problem. As pointed out earlier, the time lag between discovery and commercialization in nanoscience is long, typically 3—10 years. Patient money is required and incentives should be considered to increase this investment.

- Establish a Fund of Funds to increase the number venture capital investments
- Establish a National Nano Investment fund similar to the CIA fund to move promising technologies firms forward.
- Provide incentives for Angel investors

Conclusion

Advances in the field of nanoscience present a tremendous opportunity to improve the quality of life and create economic wealth. It represents a long term investment with large returns. We must continue to press forward in nanotechnology development with a sense of urgency. One could liken this to President Kennedy's call to land a man on the moon by the end of the decade. A strong, concerted effort to accelerate the potential of nanoscience and technology by the end of this decade is warranted. It should be a prominent national agenda that the country can rally around. It must be done by increasing the level of discovery, creating strong partnerships between academia and industry, and by filling the gaps in the commercialization ecosystem. An entrepreneur-centric approach is needed even when large commercial entities are involved.

The commercialization of nanoscience, as with many technology companies, is a messy business. If you've met one entrepreneur with their business needs, you've met one entrepreneur with their business needs. The entrepreneur must be at the center of the innovation ecosystem. Identifying them, engaging them, and supporting their needs in real time are key to increasing their success rates and helping them reach their full growth potential.

Universities are increasingly "getting it" in terms of commercialization but have very limited resources and need their rewards systems to align with commercialization. Faculty that start new companies to commercialize their research should be helped and guided through the process to make sure everything is done properly and compliance becomes a service as opposed to a policing action. The entrepreneurs (faculty or not) should be celebrated and given the time they need to be successful. Faculty members have full time jobs when they start a commercialization activity—teaching, conducting research, and doing service tasks. They need to be relieved of some of these responsibilities to increase chances of commercial success or, at a minimum, not be penalized by time and effort reports if they chose to work extra time on the commercialization activities!

Sincerely,

THOMAS O'NEAL.

Auxiliary Information on 2011 Testimony—July 12, 2011

COMMERCIALIZATION AND POTENTIAL FOR NANOSCIENCE TECHNOLOGY

Prepared by: Dr. Thomas O'Neal, University of Central Florida, Office of Research & Commercialization

NANOTECHNOLOGY IMPACT: GLOBAL, U.S., & FLORIDA

Nanotech Workforce

— The National Science Foundation estimates that *up to one million nanotechnology workers will be needed in the U.S. itself* (Roco and Bainbridge, 2001)
— The referenced paper provides information on an interesting study on nanotechnology training programs previously implemented in NY, PA, CA and Mexico: "Training California's New Workforce for 21st Century Nanotechnology, MEMS, and Advanced Manufacturing Jobs" (Koehler, 2006)

Global Trends

— Total worldwide sales revenues for nanotechnology were $11.6 billion in 2009, and are expected to increase to more than $26 billion in 2015, at a CAGR of 11.1 percent ("Nanotechnology: A Realistic Market Assessment", BCC Research, 2010)
— The largest nanotechnology segments in 2009 were nanomaterials, followed by nanotools (shows largest growth potential) and nanodevices ("Nanotechnology: A Realistic Market Assessment", BCC Research, 2010)
— Various governments *have appropriated $40 billion in global nanotechnology funding* over the last decade and *almost $10 billion more was added in 2010* ("Nanogeopolitics 2009: The Second Survey", ETC Group, 2009)
— In 2009, the *combined European Union member states spent 27 percent of the global nanotechnology funding, Russia spent 23 percent, U.S. spent 19 percent and Japan spent 12 percent* ("Nanogeopolitics 2009: The Second Survey", ETC Group, 2009)
— The International Association of Nanotechnology (IANT), is a non-profit organization with the goals of fostering scientific research and business development in the area of Nanoscience and Nanotechnology *http://www.ianano.org/*
— Countries with extensive nanotech programs, both in private and government spending and research efforts include: Russia, Japan, Korea, Singapore, and UK

Russia

Rusnano, the state-sponsored nanotech investment arm founded in 2007, provides funding for research and commercialization of nanotechnology in an effort to revitalize the economy. As a direct result of the formation of Rusnano, Russia drastically improved its government funding, nanotech initiatives, nanotech R&D center scores, and publication counts. Rusnano has received more than 2,000 proposals for research products and centers, and approved 111 projects to date, in the categories of medicine and pharmaceuticals, energy efficiency and clean technologies, optics and electronics, coatings and surface modification, and nanomaterials. Rusnano is investing $500 million into Russian nanotechnology companies as well. (DiChristina, 2011)

Japan

Though not as well coordinated or as well-funded as its U.S. counterpart, Japan has a healthy government program and network of research centers for supporting nanotech, and its technology-oriented private sector helps to make up the funding gap. Patents and publication counts are healthy, and giant conglomerates like Toray and Sumitomo are very active in nanotech research and commercialization. Over 60 companies in nanotechnology are thriving throughout the country. These companies currently dominate in three markets—nanotubes, food, and semiconductors. The country and private sector *have invested over $1 billion* in funding towards nanotech (Haxton & Meade, 2009).

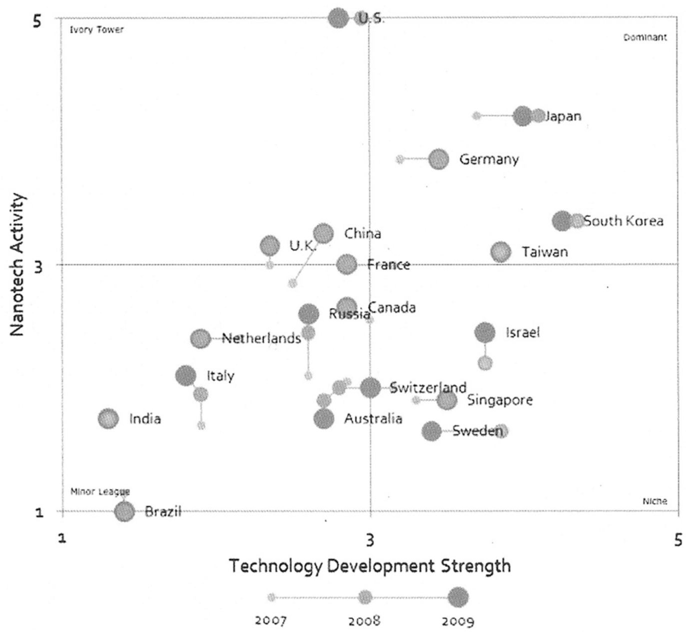
http://www.nanonet.go.jp/english/aboutus/
http://www.nanowerk.com/nanotechnology/Nanotechnology__Companies__in__Japan.php

China

Nanotech is a recurring theme in many of China's technology economic development plans, and both public and private funding has grown quickly over the years. The number of publications grew as an effort of Chinese scientists pursuing nanotechnology, but the patent count has remained similar to previous years. The nanotech companies that do exist in China are usually generic nanomaterial producers (such as Shanghai Huzheng Nano Technology Co. or developer Tianjin Tianhezhongxin Chemicals Co.), supporting the notion that China's research has produced little proprietary, and therefore, hardly commercial technology, to date.

India

India's Prime Minister has voiced concerns that India may be missing the nanotechnology wave (The Economic Times, 2011)

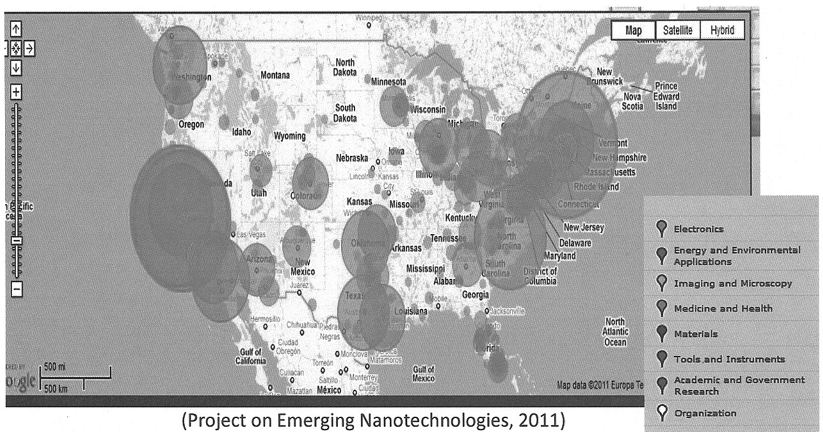


("Ranking the Nations on Nanotech: Hidden Havens and False Threats", LUX Research, 2010)

U.S. Trends

— The U.S. market is responsible *for more than 50 percent of the nanoproducts currently sold* throughout the world ("Nanogeopolitics 2009: The Second Survey", ETC Group, 2009)
— President *Obama's 2011 budget approved nearly $1.8 billion for the National Nanotechnology Initiative (NNI)* (Sargent, 2011)
— The *U.S. Department of Energy is making the largest investment among the various NNI agencies, with $424 million* in 2011. (Harvey, 2011)
— *U.S. companies spent a total $3.2 billion* on nanotech-related research and development in recent efforts. (Harvey, 2011)
— From January 2008 to July 2010, U.S. venture capitalists invested nearly $1.3 billion in nanotech-related startups (Harvey, 2011)
— Corporations (*i.e.,* 3M and IBM), researchers, and private equity investors funded the National Nanotechnology Initiative, funneling billions of dollars into nanotech and attributing to thousands of patents filed on nanotechnology in 2009. ("Ranking the Nations on Nanotech: Hidden Havens and False Threats", LUX Research, 2010)

— The top 4 nanotechnology "economy-established" states, reported on parameters established by the Project on Emerging Nanotechnologies, are: California, Massachusetts, New York, and Texas. (Project on Emerging Nanotechnologies, 2011)
— All 50 states and the District of Columbia have at least one company, university, government laboratory, or organization working in the field of nanotechnology. (Project on Emerging Nanotechnologies, 2011)
— The top 6 Nano Metros (also based on criteria from the Project on Emerging Nanotechnologies) are: Boston; San Francisco; San Jose, Calif.; Raleigh; Middlesex-Essex, Mass.; and Oakland, Calif. (Project on Emerging Nanotechnologies, 2011)
— The number of U.S. universities and government *laboratories working in nanotechnology is still substantial, with 182 identified as of 2011.* (Project on Emerging Nanotechnologies, 2011)



(Project on Emerging Nanotechnologies, 2011)
http://www.nanotechproject.org/inventories/map/

STATE-SPECIFIC NANOTECH PROGRAMS

Oklahoma NanoInitiative

The Oklahoma Nanotech Initiative (ONI) is a project coordinated by The State Chamber of Oklahoma and funded by the Oklahoma Center for the Advancement of Science and Technology (OCAST). In 2006, Oklahoma had over 50 scientists who were doing research in the nanotech field. The program appears weaker than its inception in 2005. Nearly all of the 50 Oklahoma-based companies with product lines involving nanotechnology are still in business since the initiative began. They cover a broad range of applications including medicine, sporting goods, cosmetics, textiles and optics.

In 2006, state legislation pushed the Oklahoma Nanotechnology Sharing Incentive Act established the Oklahoma Nanotechnology Applications Project (ONAP) *which provides $2 million to state efforts* (Oklahoma Nanotech Initiative) to be used to promote and provide incentives to further "applications of nanotechnology". The ONI program has proved successful: "for the last three years, the return on the state's investment has been about 37 to one—*for every dollar the state spent, we brought $37 into the state.*" (Fairchild, 2010). The state also created "nano technician" jobs and education, as courses at universities and community colleges include: Nano Instrumentation, Nanotechnology and MEMS. The Oklahoma State Dept. of Career and Technology and OSU Okmulgee are partnered on an NSF grant to create the Oklahoma Nanotechnology Education Initiative that is currently being rolled out. Additionally, this nanotech initiative also has some of the most comprehensive K–12 education tools/multimedia in the country.

Notable, recently funded companies and research efforts include: Southwest Technologies (high-volume CNT production); Charlesson (improved eye disease drops); Amethyst Research (hydrogenation process for fire fighting, thermal mapping and border security); Caltech Global (hydrogen sulfide granular scavenging for oil/gas/landfill gas filtration); NanoBioMagnetics (drug delivery); University of Tulsa (nanobatteries); OK State U has *$51 million nanotech center,* 40 faculty/staff, and 100 grad students (nanofood/ag; nanowires, energy).

http://www.oknano.com/research.html
http://www.oknano.com/oklahoma__companies.html
http://www.ok.gov/ocast/Programs/Oklahoma__Nanotechnology__Applications__Project__%28ONAP%29/index.html

Texas NanoInitiative

Dallas/North Texas initiatives developed after donations to the University of Texas at Dallas to create the Alan G. MacDiarmid NanoTech Institute. The donor was the founder of Zyvex Labs, claimed the world's first nanotech company. Several large corporations in the area have since started nanotech programs in the area including: Texas Instruments, Raytheon, and Lockheed Martin. These companies have initiated these programs in the local universities, rather than internally, to reduce R&D financial risks.

VCs *invested $57 million in Texas-based nanotech companies* (Harvey, 2011). From April 2006 to October 2010, the state-run Texas Emerging Technology Fund (ETF) funded *about $22 million in grants* for nanotechnology-related research at Texas universities (Harvey, 2011). During the same period, the ETF *invested about $14.6 million in companies* (Harvey, 2011) looking to commercialize nanomedicine, nanoelectronics, and nanomaterials products.

Major university players and associated projects/applications: U of Texas-Dallas (CNT airplane paint, superconductive power cables, Solarno PV spin-out, CNT artificial muscles); U of Texas—Arlignton (solar cell coatings, medicine toxicity/reaction biosensors).

http://www.dmagazine.com/Home/D__CEO/2011/January__February/Technology__Issue/North__Texas__Research__Pushes__Future__of__Nanotechnology.aspx?p=1

Colorado Initiatives

The Colorado Nanotechnology Alliance is not-for-profit economic development organization governed by a strong board of directors whose core represents nanotechnology companies in the state. The Alliance *has more than 75 companies which employ 19,000 workers at an average salary $55,720*.

CU-Boulder has emerged as a significant academic nanotech player. The Nanoscale Science and Technology for Integrated Micro/Nano-Electromechanical Transducers (iMINT) was built on a DARPA grant and now has more than $2.5 million in research funding from the govt, Lockheed Martin, GE and Raytheon (Nanotechnology Now, 2008). More than 100 faculty in engineering, biology, chemistry, physics, dentistry, pharmacy, and medicine from CU-Boulder and the Anschutz Medical Campus in Denver are involved in micro/nano technology research in some way. (Nanotechnology Now, 2008).

Major university players and associated projects/applications: CU at Boulder (electronics thermal management, nanoscale characterization, melanoma detection); ITN Energy (solar); Colorado State University (extreme UV pulse lasers); CO School of Mines (works 100+ companies in materials processing research).

http://www.coloradonanotechnology.org/home/index.php
http://www.colorado.gov/cs/Satellite/OEDIT/OEDIT/1167928387048
http://ncf.colorado.edu/?p=news&sub=tinytech&id=63

California Initiatives

The state has fragmented nanotechnology efforts. One of the state's main areas is in nanomaterial safety and hazards, under the California Department of Toxic Substances Control, which is partnering on these efforts with the U.S. EPA. The Northern California Nanotechnology Initiative, NCnano, is an economic development initiative focused on developing the nanotechnology and the nano-bio-IT convergence technology economy of Northern California. Started in 2003, the Initiative's goals included bringing $6B in nanotechnology investment/grant money to the areas and to create 150,000 new local jobs (North California Nanotechnology Initiative).

The state's nanotech efforts are dominated by the universities. Every major state university has nanotechnology centers, as do notable private institutions. The California Institute of Nanotechnology offers training and commits research entirely in the nanotechnology field. The center works with the Cleantech Institute in the areas of renewable energy and clean tech. The Institute is primarily working in energy storage (novel batteries and fuel cells) as well as drug delivery mechanisms.

The national labs of Sandia and Lawrence Berkeley both have extensive nanotechnology programs in the particular areas of CNTs, nanocomposite alloys, and nanoporosity, and a molecular foundry focused on energy, respectively. Other university research efforts of note include: University of South CA (nanowires, graphene thin films); UC of Santa Barbara (NSF funded "nanotech in society" center which studies politics, economics, etc.); $100 million funded UCLA's NanoSystems Institute *has*

$350 million in research and development grants from industry (nanotoxicology, carbon dioxide capture, drug delivery) (The New York Times, 2009); Librede (drug screening); NanoH_2O (reverse osmosis/filtration); QuantumSphere (battery material enhancement); and CFX Battery Inc. (lithium ion batteries).

http://www.ncnano.org/

http://www.dtsc.ca.gov/TechnologyDevelopment/Nanotechnology/nanoport.cfm

http://www.dtsc.ca.gov/TechnologyDevelopment/Nanotechnology/nanopartners.cfm

http://www.cinano.com/Training/index.html

http://dealbook.nytimes.com/2009/07/16/californias-glimmer-of-hope-nanotechnology/

http://foundry.lbl.gov/

New York Initiatives

In 2010, the Empire State Development (ESD) and the New York State Foundation for Science, Technology and Innovation (NYSTAR) today announced the merger of two of New York State's Centers of Excellence-Infotonics Technology Center (ITC) in Canandaigua and the Center of Excellence in Nanoelectronics and Nanotechnology at the College of Nanoscale Science and Engineering (CNSE) in Albany. Empire State Development and NYSTAR *will invest up to $10 million to the merged operation,* the Smart System Technology & Commercialization Center (STC), which will be managed and supported by CNSE.

CNSE's Albany NanoTech Complex has *$7 billion in investments and is an 800,000-square-foot complex* (College of Nano Science and Engineering, University of Albany). The UAlbany NanoCollege houses the only fully-integrated, 300mm wafer, computer chip pilot prototyping and demonstration line within 80,000 square feet of Class 1 capable cleanrooms ("New York State Announces . . .", Nanowerk, 2010). *More than 2,500 staff the complex,* from companies including IBM, AMD, GlobalFoundries, SEMATECH, Toshiba, Applied Materials, Tokyo Electron, ASML, Novellus Systems, Vistec Lithography and Atotech. A new goal is to expand the complex to 1,250,000 square feet of next-generation infrastructure housing over 105,000 square feet of Class 1 capable cleanrooms and more than 3,750 staff. In a *$10 million joint development project,* Apic Inc.'s photonics systems and devices will be combined with the CNSE's nanoelectronics resources, to result in at *least 20 jobs over the next 18 months* (College of Nano Science and Engineering, University of Albany). Moser Baer Technologies is investing more than *$17 million* at CNSE, acquiring state-of-the-art equipment for the pilot production line, creating more than *50 high-tech jobs by 2013* (Smart Systems Tech, 2011).

The Infotonics Technology Center of Excellence in Photonics & Microsystems is a technology commercialization center that maintains *140,000 square-foot* with over 25,000 square feet of cleanrooms for MEMS fabrication and packaging ("New York State Announces . . .", Nanowerk, 2010). ITC works with industrial participants such as Corning Inc., Eastman Kodak Company, and Xerox Corporation. Academic participants include *approximately twenty New York State colleges and universities,* including the Rochester Institute of Technology and the University of Rochester.

Notable research/commercial entities include: CNSE U of Albany (PV control/monitoring center, photonic integrated circuits, solid state lighting); IBM of Yorktown Heights (CNT); Rensselaer Polytechnic Institute (thin films novel planarization and metallization); Auterra/Applied Nanoworks (specialty inorganic compounds); NanoMas (nanoparticles for printed electronics). Full database of NY research in nanotechnology:

http://www.nystar.state.ny.us/rsch/nanotech.htm

http://www.nanowerk.com/news/newsid=18133.php

http://www.nylovesnano.com/industry/industry.php?m=5

http://www.nynanobusiness.org/

http://www.research.ibm.com/nanoscience/

http://cnse.albany.edu/WorldClassResources.aspx

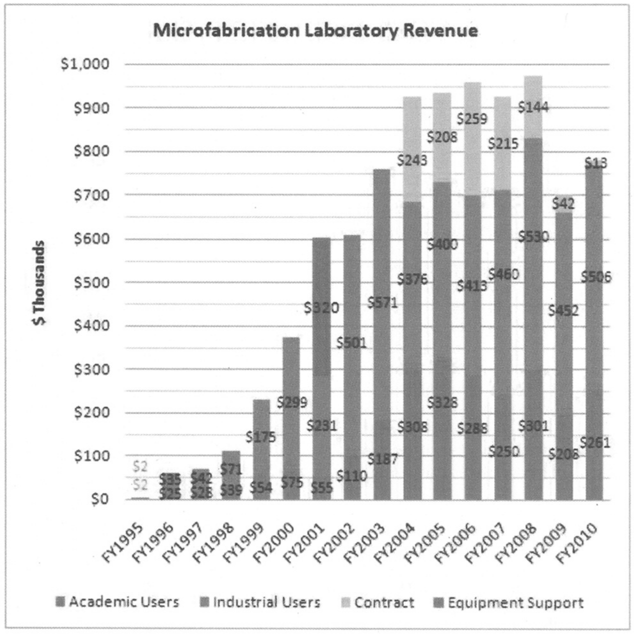
http://cnse.albany.edu/LeadingEdgeResearchandDevelopment/ResearchProfiles/ProfilesArchive.aspx

http://dpwsa.electroiq.com/index/display/photovoltaics-article-display/2478462125/articles/Photovoltaics-World/industry-news/2011/6/cnse-nanotech-complex-plans-pv-control-center.html

http://www.itcmems.com/news_June.html

Washington Initiatives

The Washington Technology Center, Avogadro Partners, LLC, the University of Washington, Washington State University and Battelle's Pacific Northwest National Laboratory, with seed funding sponsored by Senator Maria Cantwell, have come together to launch the Washington Nanotechnology Initiative (WNI). The state has many expectations for a nanotechnology economy that are complementary to its current infrastructure. The graphs below show trends that exist or are anticipated in the state.



Microfabrication Lab Revenues (Washington Technology Center, 2005)

KEY WASHINGTON SECTORS FOR NANOTECH	Location Quotients[3]	Jobs 2003[4]	Jobs 2012 est[5]
Transportation Equipment	2.37	76,218	75,000
Aerospace Manufacturing	8.12	65,274	62,000
Energy	1.00	15,072	20,000
Electronics	1.00	22,238	28,000
Instrumentation	1.13	10,119	12,000
Life Sciences	1.09	18,706	25,000
Agriculture	3.29	71,038	70,000
Software	7.51	37,005	50,000
Telecommunications	1.19	23,477	28,000
Other IT	1.75	22,002	28,000
TOTAL		361,149	398,000

(Washington Technology Center, 2005)

Notable research efforts: U of Washington (malaria testing, biomaterials, jointly work with PNNL).

http://www.watechcenter.org/resources/washington-nanotechnology-initiative

http://www.avogadro.us/news/2005/05/new-washington-state-nanotechnology.html

South US/Georgia/NC Initiatives

The National Science Foundation's National Nanotechnology Infrastructure Network has two facilities in the South: the Microelectronics Research Laboratory at Georgia Institute of Technology, and the Microelectronics Research Center at the University of Texas-Austin. The National Cancer Institute's Centers of Cancer Nanotechnology Excellence include the Nanotechnology Center for Personalized and Predictive Oncology, which is an Emory University-Georgia Tech partnership, and the Carolina Center of Cancer Nanotechnology Excellence at the University of North Carolina.

http://www.techjournalsouth.com/2010/11/coin-seeks-materials-from-nc-nanotech-firms-for-dc-conference/

Ohio Initiatives

The Center for Multifunctional Polymer Nanomaterials and Devices (CMPND) was formed as a research and commercialization partnership in polymer nanotechnology. Centered at The Ohio State University, CMPND works with the University of Akron and the University of Dayton, three additional Ohio universities, 50 large and small Ohio companies, the National Composite Center, polymer organizations and national labs, all situated in Ohio. *CMPND was awarded $22.5M from the State of Ohio Third Frontier Project and in return will contribute more than a total of $78M toward nanotechnology research and commercialization.* CMPND seeks to have a statewide economic impact by expanding existing business and creating and retaining *more than 5,000 high-paying 'white collar' jobs and 20,000 to 25,000 skilled manufacturing jobs* (Center for Multifunctional Polymer Nanomaterials and Devices).

Over 50 small and large companies, serving the industries of automotive, aerospace, biomedical, consumer products, electronics, and materials engineering; *have contributed nearly $49 million* of support to develop CMPND. The Universities (OSU, UD, UA, KSU, UT and WSU) have added *additional support of over $28 million, providing support to CMPND totaling more than $77 million, over three years* (Polymer Ohio, 2004). Along with names such as Honda, Delphi, Goodrich, Lockheed Martin, Goodyear Tire, MeadWestvaco, Boeing, Ashland, AES/Exxon Mobile, Milacron, Noveon, and Timken on the list, are the large companies of Ohio 's future: Applied Sciences, Cornerstone Research (R&D services), Nanosperse (design services), Maverick (hi-temp materials), Nanofilm (thin films for glass coatings and stain proofing), Sajar Plastics (injection micro-molding), Vector Composites (advanced composites), and WebCore Technologies (core composites).

http://www.polymerohio.org/download/pdf/NanoVer2.pdf

http://cmpnd.org/index.php?option=com__content&view=article&id=45:polymer-industry-is-ohios-largest-at-49-billion&catid=1:latest-news&Itemid=50

Pennsylvania Initiatives

The Pennsylvania Initiative for Nanotechnology (PIN) is a statewide strategy that currently combines the efforts of the Pennsylvania Department of Community and Economic Development (DCED), the Commonwealth's research universities, the Pennsylvania State System of Higher Education, *over 125 companies,* and economic development organizations. PIN is leveraging Pennsylvania's clusters of research, industry, and workforce development assets to make Pennsylvania a global leader in nanotechnology research, commercialization and economic development activities. Using worldwide forecasts, Pennsylvania is projected to *produce at least $7.75 billion worth of nanotechnology products by 2015* (Pennsylvania Commonwealth).

The Pennsylvania NanoMaterials Commercialization Center is *making available $700,000 in funds.* The Center invites Pennsylvania university researchers and companies to submit proposals for funding early-stage commercialization of nanomaterial research for energy applications. The Center is particularly interested in technology development focused on renewable, clean and efficient energy solutions. The Center was founded in 2006 under the auspices of the Pittsburgh Technology Council by a consortium of four western Pennsylvania companies; Alcoa Technology, Bayer MaterialScience, PPG Industries and U.S. Steel. Today, the Center enjoys partnerships with Carnegie Mellon University, University of Pittsburgh, Penn State University, Lehigh University, the Department of Community and Economic Development for the Commonwealth of Pennsylvania, Air Force Research Labs and approximately 300 companies, organizations and individuals involved in nanotechnology.

Since 2007, the Pennsylvania NanoMaterials Commercialization Center has provided seed grants to 15 companies to support 19 early stage prototype development projects using nanotechnology and three pre-commercialization projects with universities. The total public investment has been $4,191,582, which has been matched by the recipient companies in the amount of $2,994,388. Recipients reported the following economic impact from this investment: *115 jobs created* and retained, *$43,219,000 leveraged investment by companies* due to the Center's funding, and *17 new patents filed* (NanoVIP, 2010).

Notable research projects include: U of Penn (monitoring molecular motions, single molecule probes, biomolecular optoelectronics); Penn State U (buckyballs, acoustic tweezers, nanodomes, strong in nano education); Carnegie Mellon (atom transfer radical polymerization, conductive organic materials, magnetic nanocrystals); Metalon Inc. (molecular inks); Illuminex (Si nanowire solar equipment).

http://www.gonano.psu.edu/facts/

http://www.newpa.com/build-your-business/key-industries/high-technology/nanotechnology

http://www.pananocenter.org/nano-center-about.aspx

http://www.nanovip.com/pa-nanocenter-awards-250k-to-pa-based-nanotechnology-companies-releases-industry-impact-data.html

Massachusetts Initiatives

Most data, groups and websites are available before 2005. Here is what they started their initiative with. Massachusetts had over *100 self-identified nanotechnology* firms and *over $110 million in venture capital* was invested in nanotechnology firms in 2003. The existing industries of bio/pharma, medical devices, semiconductor equipment, and material innovations drove clusters within the nanotech start-ups. The state also has major nanotechnology research centers at most university campuses, and three of these are National Nanotechnology Initiative Centers of Excellence: MIT Soldier Nanotechnology Center, Harvard Center for the Science of Nanoscale Systems and their Device Applications, and Northeastern University/UMass Lowell/University of New Hampshire Nano Science & Engineering Center.

http://www.masstech.org/mni/

Florida Trends

Florida is also making strategic investments in the new and promising field of nanotechnology. The nanotechnology cluster in Florida includes at *least three dozen companies.* In addition, Florida universities are also busy building the infrastructure needed to conduct high-quality R&D in the field.

http://www.eflorida.com/ContentSubpage.aspx?id=316

Why the nanotechnology market is not necessarily worth $1.5 trillion now: An article by Nanowerk regarding whether the market report numbers available on the industry thus far have been inflated.

Estimates of the *global nanotechnology market* in 2010 ranged from about $15.7 billion to $1 trillion. By 2015, the market may be worth more than $2.4 trillion, according to different analysts. These differences reflect not only different analytical methods and assumptions, but also different definitions of the *nanotechnology market* (*e.g.,* whether to include decades-old technologies such as carbon black rubber reinforcers and photographic silver, or whether to base the market value on nanotechnology inputs alone, as opposed to the total value of products that incorporate nanotechnology).

In the latest Lux report, a trusted source amongst the nanotechnology industry, a pragmatic decision was made to exclude certain types of materials and devices from the report that technically fit the definition of nanotechnology. These exceptions include carbon black nanoparticles used to reinforce tires and other rubber products; photographic silver and dye nanoparticles; and activated carbon used for water filtration. These materials were excluded because they have been used for decades, long before the concept of nanotechnology was born, and their huge volumes (especially carbon black and activated carbon) would tend to swamp the newer nanomaterials in the analysis.

Nanoscale semiconductors are also excluded from the study, although the tools used to create them are included. Unlike carbon black and activated carbon, nanoscale semiconductors are a relatively new development. However, they have been analyzed comprehensively elsewhere, and like carbon black and activated carbon, would tend to overwhelm other nanotechnologies by their sheer volume in the out-years towards 2015.

http://www.nanowerk.com/spotlight/spotid=1792.php

Market Opportunities

Applications of Most Promise:

(1) Thin films in solid state devices (*i.e.,* energy, lighting, semiconductors)
(2) Surface treatments/functionalizations (*i.e.,* wet/stain proofing, improving cell/DNA/molecular particle adhesion)
(3) Drug delivery
(4) Semiconductors/memory devices
(5) Wireless sensor networks (*i.e.,* dust nodes)
(6) Printed/flexible electronics
(7) Smart textiles

Other opinions—The following list provides applications of nanotechnology the Oklahoma Nano Initiative anticipated to be of great commercial success, by year ranges:

- 2004–7 burn and wound dressings, water filtration devices, paints, cosmetics, coatings, lubricants, textiles, memory/storage devices
- 2008–10—medical diagnostics, displays, sensors, drug delivery, composite materials, solid state lighting, bio-materials, nano arrays, more powerful computers, protective armor, chem-bio suits, and chem-bio sensors
- 2011–15—nanobiomaterials, microprocessors, new catalysts, portable energy cells, solar cells, tissue/organ regeneration, smart implants
- 2016 and beyond—molecular circuitry, quantum computing, new materials, fast chemical analyses

(Oklahoma Nano Initiative)

Big Players:

Almost every technology based Fortune 100 company has some nanotechnology initiative. Several of these corporations have in-house venture arms or other mechanisms that would seek out nanoscale technology research from any source. Here are the larger players and what domain their nanotechnology programs belong to. That is then followed by specific profiles of companies with very specific, yet unique nanotechnology product lines.

Defense/Security:

— Lockheed Martin
— Raytheon

Health/Food/Cosmetics:

— Proctor & Gamble
— Kraft
— Nestle
— GlaxoSmithKline
— Johnson & Johnson
— Unilever
— Amgen
— Baxter

Consumer Electronics:

— NEC
— Xerox
— Microsoft
— Nokia
— Fujitsu
— HP
— Canon
— Philips
— Samsung
— HItachi

Semiconductors/Mfg Equipment:

— ST
— Intel
— Texas Instruments
— Lucent Technologies
— AMD
— ASML

Chemicals:

— Sumitomo
— BASF
— Dupont
— Dow
— Degussa
— Cabot
— Air Products
— Praxair

Agriculture:

— Monsanto

Energy:

— ExxonMobil
— ConocoPhillips
— ChevronTexaco
— Siemens
— GE
— Mitsubishi

Consumer Products:

— Wilson
— Easton

Transportation:

— GM
— DaimlerChrysler
— BMW
— Caterpillar
— Boeing

Specific Corporate Nanotechnology Product Profiles

Raytheon—Along with partners, DuPont and Partners Healthcare, Raytheon currently sponsors the Institute for Soldier Nanotechnology at Massachusetts Institute of Technology. They act as liaison to the Institute's Network Centric Systems group. The collective group is re-designing body armor materials to mimic the iron sulfide rich, uniquely structured shell of particular snails.

http://www.raytheon.com/newsroom/technology/rtn10_snail_armor/index.html

ExxonMobil—Sarnoff Corporation entered a five-year strategic agreement with ExxonMobil Research and Engineering Company (EMRE), in 2005, to commercialize EMRE's groundbreaking portfolio of mesoporous materials. Sarnoff was tasked to market outside of the petrochemical industry. The materials, which include novel high surface area silicas, were among the first nanomaterials ever created and have been commercialized by ExxonMobil for its own use.

http://www.nanotech-now.com/news.cgi?story_id=12688

BMW—BMW established a group of a dozen plus materials scientists to scan the field of nanotechnology and its applications in various industries. The idea was to initiate projects which would lead to the use of nanotechnology in BMW automobiles. That resulted in BMW applyings applications of nanotechnology in some models. There are now rear window systems in the 5 and 7 series cars which feature a "nanolayer laminate." This ultra thin layer helps reflect the heat of the sun while at the same time allowing in electromagnetic signals for telephone and other applications.

Johnson & Johnson—J&J concentrates on the areas of kidneys, diabetes, and cardiovascular systems and is looking towards nanotechnology for personalized medicine applications. J&J's biopharma interests include the areas of trophic, restore/replace, small molecules, and biological organisms. J&J recently invested in nanotech and in particular, start-up, Vesta Organano, though their partnership is not fully disclosed on all details.

http://organano.com/

Kraft—In 2000, Kraft Foods began sponsoring the NanoteK Consortium. The members of the Consortium include researchers from 15 universities, three national labs and three start-up companies. Harvard University, the University of Nebraska, the University of Connecticut, Los Alamos and Argonne National Laboratories, the Universities of Seville and Malaga in Spain and Uppsala University in Sweden are some of the institutions involved in this collaboration. Some of the research areas identified by the consortium members are the development of low cost sensors that detect the presence of foodborne pathogens, filters for removing undesirable compounds from foods and beverages, and nanoparticles to store flavors and nutrients inside food and release them at designated organs in the body when they are needed.

Nestle—Nestle's research center in Switzerland assigned a group of scientists to investigate the potential benefits of nanotechnology for food systems. Nestle was exploring nutraceuticals—nano-capsules that deliver nutrients and antioxidants to specific parts of the body at specific times. The technology turns previously insoluble nutrients into nano-sized particles that can be released into the body and properly absorbed, with big potential benefits for a whole new kind of health food.

Lockheed—Lockheed Martin has had a corporate focus on nanotechnology for the past 7 years which has helped shape the development of nanotechnology applications in all of its four Business Areas. Nanotechnology is one of 15 strategic technology threads in Lockheed Martin which focus on technologies that enable strategic growth. There is an on-going corporate funded project to develop ultra light weight structures. This project includes the development of processes for growing carbon nanotubes and testing new substrates and materials. The expected outcome is higher performance, lighter weight, and lower cost materials for many of our subsystems. Furthermore, the company is hiring the best and the brightest in this space, creating job titles with "nanotechnology" in the name and job expectations.

Caterpillar/Firefly Energy—In 2006, in a hushed deal between Caterpillar and Firefly Energy, a joint venture was struck to develop a battery comprised of an electrical current collector constructed of carbon or lightweight graphite foam. This foam exhibited a sizeable increase in surface area for chemical reactions to take place and eliminated the need for heavy lead plates found in traditional batteries. The graphite material resists corrosion and sulfation build-up, thus contributing to longer battery life and is lighter in weight than today's lead acid batteries. The nanotechnology application at Firefly Energy pertains to the battery's grid coating process, which refers to the nanoscale nature of the coating.

Technology Background

Nanotechnology 'Formats' Basics

While each format of nanotechnology harbors different mechanical, optical and electrical properties, their cost to produce and feasibility of scale-up varies just as much. These unique formats with different process procedures include:

(1) Nanotubes (*i.e.,* Carbon Nanotubes [CNT])
(2) Nanoparticles
(3) Thin films
(4) Self-assembled monolayers
(5) Sol-gels

http://www.nanomagazine.co.uk/index.php?option=com_content&view=article&id=824&Itemid=139

(6) Nanocomposites
(8) Nanotools (*i.e.,* nanolithography tools and scanning probe microscopes)
(9) Nanodevices (*i.e.,* nanosensors and nanoelectronics)

Commercialization Hurdles and Risks

— Manufacturing/scale-up is a challenge for nanotechnologies—Thin films/surface treatment deposition techniques are often expensive because they require large vacuum chambers and/or complex chemical/gas vapor management systems. In high volume, large surface area applications, the scale up of chambers and vapor systems can increase costs by at least one order of magnitude. Furthermore, such geometrically limited systems with low vacuum pressure requirements, cannot accommodate the cost-effective manufacturing that is afforded by roll-to-roll production. Other production complications are due to the sheer scale-up of producing nanoscale products. Lastly, metallic and ceramic nanoparticles are very difficult to produce in uniformity, and are especially difficult to uniformly produce in high volume manufacturing.

— Nanoscale devices operate in a new realm of physics. Known as "scaling phenomena", scientists cannot predict how these devices will operate when compared to macroscale systems. Simulations and modeling techniques are still under investigation as researchers delve further into nanotechnologies.

— There are a number of FDA hurdles for nanoparticles, as the only nanoparticles approved by the FDA for commercial use are Dendrimers, a particular type of polymer-based nanoparticle with a limited scope of attributes. The main reason by the FDA for slow approval of all nanoparticles refers to the first complication of unreliable uniform production. Any metallic or ceramic nanoparticle is susceptible to poor uniformity in bulk production, and if these particles should be less than 100 nanometers in diameter, FDA staff are not sure of the consequences of live cells/tissue. The FDA fears that sub-100 nm particles could interact with DNA and/or cause cell damage.

— Because of many of the above hurdles regarding unknown information on the technology, nanotechnology product development cycles are very long.

— Venture capitalists, who typically invest in early stage start-ups, especially from university resources, are investing in nanotech, but not aggressively, due to the long cycles it takes from discovery to commercial viability.

— The U.S. stronghold on R&D talent across all science and technology fields is diminishing. Compared to other developed countries, students in the areas of science and technology are not performing as well in their subjects are their peers in other nations. Also, the number of graduates with tertiary science and engineering degrees per capita in the U.S. is among the lowest of the developed countries—less than half of that of Taiwan, South Korea, and Singapore, and less than one-third the amount in Russia—which is a grave concern for the US's technology development strength in the long-term. ("Ranking the Nations on Nanotech: Hidden Havens and False Threats", LUX Research, 2010)

Additional Resources/Sites

http://science.house.gov/sites/republicans.science.house.gov/files/documents/hearings/Tour%20Testimony.pdf

http://www.nanotechproject.org/inventories/map/

http://www.nanotechproject.org/news/archive/putting__nanotechnology__on__map/

http://2020science.org/2011/01/04/us-national-nanotechnology-initiative-draft-ehs-strategy-good-in-part/

http://knowledge.wharton.upenn.edu/article.cfm?articleid=1413

http://crnano.typepad.com/crnblog/2007/02/nanotechnology.html

**** http://www.electroiq.com/articles/stm/2010/08/ranking-the-nations.html*

http://www.austrade.gov.au/Invest/Opportunities-by-Sector/Advanced-Manufacturing/Nanotechnology/default.aspx

http://grouper.ieee.org/groups/nano/initiatives.htm

http://www.technologyreview.com/computing/13533/

Bibliography

BCC Research. "Nanotechnology: A Realistic Market Assessment". Available from: *http://www.bccresearch.com/report/NAN031D.html* [Accessed: 08/07/2011]. July, 2010.

California Institute of Nanotechnology. *http://www.cinano.com/index.html* [Accessed: 08/07/2011]. 2009.

Center for Multifunctional Polymer Nanomaterials and Devices. "Polymer Industry is Ohio's Largest, at $49 Billion". *http://cmpnd.org/index.php?option=com__content&view=article&id=45:polymer-industry-is-ohios-largest-at-49-billion&catid=1:latest-news&Itemid=50* [Accessed: 08/07/2011]. 2011.

College of Nanoscale Science & Engineering University of Albany. *http://cnse.albany.edu/WorldClassResources.aspx* [Accessed: 08/07/2011]. 2011.

Colorado Nanotechnology Alliance. "Doing Business in Colorado". *CO Nano Roadmap*. Available from: *http://www.coloradonanotechnology.org/home/index.php?option=com__content&task=view&id=16&Itemid=28* [Accessed: 08/07/2011]. 2011.

Colorado Official State Web Portal. "Nanotechnology". *Office of Economic Development and International Trade. http://www.colorado.gov/cs/Satellite/OEDIT/OEDIT/1167928387048* [Accessed: 08/07/2011]. 2011.

Commonwealth of Pennsylvania. "Pennsylvania Initiative for Nanotechnology". *http://www.newpa.com/build-your-business/key-industries/high-technology/nanotechnology* [Accessed: 08/07/2011]. 2011.

DiChristina, M. "Big Plans for Nanotechnology in Russia". *Scientific American.* Available from *http://www.scientificamerican.com/blog/post.cfm?id=big-plans-for-nanotechnology-in-rus-2011–05–30* [Accessed: 08/07/2011]. May 30, 2011.

Enterprise Florida. "Nanotechnology". *http://www.eflorida.com/ContentSubpage.aspx?id=316* [Accessed: 08/07/2011]. 2011.

ETC Group. "Nanogeopolitics 2009: The Second Survey". Available from: *http://www.lawbc.com/other__pdfs/00048599.PDF* [Accessed: 08/07/2011]. July, 2009.

Fairchild, P. "Nanotechnology: The Art and Science of Manipulating Matter". *Distinctly Oklahoma.* Available from: *http://distinctlyoklahoma.com/science/nanotechnology-the-art-and-science-of-manipulating-matter/* [Accessed: 08/07/2011]. August 1, 2010.

Flanagan, J. "Collaborating for Profits in Nanotechnology". *The New York Times.* Available from: *http://www.nytimes.com/2009/07/16/business/smallbusiness/16edge.html?dbk* [Accessed: 08/07/2011]. July, 15, 2009.

Harvey, P. "Why Small is the New Big North Texas research is pushing the future of nanotechnology". *Special Report: DFW Technology 2011.* Available from: *http://www.dmagazine.com/Home/D__CEO/2011/January__February/Technology__Issue/North__Texas__Research__Pushes__Future__of__Nanotechnology.aspx* [Accessed: 08/07/2011]. January 4, 2011.

Haxton, B.M. & F. Meade. "21st Century Vision: Developing a Global Sustainable Science and Technology Park Strategy and Creating Economic Development Worldwide". Available from: *http://www.i2sl.org/elibrary/documents/haxton__meade.pdf* [Accessed: 08/07/2011]. 2009.

IBM Nanoscale Science Department. *http://www.research.ibm.com/nanoscience/* [Accessed: 08/07/2011]. 2006.

John Adams Innovation Institute. "Massachusetts Nanotechnology Initiative". *http://www.masstech.org/mni/* [Accessed: 08/07/2011]. 2008.

Koehler, G. "Training California's New Workforce for 21st Century Nanotechnology, MEMS, and Advanced Manufacturing Jobs", *Workforce Learning Initiative, Economic and Workforce Development Program,* California Community Colleges. 2006.

LUX Research. "Ranking the Nations on Nanotech: Hidden Havens and False Threats". Available from: *https://portal.luxresearchinc.com/research/document__excerpt/6806* [Accessed: 08/07/2011]. August 17, 2010.

Nanotechnology Now. "CU-Boulder Wins $1.5 Million Contract To Aid In Cooling Of Electronic Devices". Available from: *http://www.nanotech-now.com/news.cgi?story__id=29236* [Accessed: 08/07/2011]. May 7, 2008.

Nanotechnology Now. "Sarnoff To Commercialize ExxonMobil's Nano Materials In Non-Petrochemical Markets". Available from: *http://www.nanotech-now.com/news.cgi?story__id=12688* [Accessed: 08/07/2011]. November 28, 2005.

NanoVIP. "PA NanoCenter Awards $250K to PA-Based Nanotechnology Companies; Releases Industry Impact Data". Available from: *http://www.nanovip.com/pa-nanocenter-awards-250k-to-pa-based-nanotechnology-companies-releases-industry-impact-data.html* [Accessed: 08/07/2011]. December 7, 2010.

Nanowerk News. "New York State Announces Unprecedented High-tech/nanotechnology Initiative". Available from: *http://www.nanowerk.com/news/newsid=18133.php* [Accessed: 08/07/2011]. September 20, 2010.

Nanowerk Spotlight. "Debunking the trillion dollar nanotechnology market size hype". Available from: *http://www.nanowerk.com/spotlight/spotid=1792.php* [Accessed: 08/07/2011]. April 18, 2007.

New York Loves Nano. *http://www.nylovesnano.com/index.php* [Accessed: 08/07/2011]. 2011.

Northern California Nanotechnology Initiative. *http://www.ncnano.org/* [Accessed: 08/07/2011]. 2003.

NYSTAR. "New York State Research Centers by Discipline: Nanotechnology/Microelectronics". *http://www.nystar.state.ny.us/rsch/nanotech.htm* [Accessed: 08/07/2011]. 2011.

Oklahoma Nanotechnology Initiative. *http://www.oknano.com/index.html* [Accessed: 08/07/2011]. 2005.

Pennsylvania NanoMaterials Commercialization Center. "About the Pennsylvania NanoMaterials Commercialization Center". *http://www.pananocenter.org/nano-center-about.aspx* Accessed: 08/07/2011]. 2011.

Pennsylvania State University. "Nano @ Penn State Fast Facts". *Nano@Penn State. http://www.gonano.psu.edu/facts/* [Accessed: 08/07/2011]. 2011.

Photovoltaics World. "CNSE nanotech complex plans PV control center". Available from: *http://dpwsa.electroiq.com/index/display/article-display/2478462125/articles/Photovoltaics-World/industry-news/2011/6/cnse-nanotech-complex-plans-pv-control-center.html* [Accessed: 08/07/2011]. June 7, 2011.

Polymer Ohio. "Center for Multifunctional Polymer Nanomaterials and Devices (CMPND)". *http://www.polymerohio.org/download/pdf/NanoVer2.pdf* [Accessed: 08/07/2011]. 2004.

Ray, D. "Smallest Science Becoming Big Industry". *University of Colorado-Boulder.* Available from: *http://ncf.colorado.edu/?p=news&sub=tinytech&id=63* [Accessed: 08/07/2011]. January 4, 2009.

Raytheon. "NCS Engineer Studies Snail's Shell for Soldier Body Armor". Available from: *http://www.raytheon.com/newsroom/technology/rtn10_snail_armor/index.html* [Accessed: 08/07/2011]. March 16, 2010.

Roco, M.C. & W. Bainbridge eds., "Societal implications of nanoscience and nanotechnology". *National Science Foundation Report.* Kluwer Academic Publishers, Boston, MA. 2001.

Sargent, J. "The National Nanotechnology Initiative: Overview, Reauthorization, and Appropriations Issues". *Congressional Research Service Report for Congress.* Available from: *http://www.fas.org/sgp/crs/misc/RL34401.pdf* [Accessed: 08/07/2011]. January 19, 2011.

Smart System Technology & Commercialization Center of Excellence. "Moser Baer Technologies wins $2.9M U.S. Department of Energy Award to Enable Green Energy Research and Pilot Production at CNSE's Smart System Technology & Commercialization Center of Excellence". *College of Nanoscale Science & Engineering University of Albany.* Available from: *http://www.itcmems.com/news_June.html* [Accessed: 08/07/2011]. June 9, 2011.

State of California. "Welcome to the Portal for the California Nanotechnology Initiative". *California Department of Toxic Substances Control.* Available from: *http://www.dtsc.ca.gov/TechnologyDevelopment/Nanotechnology/nanoport.cfm* [Accessed: 08/07/2011]. 2007.

State of Oklahoma. "Oklahoma Nanotechnology Applications Project (ONAP)". *Oklahoma Center for the Advancement of Science and Technology.* Available from: *http://www.ok.gov/ocast/Programs/Oklahoma_Nanotechnology_Applications_Project_%28ONAP%29/index.html* [Accessed: 08/07/2011]. March 28, 2011.

The Economic Times. "India in danger of missing 'nano bus': PM's scientific advisor". Available from: *http://articles.economictimes.indiatimes.com/2011–07–06/news/29743451_1_nanotechnology-science-fiction-rao* [Accessed: 08/07/2011]. July 6, 2011.

Washington Technology Center. "Washington Nanotechnology Initiative." Available from: *http://www.watechcenter.org/sites/default/files/docs/nanotech_reportfnl_011005.pdf* [Accessed: 08/07/2011]. January, 2005.

Woodrow Wilson International Center for Scholars and the Pew Charitable Trusts. "US NanoMetro Map". *The Project on Emerging Nanotechnologies.* Available from: *http://www.nanotechproject.org/inventories/map/* [Accessed: 08/07/2011]. 2011.

Senator NELSON. Thank you, Dr. O'Neal.

Dr. McLendon?

STATEMENT OF DR. GEORGE McLENDON, HOWARD H. HUGHES PROVOST AND PROFESSOR OF CHEMISTRY, RICE UNIVERSITY

Dr. MCLENDON. Thank you, Chairman Nelson and distinguished Senators and guests and my distinguished colleagues here. I certainly appreciate the opportunity to speak with you today.

In my career, I've taught thousands of students. I've published a number of scientific papers and books and, importantly, for what we're talking about today, a number of patents that supported the creation of new successful businesses. So that's the background that I'm bringing to discuss today—how Federally-funded nanotechnology research has been leveraged by private investment to produce new technologies and new commercial enterprises with transformational advances in energy, environment, and medical sciences, leading to the creation of new high-quality jobs.

I'm going to give three examples. I've been at Rice for a year, and so my three examples are going to be drawn from one university over one year. And then you can do the math to scale that. These are Rice technologies, which was spawned by Federal funding, each of which led to new commercial enterprises.

Let me start with energy. Both current and future energy technologies depend on the quality of the electric grid. One of my Rice colleagues, Matleo Pasquali, at the Smalley Institute and in the Department of Chemical Engineering, has partnered with private industry to improve the efficiency of the carbon nanotubes that some of you spoke of earlier to create much higher quality electricity conduction for both local and broad grid applications. Those kinds of materials, when fully developed, can accelerate and transform development of a smart grid. Similar stories could be told for battery technology, for solar power, for safe oil and gas recovery, all based on the foundation of these materials in nanotechnology.

Let me turn to an environmental example. Professors Vicki Colvin and Pedro Alvarez have developed a nanorust which cheaply and safely removes toxic arsenic from water. This has been field tested in Guanajuato. It's being used to create safe drinking water where none was available previously to those folks. Similar approaches will be applicable in water remediation in many other contexts.

As a third example, my colleagues, Jennifer West and Naomi Halas, have created nanoparticles which can bind to tumors and use light to selectively heat and destroy the tumor while minimally affecting surrounding tissue. This breakthrough depended on fundamental studies of the optical properties of those nanocrystals and resulted in a new venture-funded company that has clinical trials currently in progress and is helping people right now.

So my point is that I hope you can see that nanotechnology really is remarkable, as Chad said, in its ability to translate fundamental discoveries on relatively short time scales into commercial practice, which improve lives worldwide and create new, high-technology, high-quality jobs right here in America. In supporting such research through the National Nanotechnology Initiative, we create opportunities to leverage that Federal investment. We're creating transformational technologies and associated jobs while we're educating the workforce to sustain and build on the U.S. lead in this rapidly developing field.

I might note in passing, for example, that one way in which my Texas senator helped was to help create a way of sharing equipment across many institutions. The kind of equipment that's necessary to do these very difficult experiments would be difficult to recreate in many, many places or in many, many labs. By sharing that, you leverage that investment. And all three examples that I gave you used that kind of shared equipment that came out of SPRING funding.

So at Rice, we've found that these public-private partnerships are a dynamic and growing opportunity to create new national wealth and global improvements in energy, healthcare, and the environment. So as we're all struggling to figure out how do we deal with the budgetary issues, one way that I would suggest is let's grow the pie rather than figure out how to slice it differently. And I hope that the kind of examples that I and my colleagues have given show ways in which we can grow that pie.

I'm grateful to acknowledge the fruits of this public investment. I thank the citizens who created that public investment and thank you for this opportunity to share these small stories and for your service to the Nation that we all love. And I'll be happy to answer any questions.

Thank you.

[The prepared statement of Dr. McLendon follows:]

PREPARED STATEMENT OF DR. GEORGE MCLENDON, HOWARD H. HUGHES PROVOST AND PROFESSOR OF CHEMISTRY, RICE UNIVERSITY

Chairman Nelson, Arkansas Senator Boozman, and Members of the Committee,

I appreciate the opportunity to testify today about the developing impact of nanotechnology and the role of Federal support in maintaining U.S. leadership in this field. While my brief remarks will focus on research, education, and commercialization at Rice University, when combined with the testimony of colleagues, I hope you will see a picture of the vibrancy and future impact of this critical field.

My name is George McLendon. I am the Howard H. Hughes Provost and Professor of Chemistry at Rice University in Houston, Texas. I have published hundreds of articles and hold a number of commercialized patents in areas ranging from nanotechnology to oncology. I am committed to insuring that the fruits of federally funded research translate into commercial products that create jobs at home, and improve lives in the U.S. and worldwide.

In my brief remarks, I will highlight three examples of work from Rice University Smalley Institute for Nanoscale Science and Research. The Smalley Institute is named in honor of the late Richard Smalley, who received the Nobel Prize for the discovery (at Rice) of the buckminsterfullerene (a.k.a. C_{60}, a.k.a. "buckyball"). The Smalley Institute was the first university research institute devoted to nanoscience and nanotechnology, and is ranked among the world's best. We draw together colleagues independently from (15) different departments at Rice, alongside scientists from industries both large and small. The Institute also spawned CBEN, which pioneered investigation of biological and environmental implications of nanotechnology bringing state of the art research to stakeholders from industry to the Environmental Defense Fund. We are also deeply committed to translation of basic research to sustainable commercial practice, which allows such research to benefit the citizens who have supported it.

Nanotechnology is a foundational technology that can create hundreds of thousands of new jobs to make new products and my colleagues help create . . . According to a presentation by Clayton Teague, former Director of the Federal National Nanotechnology Initiative, the nanotechnology industry currently employs over 150,000 Americans and that number is expected to grow significantly. It is estimated that there could be as many as 800,000 jobs in nanotechnology by 2015. Nanotechnology can be the major driver of economic growth over the next two decades. The U.S. needs to make important decisions now to ensure that this growth occurs in the United States where it can be of greatest benefit to U.S. citizens who provided the resources to fund this technology.

Rice does this in several ways. First, we have formed direct partnerships with major corporations (*e.g.,* Lockheed Advanced Nanotechnology Center at Rice—LANCER), which performs basic research in support of the technology challenges posed by the state of the art (defense) technologies needed by Lockheed Martin. In the course of such research partnership, we have also educated over 200 Lockheed scientists in the basics of nanotechnology via targeted courses.

This highlights a critical role of universities in sustaining U.S. leadership in nanotechnology: the education of the next generation of leaders.

A second example addresses the U.S. need for energy independence. The Advanced Energy Consortium (AEC) includes ten major energy companies who support work on nanotechnology which helps increase domestic production of hydrocarbon resources, with decreased environmental impact: "greener carbon," which ranges from "down hole" sensing, to advanced drilling technologies to mitigate environmental impacts of hydrocarbon production, to remediation of water which may be affected by energy production.

Two specific examples may be germane. Professor Andrew Barron has developed "green muds" which enhance efficiency of oil by combining nano particles into drilling fluids. This technology has spun out into an independent company, which is currently producing and selling these advanced materials for conventional and unconventional enhanced recovery.

A personal favorite example lies at the interface of chemistry and environmental science. Two of my colleagues, chemist Vicki Colvin and engineer Pedro Alvarez, are developing nanotechnologies to cheaply and safely remediate water pollution. For example in Guanajuato, Mexico much well water is hazardous, because of high local arsenic levels. Colvin and Alvarez showed how "rust" nanoparticles could cheaply, safely and effectively remove the arsenic to safe levels, making safe local drinking water available for the first time for many people. Similar approaches can remediate water, which has come in contact with other pollutants.

Similar stories emerge in health care. My colleague on this panel Professor Mirkin, pioneered nanodiagnostics. Similar approaches have been further developed and engineered by my Rice colleague, John McDevitt, to produce "labs on a chip." Technologies which allow point of care diagnostics from AIDS tests to drug screening at a fraction of current costs, and in ways that fully integrate health care with IT with huge potential. These novel technologies are being commercialized by a privately funded start-up, Force Diagnostics. The next generation of such technologies will depend on Federal private partnerships to reach their full potential.

A second example draws from my own interest in oncology. Rice colleagues Jennifer West and Naomi Halas have used nanochemistry to engineer nanoparticles, which absorb light to which our bodies are transparent. This absorbed light heats the particles and destroys nearby tumors. These inventions have also spurred venture funding of a novel start up, and clinical trials are underway.

Rice has worked diligently in these areas to develop an "innovation ecosystem," combining state, Federal and private funding for entrepreneurship. For example, in the life sciences, we are creating, in partnership with the state and private investors, a "think tank" accelerator which combines venture funding, successful entrepreneurs and entrepreneurs in training, CRO support and foundational and applied science and engineering to serve the Texas Medical Center, the world's largest research medical center.

Federal support for fundamental science is the critical first step in such partnerships, which, as noted, can translate these fundamental discoveries to commercial practice to provide sustainable social benefits.

I have given only a few examples of many extraordinary advances in science and technology developed at Rice. These illustrate an approach in which initial government funding is highly leveraged again and again by private sector investment to produce new products and services that transform lives, whether in creating new energy resources or safer drinking water.

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

Senator NELSON. As I turn to my colleagues for their questions, let's get you to—as we want to grow this pie, as you say, Dr. McLendon, realizing that we're in a budget crunch and realizing that the U.S. got the jump on everybody else 10 years ago, and we put $14 billion into this over that decade, but now we've got a whole bunch of other countries that are investing in nanotechnology research—so as we try to grow this pie, give us some of your blockbuster examples—so that we can disseminate it to the public—of the most important technological or market successes in this past decade on nanotechnology. Let's just start with you and just go down and quickly do it, and then I want to turn to my colleagues for their questions.

Dr. MIRKIN. OK. I'll talk about some of the ones that I'm very familiar with. So you mentioned at the start diagnostic tools, tools that now are commercialized, FDA cleared. Some are produced by a company called NanoSphere that I started 10 years ago. It's now traded on the NASDAQ. It's a public company, an example of roughly $20 million of investment in terms of Federal investment. This is a great example of basic research at the university level getting translated into hundreds of millions of dollars of investment in terms of venture capital——

Senator NELSON. What's an example of a diagnostic tool?

Dr. MIRKIN. A diagnostic tool would be a medical diagnostic that would screen you for a disease marker so that we could diagnose disease much earlier, catch cancer at its earliest stages when you have a chance to treat it and ultimately cure it, or to catch the early stages of Alzheimer's disease. So you actually have a real diagnostic as opposed to one that is subjective or a subjective analysis of how you're behaving. We don't have a real diagnostic yet. The nanotech routes are actually leading to a real diagnostic, which is exciting. And, in fact, there are platforms that are commercialized and ready to go now.

You mentioned prostate cancer. Being able to detect markers years earlier than we can with conventional tools is not only important for screening, but for looking at recurrence. When men have their prostates removed, PSA levels drop to below detectable. With these new tools, they're detectable and you can now look and see whether somebody's flat-lining and tell them they're cured. They don't have to wait 7 years to find that out. That takes the weight of the world off their shoulders.

And then the other 52 percent of the people will be slow risers, and if you can catch them early, you can say now you can try experimental therapeutics, many of which are nano-based, and you can use the diagnostic to validate those therapies. So it's not only going to be new ways of tracking, but it's going to lead to new ways of finding really important therapeutics that will lead to cures for many types of diseases.

Senator NELSON. OK. Others?

Dr. ROMINE. I can give you one significant example in the CNST, the Center for Nanoscale Science and Technology. We were approached by IBM to gain access to our systems in order for them to devise the prototype electronics for their new supercomputing capabilities. And so I've actually referenced that in the testimony that I have.

In talking with them, they certainly had the resources that they could have used to procure some of the capabilities that we had already available at the CNST. But the fact that they could gain ready access to our facilities and to the unique capabilities that we provided there in terms of collections of capabilities, they tell us, cut at least 6 months off their development time. And six months, as you know, in the development of supercomputing technologies, is a lifetime. And so that kind of competitive advantage is something that I think the CNST was able to provide.

Senator NELSON. Dr. Leslie-Pelecky?

Dr. LESLIE-PELECKY. One of my favorite ones I like to talk about is because people are hoarding 100-watt incandescent light bulbs right now. They're doing that because they don't like the way the compact fluorescents make you look. They make you look blue and sort of sickly. There's a company, QDVision, that's using nanotechnology—quantum dots—to make something that you put over the compact flourescent light bulbs that would change the spectrum of the light so it would more closely mimic natural light. And that's an incredible advantage, because if we could get rid of the incandescent light bulbs, the energy savings would be enormous.

Senator NELSON. And to do that cheaply, and it saves a lot of electricity. Or are you talking about just something that goes over a regular incandescent bulb?

Dr. LESLIE-PELECKY. No. This would actually go over a compact fluorescent bulb or even an LED. And so you'd be able to use the energy saving technology and you basically wouldn't know that it was any different than an incandescent light bulb.

Senator NELSON. I see.

Dr. O'Neal?

Dr. O'NEAL. A couple of examples from UCF. There's a company we just spun off called Speckle Dot. Speckle Dot—one of our faculty members uses nanoscale particles to detect the coagulability of blood in real time and non-invasively. So that can actually go into the emergency room or in places where you can see—when someone has a stroke, and you can see if they need to have their blood thinned or thickened or whatever. So that really helps save lives. You can do it—bring it into operating rooms and really help—really just establish if the blood is, how coagulable it is.

There's another thing called PTR glass, or photothermal-refractive glass, and it's used to bend light. So it has got a lot of communications and things. So you can take lasers and you can split the frequencies out and you can broadcast them over and put them back together again in kind of a really neat way that's a passive device. Really, it's a piece of glass, and you can actually put holograms in there and store data. A lot of different things you can do. These are all the nanoscale particles and glass that make that happen.

And there are interesting things being done with cerium oxide, everything from help with Alzheimer's to, actually, increasing the fuel efficiency in diesel. So there are very neat applications coming out of a broad range of nanoscale particles.

Senator NELSON. Dr. McLendon?

Dr. MCLENDON. I already gave a brief example——

Senator NELSON. You did. Give us an example before you got to Rice. You gave us the ones——

Dr. MCLENDON. Right. I'll give you a wonderfully Texas example that has to do with creating drilling mud. It turns out that to optimize the production of oil and gas, it matters—and to do that as safely and effectively and environmentally appropriately as possible, it matters enormously what your drilling materials are. And building in engineered nanoparticles, it turns out, can help you find out what's going on in real time and improve the efficiency of that. There's a company from Rice that is doing exactly that right now. It has huge implications for our energy security.

One before I got to Rice—I was involved in helping start a company in California that uses extremely small amounts of picoliters of liquid to move around materials with exceedingly high precision. That turns out to be critical to the pharmaceutical industry when they need to create libraries of compounds that they use to test for new drugs and allows you to make copies of those libraries far more cheaply and efficiently than was ever possible before. That company now does about $40 million in business a year, and it's been increasing at 30 to 40 percent a year. That's a good example of something that came from very basic research, turned into something commercial, and is growing at a rate that exceeds the rate of growth of the U.S. economy by a substantial margin.

Senator NELSON. Well, thank you for these examples. I assume that things like lightweight aircraft of the future is another example?

Dr. MCLENDON. Absolutely.

Senator NELSON. OK.

Senator Rockefeller?

The CHAIRMAN. Thank you, Mr. Chairman. I want to ask three questions if I can get away with it.

The first will be to you, Dr. Mirkin, and you, Dr. Leslie-Pelecky. You both talked about cancer and you both talked about Alzheimer's. I've paid a lot of attention to both. One of the extraordinary things is that the great teaching universities, including Rockefeller University, I have to say, and Howard Hughes Institute, and all these giant research people who have been putting hundreds of millions of dollars of research into Alzheimer's for years and years have basically hit a brick wall. Nothing has really happened. No cure—diagnostics are being worked on, but no cure is in sight.

The same for cancer. And there's an incredible book, incidentally—wasting your time—called *The Emperor of All Maladies,* which you ought to read. It just won the Pulitzer Prize. It's the best book on cancer that, I think, has ever been written.

But with cancer, let's say you've discovered a little spot in the liver. And, traditionally, what you'd do to make sure of the whole situation—you do chemotherapy. Then you do radiation. Radiation is what I have in mind, because radiation goes directly to the spot, wherever that may be, and you may pay a hellacious price for that radiation.

Now, can nanotechnology, through—because you've said it can—these gold-plated little tiny particles—can you focus that in two ways, one, on the spot in the liver? You talked about magnetizing it and then holding it over a certain place. Is that like radiation, or is that just identifying it? Is that just saying this is a marker?

Also, in Alzheimer's, one of the big problems is getting through the blood brain barrier so that you can put a curative medicine, if we had one, on a particular synapses or plaque or whatever within the brain. Otherwise, you have to wait until the person is dead, really, and then do an autopsy and find out what happened, which is not a fast way of doing things.

So how does nanotechnology apply in each of those two examples, potentially?

Dr. MIRKIN. OK. I'll take a crack at that. So those are great questions. First of all, you have to recognize these are big problems. And so it's, I think, wrong to oversimplify the solutions, from our perspective. But the bottom line is much of what you're saying is correct. I mean, these are enormous challenges. Nanomaterials offer, though, the ability to overcome a lot of those challenges.

We have, for example, the first types of particle constructs that will cross the brain blood barrier and affect gene regulation in glioblastoma type tumors. That's really exciting. That's very, very exciting, because——

The CHAIRMAN. How?

Dr. MIRKIN. Because they're small, and they've been chemically modified in such a way that they can pass the brain blood barrier by virtue of size and then target the cancer cells based upon sticky groups that we've put on them that go exclusively for those cells. And the other thing they have is the ability to penetrate tissues better than anything that's ever been studied before. And that's really exciting, because that means if you get things close, they can diffuse to the disease site.

And, for example, for a brain tumor, that's one of the problems. One of the reasons the prognosis is so bad is that the surgeon can remove the tumor in certain cases, but they leave a few cells behind, and it's those few cells that are left behind that kills the patient. And so having particles that can get in and then diffuse and then selectively target those cells and cause them to die and not touch the healthy cells is the trick. And there are a lot of promising results, in fact, this year that suggest that that is going to happen and going to happen soon.

The problem is even worse, though, than what you say in terms of, you know, detecting a little speck. I had a colleague—I won't mention her name, but she had a tumor growing in her the size of a softball. This is a 34-year-old lady. It is amazing that we don't have technologies that can tell us that's growing in her—you know, when it's the size of a golf ball or a pea, let alone a softball. When she went to try to get screened, the only thing they could do was an imaging technique, which then, of course, told her that she had a softball—there was nothing about the regular checkup that would allow you to diagnose that she has something radically different from a healthy person and something that big growing inside of her.

We need technologies that allow us to catch these things at early stages and therapeutic interventions that allow us to ultimately treat them and stop the damage they cause. And that's where nanotech is really going to play a role, because these materials do things that conventional materials can't do, and I mentioned a couple of those in the start of the statement.

The CHAIRMAN. Dr. Leslie-Pelecky, my time has run out. So can you do this in about 30 seconds?

Dr. LESLIE-PELECKY. Certainly. You talked about radiation, for example. There's a number of people who are attaching radioactive materials to nanoparticles and then delivering those nanoparticles to the places where the tumors are. So instead of going through the body, you're actually going in and getting to exactly where you need to go. I think about a tumor as sort of like a puzzle piece, and each type of cancer has different types of puzzle pieces. Our job is is to take our nanoparticles and find a way to make them fit into that particular type of puzzle piece.

So as Dr. Mirkin mentioned, specificity is really the issue. Chemotherapy drugs work by basically killing the fastest dividing cells, which include hair follicles. That's why your hair falls out. The more specific we can make these drugs and the more accurately we can deliver them, the more effective they're going to be with fewer side effects.

The CHAIRMAN. Thank you both very much.

Senator NELSON. I leaned over to Senator Boozman and said, "This is really exciting." All right.

Senator Hutchison?

Senator HUTCHISON. Well, thank you. It really is exciting.

And I think that you have all identified specifics that we can understand where nanotechnology has done wonderful things in the past. And I want to mention also that the idea that both Dr. Pelecky and Dr. McLendon have both mentioned is that we really do need to have the collaboration in the funding area. And if we can get this bill through, what you have suggested will be part of this bill; that if there is not a clear agency function there would be some discretion in giving worthy research to something that's a little bit out of the box. So we will handle that.

But the other thing that Dr. McLendon mentioned that I think we need to also prioritize is the sharing of information and equipment, because putting the same piece of equipment in two places is not efficient, especially when you can collaborate either through the technology or communications. I think that sharing is something that we should also promote in the reauthorization.

So here are the questions that I want to throw out to all of you. Number one, has the National Nanotechnology Coordination Office ever assisted in commercialization efforts that any of you would be making at your respective institutions, and, if so, was it effective in helping transition your research to the marketplace? And, if not, what can we do to ensure that is a part of our efforts? If we are going to put Federal funding into this research, we certainly need to take it to the next step, with some reward going back to the researcher and the institution, but also some sort of reward that would spur other Federal investments. In other words, some reward back to the government funding agency and some to the research institution that would be a win for both when you commercialize the project.

So I would throw it open to any of you on those questions.

Dr. O'NEAL. I can start. We have not worked with the institute to commercializing currently. But certainly one of the things I like to talk about—when you've got research rewards or commercialization, you know, most tech transfer offices really—never really break even, much less make a lot of money. And so I think you need to keep that in mind. It's an investment in something where sometimes the return on investment doesn't come back directly to the university or a tech transfer office. But we need to make a way so it really becomes an incentive for folks to continue that behavior regardless. And how we do that needs to be understood better. But, again, we'd love to work more with them, and I would like to talk with someone about how to do it.

Senator HUTCHISON. Well, what's the right entity? Where should we be focusing? Is it the National Nanotechnology Coordination Office? Is that the right entity that would be able to be helpful, or is there something else?

Perhaps, Dr. Romine, you might have a view?

Dr. ROMINE. Yes. I can certainly say that the NNCO is, I think, indirectly extremely helpful in terms of coordination across the Federal Government programs in nanotechnology. And so, indirectly, it provides kind of support for emphasizing and sharing best practices with respect to technology transfer, and I think the agencies do that. We have different ways of going about it.

Senator HUTCHISON. What about helping on commercialization and establishing a reward?

Dr. ROMINE. Right. I'd have to think some more about that. It's not obvious how a coordinating function like that represented by the NNCO would take on the added responsibility of commercialization except through, again, the coordination of the Federal agencies involved.

Senator HUTCHISON. Are there any other thoughts on that?

Dr. LESLIE-PELECKY. I would echo something that was said about the STTR and SBIR programs. Those are outstanding ways of bringing together the academicians and the people who want to do commercialization. I'd also echo something that Dr. O'Neal said about the problems of just getting through starting a business and compliance. There need to be some guides. Faculty members are all busy. They're doing a thousand things. Having a way to help them into that entirely new world would be very useful.

Senator HUTCHISON. I hear complaints from all sectors about how long it takes to take an idea or a research project or a product through the systems at the FDA. Is there anything there that you have experience with or suggestions on how we could help shorten those wait times?

Dr. MCLENDON. Yes, but not in minus 30 seconds.

Senator HUTCHISON. And that's exactly where I am. Well, why don't I just ask you to submit for the record——

Dr. MCLENDON. I would be delighted.

Senator HUTCHISON.—suggestions as we are writing this reauthorization? That's why we're having the hearing; so we can do the right thing with the Federal dollars. So I would——

Dr. MCLENDON. Thank you.

Senator HUTCHISON.—invite all of you to submit suggestions.

Dr. MCLENDON. Thank you, Senator.

Senator HUTCHISON. Thank you.

Senator NELSON. Thank you, Senator.

Senator Boozman?

Senator BOOZMAN. Thank you, Mr. Chairman.

I'd like to follow up a little bit with Dr. Mirkin, you and Dr. Leslie-Pelecky talked about the tremendous advances—and potential that we have for as medical health, but there are also some concerns that it could go the other way. That perhaps we don't understand quite enough yet.

The FDA has not yet identified particular safety issues related to nanotechnology applications and FDA-related products. But, nevertheless, they recently released draft guides with criteria to determine whether nanotechnology is used in an FDA-regulated product. So I would like for you two to comment on that. And what effect has that had? Is that a chilling effect? How do we sort that out and go forward?

Dr. MIRKIN. OK. I'll take a stab at that. You know, this is an issue with any technology. Any new technology can have positive impact and it can have negative impact. There is nothing to fear here in terms of size. That doesn't make things special in this regard. It's a combination of the size of the particles, the shape of the particles, and, as I said, the chemical attachments that we add to the particles that make them ultimately effective.

I think the FDA is actually thinking about this fairly proactively, not perfectly, but proactively. A lot of the agencies have been thinking about this proactively and have been taking a pretty healthy view toward developing methods for screening new constructs and determining whether they have potential negative consequences that you're alluding to.

You can't do that at the start, in terms of taking all of these materials and running them through screens, because it'll just bankrupt the system and it doesn't make sense, because many of them will be made and then never be used. They're just an entry into the encyclopedia of knowledge.

But the ones that you take down paths that ultimately lead to real products that are either disseminated in the environment or used by people—you have to raise the bar and apply many of the tools that we've developed for other types of chemical constructs with an understanding of what makes nanomaterials different to figure out whether or not they are safe, and those types of methods are being developed. There are a variety of centers around the country at universities that focus exclusively on developing those types of tools. And I think it's still very early. Those types of centers are going to become more important and the knowledge that they're producing is going to become more important as we get closer and closer to primetime in terms of using these as, for example, therapeutics.

On the diagnostic front, though, you know, we have our diagnostic systems. We've got, I think, five different FDA-cleared systems. So we've been able to work with the FDA and they've been able to—sometimes gives a lot of push-back, but ultimately get to systems that can do a lot of good.

Senator BOOZMAN. Very good.

Dr. LESLIE-PELECKY. The folks we work with at the National Institutes of Occupational Safety and Health are really working toward developing predictive capability. How do you correlate the physical and chemical properties of a nanomaterial with its bioactivity? And I think that's part of—one approach is what Dr. Mirkin said—looking at the products that are headed out for commercialization. I think the folks that we work with are really looking at it more as a function of how can we develop some basic rules that will help us predict the bioactivity of materials in the future.

Senator BOOZMAN. Very good.

Dr. McLendon, do you think there's enough venture capital investment available to the nanotechnology companies, and, if so, why? Or if not, why?

Dr. MCLENDON. Since I largely work with venture funded companies, I don't think there's enough venture investment available for anything. But——

Senator BOOZMAN. What factors?

Dr. MCLENDON.—specifically, in nanotechnology, you know, it's a very tough investment climate right now. And in the absence of some sort of differential reason to put capital at risk—some of you alluded in your opening remarks to incentive structures and their advantages and disadvantages. I think that's a place where you, as senators, could do a lot in helping us think through what the best investment incentives and structures are. I can tell you right now that it's a very tight investment climate, not just for nanotechnology, but for many cutting-edge areas in science and technology.

Senator BOOZMAN. Good.

Dr. MCLENDON. And that's a personal experience.

Senator BOOZMAN. Well, that's very helpful. And if you would give us some of the hurdles that you feel are out there and how we can help overcome them.

Dr. MCLENDON. Absolutely, sir. Thank you.

Senator BOOZMAN Thank you, Mr. Chairman.

Senator NELSON. Senator Ayotte, would you mind—Senator Rockefeller has to leave, and he has one additional question.

Senator Rockefeller?

The CHAIRMAN. Thank you, Senator.

This is interesting—shortage of venture capital, all the rest of it. But given good times, given bad times, we tend to invest our dollars—a classically American thing to do—in basic research, in other words, go find something. But we only invest a very small fraction of that, 2 percent, in translational research.

The Japanese and the Germans, for example, they're basically taking our basic research, and they're applying it in their countries through developmental applications. And I want to know if you think this is true. If we're going to do—it's just like doing anything. You can't sort of throw money out there and let people have at it. I mean, you've got to focus—you want to take a shot?

Dr. MIRKIN. Yes, I will take it. I think what you're saying is in part true, and it was probably worse 20 years ago. With the patenting system that's in place and people honoring patents more now, it has become less of an issue. And it's important to remember that most of the patenting occurs at the early basic science and discovery portion of the research phase, and that gets you the protection that you want. And, oftentimes, it's not clear—why do you invest in basic research as opposed to just bet it all on one thing? Well, basic research has led to a lot of things that we didn't anticipate in terms of technology.

Northwestern is sitting on the biggest technology transfer deals in the history of technology transfer. It's called the drug, Lyrica. It was developed 20 years ago by a guy named Rick Silverman. And he had some ideas of how it was ultimately going to be used. But it was protected and then developed by a company—Pfizer in this case—and it's now a blockbuster drug that's out there. And it's producing a lot of revenue that's coming ultimately back to Northwestern and going into research and building buildings and things like that that will keep pushing things forward.

I think it's important now in this area of nanotechnology to have a balance. But I think it's really critical that we don't ignore the basic research side of things. We have to have it. That's really the engine that creates a lot of the ideas that lead to translation.

The CHAIRMAN. I don't think I suggested ignoring it. But you have to admit if 2 percent goes into translational research, that's not very much.

Dr. MIRKIN. Oh, I know. That's why my recommendation was to expand the translational component and keep the basic research at a reasonable level so that we're constantly planting the seeds for the next stage. No, I agree there's an imbalance.

Dr. MCLENDON. Can I add to that? I think there are multiple ways that I was alluding to in my answer to Senator Boozman to do that. You can do that by directing funding, and perhaps that's one way to do it. I think Chad would argue that if you use up all the seed corn, that may be a flawed strategy. Another way to do that is to create incentives for private industry to co-invest or for individual investors to co-invest. That's another way to build these public-private partnerships.

There's no question in my mind, at least, that you need a public-private partnership to commercialize the nascent technologies that are invented in our national laboratories, in our universities, and elsewhere that the Federal Government has supported. We haven't done as good a job in translating those to commercial practice as I personally would like to see.

Dr. O'NEAL. I couldn't agree with you more. I mean, we really need to get excited about the commercialization part. Every time I hear a pitch by one of our scientists to a venture capitalist, they spend 25 minutes of a 27-minute presentation on the science. They get so excited, and it really is fun stuff. But they've really got to get excited about the business opportunity. We need to kind of complete the process here or the life cycle of the stuff and get it out. And efforts and a sense of urgency to get this stuff commercialized—we all need to kind of prepare ways to do it and get as excited about translation and commercialization as we do about the science.

Dr. LESLIE-PELECKY. I've actually just come from reviewing SBIR grants, and I can tell you that one of the things that we saw there is that because of the interdisciplinarity of these applications, you have materials companies trying to do biological things and biology-based companies trying to do materials things. You need that joint expertise. We have a lot of companies that really want to go in that direction, but they're heavy on one side or the other, and they need to expand before they can really move forward.

The CHAIRMAN. I want to thank Senator Ayotte and you, Mr. Chairman, for your courtesy.

And I apologize to the panel. You've more than lived up to your billing.

Senator NELSON. Indeed.

Senator Ayotte?

Senator AYOTTE. Thank you, Mr. Chairman.

I wanted to follow up, Dr. Pelecky. You said you review SBIR grants. Can you help me understand how the Nanotechnology Initiative is interfacing with the SBIR grants? I'm a strong supporter of this program, and I think it provides what we're hearing about today. How does that all get coordinated? And can you help me understand—maybe Dr. Romine could jump in as well—how we are making sure that we're interfacing together here?

Dr. LESLIE-PELECKY. Well, for example, the programs that I normally review for are programs that are targeted calls for the use of nanotechnology to address diagnosis and treatment of cancer. They are specifically focused on nanotechnology, and I believe that's all done through the NNI.

Senator AYOTTE. This was one of the issues that arose in my mind when I was preparing for this hearing—because when you examine the National Nanotechnology Initiative, it's basically coordinating the activities of 25 agencies, 15 of which have specific budgets for R&D. And one of the issues that just came to my mind immediately, and I would love to hear from those who are applying for grants. When you're dealing with multiple agencies like that, how has your experience been, number one? And how has the coordination been? What can we do better to make sure that the money is in the right place? Should we be centralizing more? Are we making it too difficult for you? How can we make it easier?

I'd start with Dr. Mirkin.

Dr. MIRKIN. Well, I mean, I think, in general, it's been pretty good. I mean, there has been a learning process. I think that the centers have been examples of Federal agencies cross-coordinating with one another and learning from what worked with one group and imparting that into the next call with the other. I think the CCNE efforts that I alluded to from the NCI were based in part on some of the experience that the NSF had with the Nanoscale Science and Engineering Centers.

This is a really tough thing to do, because in many respects, the NNI is kind of an influence that's making—not making, but incentivizing or telling agencies to invest in this particular area, and then it's left up to them to figure out how they are going to do it. And I think what's happened over the last decade is we've gotten a tremendous amount done, but we've lost some focus. And that's why I really think this signature initiative issue is really quite important in getting the agencies to come together and figure out what it is that we're going to go after, what bets we're going to make, and to create a theme of excellence in a few areas and really develop them extremely well.

Senator AYOTTE. I appreciate that. And as a follow-up, I certainly want to hear the rest of the panelists' comments on this issue, because I can see when we have 25 agencies involved with 15 different R&D budgets, we put a little bit in a lot of places, but not enough focus to make results the top priority.

Dr. MIRKIN. Right.

Senator AYOTTE. And that's one of the things I would like to see us address, certainly in this committee, as we look at the reauthorization.

Dr. ROMINE. So if I could make a comment a little bit on this, one of the values and, in fact, one of the essential characteristics of an office like the Nanotechnology Coordination Office is precisely that issue that the investments that the Federal Government is making are distributed over quite a number of agencies. And left to their own devices, they would do exactly what they need to do in their mission space.

By coming together and coordinating and acquainting each other with the kinds of investments that are made, two things happen. One is you get the kind of synergy that you would like to see with respect to optimizing the investments, that is, agencies will recognize when there are things that are going on that are relevant. But, more importantly, they can meet in a forum that allows this sort of development of the kind of strategic vision for the overall national program that's needed. And so the strategic initiatives is a tangible representation of that.

Senator AYOTTE. I really appreciate that initiative and what you're doing. But I'd also like to have us consider as the fundamental question, should all this money be in 25 different—or 15 different R&D budgets? I think this issue is something that needs to be looked, because one of the concerns I have is that sometimes it's not so easy to deal with the Federal Government. Furthermore, when you're dealing with multiple agencies and different requirements, it can be quite challenging. Those of you who are applying for grants to try to develop these incredibly innovative ideas and research that we hope will lead to the great development of the economy as well as lifesaving devices and products will have to deal with this. If anyone has any insight on this, I'd appreciate that as well.

Dr. LESLIE-PELECKY. I really like the idea of the targeted calls for proposals that are between, say, NSF and NIH. It's much easier for me to deal with a request for proposals and let the two agencies coordinate, or the NNCO coordinate, than it is for me to try to figure out how I split my research and get this part of it funded by NSF and this part of it funded by NIH.

Dr. O'NEAL. I concur with that. These are all topic-driven, you know. When folks go scanning the periodicals for what they want to do, they go by agency and they look for very specific topics, and they try to match what they're doing with a problem someone wants solved in an agency. If you can solve a bigger picture problem by bringing agencies together and having multidisciplinary calls, that would probably be a really interesting way to fund some of this stuff.

Dr. MCLENDON. Yes. I agree.

Senator AYOTTE. Thank you very much. And if I have just one more minute, I wanted to ask something of Dr. Mirkin who just talked to us about his experience of bringing in $20 million of research that was then translated into a successful company that produces diagnostic tools which venture capitalists invested in.

I know Dr. McLendon talked about this in his testimony and is going to provide a supplementation for the record on some of the barriers for venture capital investment that don't just apply to this area but probably would apply across the board. However, you've had the experience of getting venture capitalists investing in research-based companies and how that is translated into success. Could you share that experience with us, what insight you might have on how we could help with that, and what would be best for how we're addressing these issues?

Dr. MIRKIN. It's an interesting question, and I guess I'll go back to—I think Professor McLendon answered Senator Rockefeller's question maybe better than I did, in the sense that my experience has been that nanotech was this incredible opportunity in terms of science. But if we really were to see the impact that everybody wanted out of it, you're going to have to create a way of not only making discoveries but translating those discoveries into technologies that could impact the masses.

And early on, I realized that we'd have to build a structure that would allow us to get venture capital and begin to see these ideas in the form of startup companies. And so that's one of the reasons I started the institute at Northwestern. It's now grown to a half a billion dollar institute and brings the best and the brightest all over the world there to develop these types of ideas. It also brings venture capitalists in. It builds a structure that has enough critical mass that allows you to get people that are interested and that have the ability to invest to pitch ideas to. And so I used three examples for mine. We actually have 16 out of the institute and over $600 million now in terms of venture capital and related investment, which, to me, is extraordinary. If you look at that pre-nanotech, that just didn't happen at Northwestern.

And so I think there's a model there, and the model probably isn't moving the dollars from basic research to translational research. It's using mechanisms that take what we discover on the basic science side and lowering the barriers to getting those investments in place. And the barriers exist because of interactions, so you have to have an ecosystem. You have to have good ideas, good technology, wealthy folks who want to invest and take risks—and then you have to have talent, and you have to have ways of bringing talent to a location that might ordinarily not have talent, for example, on the business side. And that comes from building a critical mass.

So that's why I'm a believer. You alluded to—I think the U.S. has to have major arteries in these areas. And I think—and that doesn't mean you have to put everything in one spot. But we have to have a few bets that we make where we have international presence and people know this is the best place in the world to do this, because that then satisfies a lot of the requirements that I just articulated in terms of what's required to take basic science and translate it into commercializable technology and startup companies.

Senator AYOTTE. Dr. O'Neal?

Dr. O'NEAL. Just a simple answer from the VCs I talk to when we try to introduce nanotechnology companies to them —the ones that are technology agnostic, if you will, view nanoscience as really a very high risk, you know, not a well understood area, and with long lead times, sometimes, before they can get their money back. They just want to know how they're going to get their money back—it really is that simple—in a reasonable amount of time. And the time lags on nanotechnology—usually three to 10 years, which is longer than a lot of appetites for VCs. And it's a little higher risk, and there are a lot of unknowns. So they go to something safer, and a lot of times, they go to stuff further downstream.

Senator AYOTTE. But it sounds like given the successful model at Northwestern, the venture capitalists were also well aware of some of the risk. They're getting a great return on their investment, based on some of the things you discussed, even though it is a longer amount of time to invest. Hopefully, we can encourage venture capitalists to engage in what is, I believe, a very exciting field. And I'm also looking forward to hearing Dr. McLendon's more detailed answer, and I hope you'll all feel free to supplement the record on this, in terms of what's impeding venture capital. We know it's obviously well beyond the issues we're talking about in this hearing, having to do with the regulatory context and the economic issues that are impacting our country right now. But I know I would certainly like to know your views on this.

Thank you very much for being here today.

Senator NELSON. Thank you, Senator Ayotte.

The senior senator from Arkansas.

STATEMENT OF HON. MARK PRYOR, U.S. SENATOR FROM ARKANSAS

Senator PRYOR. Thank you. Thank you very much.

I want to follow up on the Senator's questions and comments there as she concluded, and that is—I actually filed a bill earlier this year. It's S. 256, The American Opportunity Act. And what it would do is provide a 25 percent Federal tax credit to angel investors and venture funds that invest in early stage technology companies. And, really, I think the goal of that would be to help folks in this area, and other areas, but help folks in this area try to get that necessary capital to try to get these ideas out into the marketplace. And so while I have a captive audience here, I would like to just get a comment or two. I don't know if you all are aware of that bill—but certainly that concept. How does that strike you?

Dr. MCLENDON. Let me start with that one. Like Dr. Mirkin, I've been involved in starting several companies that were funded by venture. And I think NanoSphere was started around 2001. Isn't that right? Yes. So in 2000, it was easier to raise money than it was in 2007—trust me, 2007.

Dr. MIRKIN. That was the implosion of the bubble. It was not easy.

Dr. MCLENDON. But I think it's a—you know, it's a very creative approach, and I think people look at total return. And total return includes things like investment credits. So it would certainly affect my own decisions, because I also reinvest now through some venture funds.

Senator PRYOR. Anybody—yes, sir.

Dr. MIRKIN. Actually, I think it's a very good idea. Professor McLendon really, I think, articulated the problem well in the sense that, ironically, in bad times, we're talking about cuts that might, you know, affect the research. But also the bar has been raised in terms of investment at the same time. So you've got two things that are not helping the translation of basic research into commercializable technology. So anything you can do to lower the bar to get investment either from individuals, venture capitalists, or partner companies into these small startup entities is a major bonus and something that will lead to more productivity in terms of startups and, I think, a greater success in terms of startup enterprises.

And that's really the challenge, because if you can get up partners, obviously, you can get a significant investment, and you have a chance to really vet the idea and see if it has a shot of going primetime.

Senator PRYOR. Yes. The other thing that I've heard today is the panel and others have used the term, nanomanufacturing. And my working definition of that is just taking these ideas that you all come up with and just getting them out into the marketplace so they can help, as one of you said, the masses—but make them available and, you know, to be able to actually manufacture them to scale in a way that they can actually get out and do all the things that they do.

And so from my standpoint, I think the venture capital idea—what we're trying to do is try to incentivize that. I think that helps. But also these public-private partnerships help. And I would like to ask you all about public-private partnerships.

Let me start with Dr. Romine.

Dr. ROMINE. Yes.

Senator PRYOR. Start with Dr. Romine about that, because I know that NIST and others have been involved in public-private partnerships, and I'd just like to get your sense of the track record. Are we utilizing those enough? And is that something that makes sense down the road? So go ahead and talk to us.

Dr. ROMINE. I think the track record is good. I talked in my testimony a little bit about the NRI, the Nanoelectronics Research Initiative, and I think that's been a very successful model in bringing together the various stakeholders and leveraging investments across the public and private sectors in a very effective way. Following up on your nanomanufacturing remark, we have a fairly robust nanomanufacturing activity at NIST, where we're investing in the development of nanomanufacturing technologies. Our proposal is to double that in the 2012 timeframe. So the president's request for 2012 for NIST in nanomanufacturing roughly doubles that amount.

From NIST's point of view, one of the things that we do on behalf of industry for the U.S. is we provide sort of a coordinating role for the development of standards in this space. We produce standard reference materials. Our Technology Innovation Program has invested a substantial amount in nanomanufacturing as well. So I think those kinds of funding opportunities that do engage the private sector can be very, very effective.

Dr. MCLENDON. Can I give one parochial example?

Senator PRYOR. Yes.

Dr. MCLENDON. At Rice, we have something called LANCER. It's the Lockheed Advanced Nanotechnology Center at Rice. And that basically matches Federal dollars with Lockheed-Martin dollars so that they essentially look at the fundamental work that we're doing and say, "Ah, there's something that we could use. Can we put one of our scientists and engineers alongside of one of your scientists and figure out how to take that material, integrate it into a much more complicated system in which that material will be useful?" So by itself, it might or might not have been able to attain its full utility. In their hands, they can see how it will be extraordinarily useful. And in the process, we've helped educate a couple of hundred Lockheed-Martin scientists and engineers in nanotechnology. So that's been an extremely productive partnership on both sides. And I'm certain there are many opportunities to do things like that at Northwestern or UCF or other places across the country.

Senator PRYOR. Thank you.

Mr. Chairman, I have several more questions for the record.

But, if possible, I would like to ask one of Dr. Leslie-Pelecky if you would grant me a little extra time.

And that would be—I appreciate your testimony and what you did in your written testimony about research on bioactivity and toxicology of nanomaterials. And I'm just curious why you think it's important that we have a robust R&D program in nanotoxicology. Why is that so significant?

Dr. LESLIE-PELECKY. Well, if I'm going to start a company and I want to make a product that involves nanomaterials, I want to know that it's going to be safe. I want to know when people are working in my factory that they are working in a safe environment. And you can't do that without that basic knowledge.

Senator PRYOR. Yes. That's kind of where I am on that too. And I just want to make sure that we, as the government—and probably in this case, it would be FDA—would have the capability of doing the testing and the necessary analysis to make sure that these great, wonderful, amazing new products that are coming out are safe, not just for human consumption or what-not, but also for the environment. So I just think that we need to really make sure that FDA and others, whoever that may be, would have that capability to do that testing and assure the public that what we're doing is safe.

Dr. LESLIE-PELECKY. Well, if I may, there's actually a huge opportunity there for companies, because a company that can come up with ways of doing this testing quickly and in real time—there's a lot of need for that right now.

Senator PRYOR. Thank you, Mr. Chairman.

Senator NELSON. Thank you, Senator Pryor.

Dr. McLendon, give us an example on that Lockheed case where there's a Lockheed scientist with one of your scientists. What are they developing?

Dr. MCLENDON. Let me just be——

Senator NELSON. Is it a secret?

Dr. MCLENDON. No, no. It's not a secret, actually. I've got a picture in my mind and it's going to take me a minute to get at it. So if I can use that as a question for the record, I will get you——

Senator NELSON. OK.

Dr. MCLENDON.—exactly the information that you want in the way that will be most useful for you.

Senator NELSON. Sure.

Dr. MCLENDON. Is the OK?

Senator NELSON. Sure.

Senator Boozman?

Senator BOOZMAN. Thank you, Mr. Chairman.

Dr. Romine, has NIST and NSF moved forward with implementing the President's signature initiatives? Does NIST have a plan for ensuring that R&D participation—participation with the EPSCoR universities?

Dr. ROMINE. Senator, I'll have to double check. I don't have a specific recollection of EPSCoR universities being spelled out in the planning that we have. But I can certainly go back and take a look to make sure. I'd prefer to get back to you with an accurate answer rather than trying to wing it.

Senator BOOZMAN. Good. I would appreciate that, and I really do think that's very important.

Dr. ROMINE. OK.

[Dr. Romine provided the following information in response.]

The NNI is moving forward with implementing the three nanotechnology signature initiatives on sustainable nanomanufacturing, nanotechnology for solar energy collection and conversion, and nanoelectronics for 2020 and beyond. Descriptions of these initiatives can be found in the 2011 NNI Strategic Plan, and agency-specific investments were reported in the NNI Supplement to the President's Fiscal Year Budget. Each of the initiatives has participation from a number of agencies in addition to NIST and NSF; NIST is an active participant in each of these groups, which are continuing to refine implementation plans. These plans identify research thrust areas and desired outcomes, including the formation of industry and academic partnerships. Though not explicitly stated in the initiative descriptions, the inclusion of EPSCoR universities as appropriate would be consistent with the spirit of the education and outreach goals expressed in the NNI Strategic Plan.

Senator BOOZMAN. With regards to nanotechnology, could you further clarify the difference between the strategy and goals for the administration's new proposed program, AMTech, and the work being done currently at NIST through the Technology Innovation Program?

Dr. ROMINE. Certainly. The Technology Innovation Program is a funding program for small businesses through a cost-sharing environment to tackle some very challenging and difficult problems. With respect to the way that we envision the AMTech program, it's patterned much more along the lines of the NRI that I talked about earlier, it's a consortium model that involves bringing together collections of businesses in a particular sector of manufacturing to tackle some of the precompetitive challenges that are associated with specific technological barriers in manufacturing. And so I think, based on the experience that we've had with the NRI and our ability to play that kind of convening role with respect to industry representatives, this, in this case, would involve not just small businesses the way that the Technology Innovation Program does, but broad sector representation. And I think we'll have some dramatic successes in that area in driving manufacturing forward.

Senator BOOZMAN. Very good.

Dr. Mirkin, I understand that you were an NSF post-doctoral fellow prior to becoming a professor. Could you share with the Committee the impact your federally funded fellowship had on your current success as a researcher and innovator?

Dr. MIRKIN. It had an incredible impact, because it gave me the opportunity to start my career post-Ph.D. at MIT, to get interested in how things are different when they're miniaturized, which led to then the development of the modern field of nanoscience and nanotechnology, and is in large part the reason I'm here today talking to you.

Senator BOOZMAN. That's really a great story. How do you think we should use scientific curriculum to better prepare students that want to go into nanotechnology?

Dr. MIRKIN. The good news is that a lot of kids do want to go into nanotechnology. I would say that right now, when I talk to young scientists and engineers, they want to either do nanotech or something environmentally related. They feel like there's something really special here and a way they can change the world and impact the world for the better.

And what that means is that we need to rethink the way we teach a lot of the old disciplines, not that you get rid of them, but you teach them in the context of these new fields. And we were talking before this testimony started that at Northwestern, I've done that in courses as early as general chemistry, where you begin to talk about how nanotechnology pertains to chemistry and vice versa. And the kids absolutely love that. They begin to feel like they're learning something that's really part of the next 100 years, not the last 200 years. And I think we're going to see a lot more of that over the next decade. A lot of the discoveries that we've made over the last decade are going to mandate that we begin to build new curricula that get incorporated into universities. And the good news is that that's happening, and the NSF has played a very big role in helping to make that happen.

Senator BOOZMAN. Good. Thank you. I think that myself and Senator Nelson also feel like there's something very special in this field, and we'll be very supportive.

Thank you, Mr. Chairman. I yield back.

Senator NELSON. Dr. O'Neal, you talked about the private-public partnerships, especially with regard to our state. What states are doing a particularly good job of sustaining nanotechnology industries?

Dr. O'NEAL. I'd have to look that up and give you an intelligent answer. I could put that on the record. Certainly, I think about the common things in—California and the Northeast are the ones that come to mind. I think there's some good work going on in Texas and—a lot of people doing good work, but we really need to concentrate on, you know, the whole spectrum of basic to applied to translational research.

Senator NELSON. And so the best practices that you think that other states ought to consider would be a lot of this bringing together of private partner—public partnerships? Standards—what do you think about the standards?

Dr. O'NEAL. I think that—yes, I think there needs to be some. Certainly, people need to be able to have a common vocabulary and know how they're going to work with each other.

Senator NELSON. And, Dr. Romine, this is in your bailiwick. Do you think the current Federal efforts to support these standards are adequate?

Dr. ROMINE. Adequacy is a tough question. I will say there's a substantial effort. NIST, under the authority in the NTTAA, the National Technology Transfer and Advancement Act, provides a coordinating role for the development of standards across this space, internationally and across the Federal Government. And I think that collection of activities at NIST that involves the coordination function but also the development of standard reference materials, of data that we make available, of testing methodologies and so on, I think is working well.

Senator NELSON. Are other countries improving on the standards so that they're getting the jump on us to commercialize?

Dr. ROMINE. I wouldn't characterize it that way. I would say other countries are certainly becoming more aware of the importance of participation in the international arena of standards. And so we are still engaging with, I'd say, more countries who are becoming more knowledgeable in this space. So that, obviously, represents some change in the landscape. But I think, overall, I wouldn't characterize it as being a threat.

Dr. MCLENDON. I'm not sure about standards, but I do know—I just got back from China and Brazil, where I spent a good bit of time talking to leading researchers there about nanotechnology. And each of those countries have their own functional equivalent to the National Nanotechnology Initiative, and they are pushing these initiatives really hard. And so I'm thrilled to be a citizen of the country that's the leader in this field, but it's not a God-given right that we will always be that leader.

Senator NELSON. Amen to that. And isn't that typical of the U.S., that we get something started and then others pick it up? And we just don't—in this promising field, we do not want that to happen here.

Dr. MCLENDON. Absolutely. Yes, sir.

Senator NELSON. Would you all—just my curiosity—since a lot of you are physicists—the two of us are scientists, but we're political scientists. By the way, I was the first and only lawyer to go into space, and NASA has still not publicized that fact.

[Laughter.]

Senator NELSON. So our curiosity is what is it about these microparticles that will actually change composition? For example, I understand that color can be different in a nanoparticle. A particle may be hard or soft, and in a nanoparticle, it's the opposite.

Dr. Mirkin?

Dr. MIRKIN. As I said, I think that's really one of the interesting things about the field and the real opportunities, and that is that everything old becomes new and miniaturized. If you take gold and shrink it down to a 10 nanometer particle, it's no longer gold in color. It's red. If you turn that 10 nanometer spherical particle into a triangular prism—it's a little nanoDorito—it's now blue in color. And so the beauty of nanotech is you don't have to take what nature gave you in terms of bulk form. You can begin to take the raw materials and shape them, if you're a good nanoarchitect, and get the properties you want for a given application. And that's why it's so powerful, because whether you're talking about nanomedicine, energy, developing tools to study the environment, all of those require new types of materials, and the fastest way to new materials is through this miniaturization effort. And I think that's what we have to capitalize upon.

Dr. MCLENDON. You're at that unique interface between single molecules, which behave according to quantum mechanics, and bulk systems that behave according to Newtonian mechanics. And you're in that funny space where things are starting to transition.

When Professor Mirkin was talking about some of the nanogold shells in response to Senator Rockefeller's question, it turns out that another way—this is the way that I alluded to from my research colleagues—by creating—whether they're nanospheres or nanoDoritos or whatever your favorite snack food is—that you can tune the color to a place where only the nanoparticle absorbs and the body doesn't absorb. And that allows you, instead of using ionizing radiation, to use infrared lights. And infrared lights are basically pretty benign things. But they'll heat up the particles which have been directed to the tumors in ways that Dr. Pelecky talked about. So you only heat up the tumor. You don't heat up the body, and that allows you to destroy things without using any of the ionizing radiation at all.

So there are really extraordinary things that can be done, but only if you've invested in the fundamental research which allows you to understand all those optical properties which was all done without thinking about, "Ah, we're going to use this knowledge to create a unique tumor destroying missile." It was done to understand the fundamental properties, and once you understood that, then a next generation of people could come in and say, "That is so cool. Now we can destroy tumors selectively." So that's why it's so important to do that basic investment.

Senator NELSON. Does the nanoparticle get to the submolecule level, or is it at the molecule level?

Dr. MIRKIN. No. A nanoparticle is actually in between a molecule and a bulk material. And it's this in-between scale that is so interesting.

Senator NELSON. Is it a combination of molecules?

Dr. MIRKIN. Yes. It can be a combination of molecules. It can be a collection of atoms. That's what is often confused, I think, in the popular press. The size is not the issue. We've been working with molecules for a long time. They're smaller than the nanostructures that we're talking about. It's this in-between region that is so fascinating, where the properties are different from molecules and different from the bulk materials, where you can find these fantastic ways of tailoring those properties to get what you want in terms of a given application.

Senator NELSON. Does the research into the subatomic particles ever spill over into nanotechnology?

Dr. MIRKIN. Not really. That's nuclear chemistry, nuclear physics.

Dr. MCLENDON. Some of the high-energy technologies, like synchotron-based radiation, turn out to be incredibly useful tools for investigating these unusual materials, however.

Senator NELSON. Senator, any more?

Senator BOOZMAN. No. Thank you, Mr. Chairman.

And I just want to thank the panel for being here and your hard work. You can be very proud of pushing forward in such an important field. Thank you all.

Senator NELSON. Indeed, this has been most illuminating. Thank you. Have a great day. The meeting is adjourned.

[Whereupon, at 12:02 p.m., the hearing was adjourned.]

A P P E N D I X

PREPARED STATEMENT OF HON. MARK PRYOR, U.S. SENATOR FROM ARKANSAS

Chairman Nelson and Ranking Member Boozman:

The National Nanotechnology Initiative is at an important crossroad. The future holds exciting opportunities to apply nanotechnology to medicine, defense, energy, and the environment. To date, our focus has been on scientific discovery. I believe in the next five years we need to make it a priority to move nanotechnology from the laboratory to the marketplace.

In December 2003, President Bush signed into law the 21st Century Nanotechnology Research and Development Act. This law authorized $809 million in Fiscal Year 2005 for nanotechnology research by five Federal agencies. Since then, the NNI program has grown to include 25 Federal agencies with a requested research budget of $2.13 billion in Fiscal Year 2012.

The United States remains the world leader in nanotechnology research and development. Our universities and companies are producing the most significant scientific discovery, our technical papers are the most widely cited, and our patents are the most valuable.

However, the world nanotechnology pie is evenly divided among the United States, Europe, Asia (Japan, China, South Korea, and Singapore), and the rest of the world. It is not clear which countries will be the fastest to commercialize the research being conducted.

Many people in the United States believe the Federal Government should only fund research and development and that it is the responsibility of companies to commercialize the technology. Unfortunately, there is a gap, the so called "valley of death", where the research needs to mature before companies are willing to invest capital.

The second large challenge facing nanotechnology is the environmental, health and safety (EHS) implications of nanomaterials. Many consumer products are already being sold that contain nanomaterials. That is why last Congress I introduced the FDA Nanotechnology Regulatory Science Act to give the FDA the resources necessary to make sure that over-the-counter drugs and cosmetics, food additives, biologics, and medical devices can be proved to be safe.

The Federal Government does a good job funding research in nanotechnology and, of course, the private sector is responsible for commercializing the R&D. What role the Federal Government should play in the space between R&D and product development remains the subject of debate.

Mr. Chairman, thank you for holding this important hearing and I look forward to the testimony of the witnesses.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN D. ROCKEFELLER IV TO DR. CHAD A. MIRKIN

Manufacturing

Question 1. Nanomanufacturing is the bridge that connects nanoscience with nanotechnology products and is essential if we are to realize the economic returns on this technology. However, nanomanufacturing infrastructure and techniques are in their infancy. How significant a barrier to nanotechnology commercialization is the absence of nanomanufacturing infrastructure, such as equipment, tools, processes, and systems?

Answer. The absence of a nanomanufacturing infrastructure is very significant. A large challenge in transitioning the ideas and technologies created from basic research into a commercial market is the cost of developing new infrastructure for mass production. Even if the new technologies generated via basic research are an improvement over current methods, they may not be readily adopted unless the improvement is significant enough to warrant the capital investment. This barrier depends greatly on the field, and is governed by how technological improvements are weighed against resistance to change.

Question 2. To make sure the United States is the global leader in nanomanufacturing, what should the Federal investment be in infrastructure development? And in what areas should we invest?

Answer. In order to lead in nanomanufacturing, it is crucial to make sure novel technology is transferred from the laboratory to industry. In addition to funding basic research to ensure a constant stream of new ideas, funding should support start-up companies and public-private partnerships (*e.g.,* STTR and SBIR), and incentivize adoption of new techniques. In addition, centers of excellence with equipment infrastructure that can be used by many are very important. Finally, we should challenge U.S. professors and students to translate their advances in nanotechnology into systems that can define our new economy. Reducing regulation and compliance burdens that create a disincentive to get involved in such activities should be considered (we are sending mixed messages). We need an American renaissance with respect to technological innovation, and we should embrace and encourage entrepreneurial activities at universities and government labs where many key discoveries and advances are made.

Workforce training and education

Question 3. Dr. McLendon's testimony indicated that the nanotechnology workforce should reach 800,000 by 2015. This sort of job growth would go a long way toward economic improvements. How can the United States make sure we have an adequate supply of engineers and technicians to support nanomanufacturing and the overall job growth projected for the field?

Answer. First, it is important to state that nanotechnology is not a single discipline but rather a collective way of thinking about and developing materials whose sole unifying characteristic is their size, and that these materials are common in all areas of scientific research. Therefore, any effort to increase the nanotechnology workforce should have facets in all disciplines. Additionally, securing our future nanotechnology workforce will require initiatives in at least three areas: (1) programs to retrain adult workers to be competitive as engineers and technicians for nanomanufacturing, (2) strong support for young researchers at the undergraduate and graduate levels, and (3) public outreach and education to capture the imagination of the younger generation. Finally, we must acknowledge that not all of the most talented candidates are here in the United States, so we must continue to attract international talent as well through our immigration policies. This is best done through centers of excellence, which act as international hubs for specific subareas of nanotechnology that are nationally important.

Question 4. What approaches will help ensure that both nanomanufacturing capacity and a trained workforce grow in tandem?

Answer. Investment in basic nanotechnology and nanomanufacturing educational goals will provide the raw human capital while simultaneous efforts to strengthen academic and industry ties to build infrastructure will attract these students to join the workforce. Creating hubs of specific areas of science and industry analogous to Silicon Valley or the research triangle would facilitate this. This would enable the smooth transition of technology from the academic research laboratory to industry and provide and act as centers for training and job opportunities in specific fields of nanotechnology.

Financing

Question 5. Financing is extremely challenging for those attempting to bring nanotechnology to market, because the path from invention to commercial production is often particularly expensive, risky, and lengthy. Dr. O'Neal, you mention in your testimony that a three to 10 year delay is typical in this area of technology. To what extent have capital issues hampered nanotechnology commercialization?

Answer. The bar for venture capital has been raised, which has widened the so-called "valley of death." Universities and government labs have replaced the role of the industrial research lab, which means technologies must be further developed before they can be licensed to an existing company or attract venture capital. We need efforts and policies that help move such technologies over these "bars" so they can attract private investment and have a legitimate shot at commercialization.

Question 6. If the venture capital community is focused primarily on short-term funding, what class of institutional investors do you think is most likely to support nanotechnology companies?

Answer. There will be a mix of venture capital and strategic partnerships with corporations. Many American corporations are establishing corporate VC arms to facilitate such investments.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. BILL NELSON TO
DR. CHAD A. MIRKIN

Technology Transfer

Question 1. A large share of NNI funding supports research at universities and Federal laboratories. Last year's review of the NNI cited the need to increase the focus on the transfer of technology from the research community to the private sector. How effectively is the knowledge generated by NNI investments being transferred from universities and Federal labs to the private sector?

Answer. See testimony.

Question 2. What mechanisms are Universities using today to facilitate this transfer and which are the most effective?

Answer. The universities I have worked with deal with this through technology transfer offices and licensing. Start-up companies are playing much larger roles, and in many respects are filling the void created by large companies shutting down their corporate R and D efforts.

Question 3. Dr. Mirkin, some feel that the National Science Foundation should do more than basic research. Since a key to realizing the economic potential of nanotechnology is the technology transfer and commercialization of basic research, should we expand their role in these areas? Why or why not?

Answer. The NSF should be focused on basic research; it is essential that we maintain a strong commitment to building the knowledge base from which commercialization and product development can arise. Partnerships between the NSF and the mission-oriented agencies, might be a way to capitalize upon the translational aspects of nanotechnology. The CCNE program at the NCI is an outstanding model for the effective use of funds for translational efforts.

Public Outreach

Question 4. Public understanding of nanotechnology will affect both the level of government investments in nanotechnology R&D and the consumer willingness to accept nanotechnology products. In many cases the American public may be unaware that basic products like sunscreen can contain nanoparticles. Is the American public sufficiently familiar with nanotechnology to judge its potential benefits and risks appropriately?

Answer. In general, the American public seems to embrace nanotechnology and understand that although it has risks, like any new technology, its benefits outweigh such risks.

Question 5. Are you concerned that a campaign to improve public understanding might, in fact, result in a backlash against nanotechnology R&D due to the potential safety implications?

Answer. Improving the public understanding can be extremely helpful, so long as the safety concerns are properly elucidated. Presenting examples of nanotechnology with familiar analogies, such as silica nanoparticles as fine sand or iron oxide nanoparticles as tiny bar magnets, can make the technology less foreign. It would also be beneficial to discuss naturally occurring nanostructures, like high-density lipoprotein (HDL), a biological entity necessary for regulating cholesterol levels in the human body. The most important benefit to be gained from educating the public is that nanomaterials are as diverse as regular materials, and that, while new methods and procedures will be needed to properly examine, monitor and regulate them, these procedures can and will be developed just as they have been for non-nanotechnology based materials.

Maximizing Return on Investment from the NNI

Question 6. Since the original authorization for the NNI expired in 2008, numerous attempts have been made to authorize the program. What do you think is needed in a reauthorization to improve the program overall and increase its return on investment?

Answer. See my testimony.

Question 7. Dr. Mirkin, one criticism of the NNI is that there is no central funding source for nanotechnology investments, but that instead funding is determined through each agency's internal budget development process. Have you found this process encourages the development of "funding silos" where certain research areas become captive to single agencies and their funding levels?

Answer. No.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARK PRYOR TO DR. CHAD A. MIRKIN

Question 1. You recommend that the NNI have a focus on signature initiatives such as the development of nanomaterials to enable the development of nanomedicine, advanced nanomanufacturing, and nanomaterials for environmental monitoring and remediation. These initiatives have also been called Grand Challenges and Research Needs of National Importance. What other Grand Challenges should the Federal Government consider? Should the lead agencies be left to self-fund these signature initiatives or should Congress authorize specific multi-year funding for each?

Answer. These change with time and discoveries. The Federal Government should have initiatives in the aforementioned areas, but should also give the agencies the flexibility to identify new opportunities as the field progresses.

Question 2. You are a member of the President' Council of Advisors on Science and Technology (PCAST) which also is designated by Executive Order to serve as the National Nanotechnology Advisory Panel or NNAP. Some people believe the NNAP should be separate from PCAST. What do you think of this idea? What are the pros and cons of PCAST also serving as the NNAP? Is there still a Nanotechnology Technology Advisory Group and, if so, how it is used by the NNAP?

Answer. PCAST as the NNAP is appropriate, as long as PCAST has reasonable representation from the Nanotechnology community. Since nanotechnology does not have a singular research focus, the breadth of PCAST is a strength in the NNAP role.

Question 3. You recommend strengthening the National Nanotechnology Coordination Office (NNCO). Presently the NNCO is funded by contributions from the NNI participating agencies. In Fiscal Year 2011, NNCO funding totaled $2.9 million. Should the NNCO be given a line item budget? If yes, how much annual funding do you recommend?

Answer. Yes. Autonomy is essential. $3.0 million is appropriate. Perhaps having a line item budget would give the NNCO greater autonomy to direct and focus the mission of NNI participants.

Question 4. The States perform a vital role in fostering economic development through business assistance programs, tax incentives, and other means. Some state and local nanotechnology-based economic development initiatives that were begun in the last decade have now disappeared? Why do you think this has happened? How can Federal-State coordination be improved to increase the commercialization of NNI funded research and improve workforce development?

Answer. The breadth of the field is both a blessing and a curse from an economic development standpoint. Unless very organized, the breadth can dilute out recognized nanotech-specific activities. For example, does nanomedicine get classified as nano or lumped in with other pharmaceutical and medical diagnostic development activities? I only have familiarity with Illinois, where the state has been reasonably organized and proactive in terms of supporting nanotech-related translational efforts. Each state needs a go-to person coordinating activities at the state level and working with appropriate individuals at the Federal agencies to maximize effectiveness.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARK WARNER TO DR. CHAD A. MIRKIN

Question 1. Nano-medicine and nano-biology hold significant promise to improve human health. How is the National Nanotechnology Initiative (NNI) supporting this critical area?

Answer. The fundamental research, novel nanoparticle synthesis, and nanomanufacturing capabilities being pursued by many of the Federal agencies, including the NIH, are all necessary components of nanomedicine research and essential in order to enable the widespread use of nanomaterials for health applications. The CCNE program from the NCI is one of the best examples of translational efforts that have brought together researchers from the sciences, engineering, and medicine to make strides in the development of powerful new diagnostic systems and therapeutics for many forms of cancer.

Question 2. Public-private partnerships between universities, government, and industry are key methods to ensure that promising research is developed into useful new technologies and products. One example of such a partnership is the new Virginia Nanoelectronics Center, a partnership of several Virginia Universities, the Commonwealth of Virginia, and Micron Technologies. How does the NNI plan to incentivize, facilitate, and further leverage these kinds of public-private partnerships?

Answer. The NNI offers development services for technology transfer and government infrastructure for R&D.

Question 3. I have heard some concern from nanotechnology researchers regarding the current state of technology transfer for nanotech research. Given that nanotech requires sophisticated manufacturing processes, for instance, to what extent is NNI focused on potential barriers to widespread use of nanotechnology-based products? Do we know, for instance, if printing and imaging technologies used in consumer electronics can be transferred to nanotechnology?

Answer. Yes, for example the integrated circuits in consumer electronics products are currently being made with nanotechnology. Other technologies such as organic LED's are now permeating the market. Not all technologies are this mature, but since they offer unprecedented advantages they can be worth the capital investment.

Question 4. Some scholars have raised ethical concerns about nanotechnology research and its applications. What are the dual use implications of nanotechnology? Should we be paying more attention to the ethical implications of this field and its products? If so, what should we be doing to prevent the possible erosion of public trust in nanotechnology research?

Answer. The dual use implications are as diverse as the nanotechnology itself. For example, a nanotechnology based diagnostic could be used for diagnosing diseases or for detecting biological weapons. Alternatively, a nanotechnology-based antibiotic can be used to treat disease or develop treatment-resistant bacteria. These implications need to be considered aggressively and on a case-by-case basis in order to maintain public trust.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN D. ROCKEFELLER IV TO DR. CHARLES H. ROMINE

Manufacturing

Question 1. Nanomanufacturing is the bridge that connects nanoscience with nanotechnology products and is essential if we are to realize the economic returns on this technology. However, nanomanufacturing infrastructure and techniques are in their infancy. How significant a barrier to nanotechnology commercialization is the absence of nanomanufacturing infrastructure, such as equipment, tools, processes, and systems?

Answer. As described in the National Nanotechnology Initiative (NNI) 2011 Strategic Plan (available at *http://nano.gov*), infrastructure such as national user facilities, cooperative research centers, and regional initiatives are needed in order to achieve the NNI goal to "foster the transfer of new technologies into products for commercial and public benefit." Physical R&D infrastructure for nanoscale fabrication, synthesis, characterization, modeling, design, and training supports another NNI goal to "develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology." The NIST Center for Nanoscale Science and Technology (CNST) national user facility provides infrastructure as the Nation's only nanocenter established with a focus on commerce. The NanoFab, a critical component of the CNST, provides streamlined, rapid access to a suite of world-class nanoscale measurement and fabrication methods and technology.

Question 2. To make sure the United States is the global leader in nanomanufacturing, what should the Federal investment be in infrastructure development? And in what areas should we invest?

Answer. Four National Nanotechnology Initiative goals outline a strategic approach to maintaining U.S. leadership in nanotechnology research and development. The second goal, "Foster the transfer of new technologies into products for commercial and public benefit," is at the heart of Federal investment in infrastructure and nanomanufacturing capabilities. The 2011 NNI Strategic Plan (available at *http://nano.gov*) outlines a number of objectives to achieve progress toward this goal, including a doubling in the share of the NNI investment in nanomanufacturing research over the next five years. Along with establishing new facilities and/or centers to provide infrastructure, the NNI Strategic Plan also identifies the need to sustain existing federally funded physical infrastructure. User facilities such as the NIST NanoFab have the ability to co-locate a broad suite of nanotechnology tools, providing access to expert staff and hands-on training of nanotechnology researchers. The three Nanotechnology Signature Initiatives, described in the NNI Supplement to the President's Fiscal Year 2012 Budget (available at *http://nano.gov*), focus on areas that NNI member agencies have identified as ripe for significant advances through close and targeted program-level interagency collaboration. NIST plays leadership roles in and supports the NNI Nanotechnology Signature Initiatives on Sustainable Nanomanufacturing and on Nanotechnology for Solar Energy Collection and Conversion. NIST also participates in and supports Nanoelectronics for 2020 and Beyond.

Workforce training and education

Question 3. Dr. McLendon's testimony indicated that the nanotechnology workforce should reach 800,000 by 2015. This sort of job growth would go a long way toward economic improvements. How can the United States make sure we have an adequate supply of engineers and technicians to support nanomanufacturing and the overall job growth projected for the field?

Answer. The realization of the promise of nanotechnology to enhance and improve applications from energy to healthcare is reliant on the cultivation of a skilled nanotechnology workforce that will include scientists, engineers, technicians, manufacturers, and laboratory personnel including trainees and students.

There are many proposed strategies to help the U.S. meet the demand for this trained workforce, including those being discussed within Congress to help develop a skilled workforce, the Administration proposals for strengthening STEM education in the U.S., and a number of recent reports from the National Science Board, the National Academies, and the President's Council of Advisors on Science and Technology.[1] Strategies recommended in these reports and discussions include important issues such as the need to cultivate an interest in STEM education with students at an early age, and outreach to the public as well as schools regarding the promise of future careers in science and technology sectors, including nanotechnology. Other essential factors described in these reports include minority representation in STEM and the need to better recognize high-potential STEM innovators from every demographic of our country. As noted in the 2011 NNI Strategic Plan, nanotechnology can help to foster students' interest in STEM because of the unique nature of properties and behaviors at the nanoscale can inspire students by creating a "wow" factor. Support and mentoring of students at all stages of education through undergraduate, graduate, and postgraduate programs, as well as early interactions with industry through internships and other programs, are important aspects in the development of a nanotechnology workforce.

NIST's strong partnerships with educational institutions encourage student interest and participation in STEM. Through a variety of programs, we bring students, post-doctoral fellows, and middle school teachers to our campuses for unique programs that have a direct impact on the creation of a STEM-educated workforce. NIST also supports faculty researchers and students through a variety of competitive grants programs.

Programs include:

- NIST's Postdoctoral Program supports a nationwide competitive postdoctoral program administered in cooperation with the National Academy of Sciences/National Research Council (~50 per year)
- Summer Undergraduate Research Fellowships (~150 per year)
- The NIST Summer Institute for Middle School Science Teachers (~20 per year)

In the past couple of years, nearly 200 scientists have completed postdoctoral research at NIST. These individuals are now employed across a variety of sectors. Based on the most recent data, former NIST postdoctoral researchers can be found in academia (nearly one-third of those reported); industry (in at least 20 different companies ranging from large corporations to small businesses); national laboratories across the U.S.; and government (nearly one-third are now employed at agencies throughout the Federal Government).

Question 4. What approaches will help ensure that both nanomanufacturing capacity and a trained workforce grow in tandem?

Answer. A key mechanism to train the next generation of nanotechnologists at NIST is the extensive postdoctoral research program, conducted through multiple programs and agreements with the National Research Council and a variety of re-

[1] For more information on NSB report, see *http://www.nsf.gov/nsb/stem/innovators.jsp;* National Academies Report, see *http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=12984; PCAST,* see *http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-stemed-report.pdf* and *http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nano-report.pdf.*

search universities. For example, the NIST Center for Nanoscale Science and Technology (CNST) operates by design with a 2-to-1 ratio of postdoctoral researchers to technical staff, ensuring a steady flow of new knowledge, experience, and ideas into the CNST, and the steady "graduation" of scientists or engineers who are fully trained in nanotechnology into the workforce.

The operation of the CNST national user facility contributes in multiple ways to building and sustaining a trained workforce to support nanomanufacturing capacity. Within the CNST, comprehensive training is available on the NanoFab's state-of-the-art commercial tool set for nanofabrication and measurement. The training is designed to prepare users with a range of skills and technical abilities to competently operate the tools they need to use. Because many users will depend on the NanoFab for extensive consultation and help, it is staffed with highly experienced process engineers drawn largely from the semiconductor industry. As a shared national resource open to all, the NanoFab brings NIST scientists together with industry, government, and academic researchers from across the spectrum of nanotechnology applications, fostering the rapid exchange of ideas and best practices related to nanomanufacturing. Researchers from outside NIST can access a host of advanced, beyond-state-of-the-art tools under development through collaboration: either to collaborate in their development or to make early measurements using a tool or method not yet available elsewhere. In addition to the two user facilities on the NIST campus (CNST and the NIST Center for Neutron Research), the NIST laboratories are also a source for educating and training a technology-savvy workforce. Collaborators at NIST include visiting professors, industrial researchers, postdoctoral researchers, graduate students, and undergraduates, with tenures ranging from several days to several years. Local high school students regularly participate in NIST campus events, and the other programs in the NIST laboratories mentioned above (*i.e.,* fellowships for undergraduate students and summer institutes for teachers) are helping to strengthen the pipeline for developing the next generation of scientists and engineers.

Business and Job Creation Within Nanotechnology Environment, Health, and Safety

Question 5. Because nanotechnology is still emerging, the United States is in a position to lead the way in creating international standards for nanotechnology safety and manufacturing. Dr. Romine, to what extent has the lack of nanotechnology-related standards affected the commercialization of nanotechnology products? What are the biggest problem areas?

Answer. The foundational nature of standards means that the availability of the appropriate standards at right times within the technology life cycle can accelerate the commercialization of any new technology, and can further spur innovation within that technology space. The same is true for nanotechnology. Standards addressing nanotechnology-related environment, health and safety (NanoEHS) will bring greater confidence in testing, measuring and evaluating the safety of nanotechnology and nanotechnology-enabled products. Addressing this aspect is an important element in accelerating the responsible commercialization of nanotechnology, which can help both increase the confidence and acceptance of consumers, manufacturers and regulators, and enhance the benefits of nanotechnology along product value chains and life cycles.

The most significant challenges currently lie in thoroughly understanding and accurately predicting the response of nanomaterials in different environments that directly impact the EHS aspects of those materials. The size scale and attributes of these materials is requiring the scientific community to develop new testing methodologies and techniques, new instruments to study these materials and the interactions with the surrounding media. In numerous instances, due to existing fundamental knowledge gaps scientific theories have to be developed, tested and/or refined to better understand and explain the materials and their behavior.

To address these various challenges, work is underway around the world in standards setting organizations such as ASTM International and the International Organization for Standardization (ISO), which will inform the work of the Organization for Economic Cooperation and Development (OECD) as it evaluates guidelines for testing nanomaterials. This work in turn leverages the scientific knowledge being generated through research and development efforts in academic institutions, Federal Government laboratories (including NIST) and the laboratories of small, medium and large enterprises.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. BILL NELSON TO DR. CHARLES H. ROMINE

Nano-Infrastructure

Question 1. The cost and complexity of the infrastructure required for nanotechnology research and commercialization can be a significant barrier to expansion of the industry. What opportunities are available to researchers looking for Federal dollars for infrastructure development and equipment?

Answer. Researchers looking for funding to support infrastructure development and equipment can also look to programs such as the National Science Foundation's Major Research Instrumentation Program (*http://www.nsf.gov/od/oia/programs/mri/*) and opportunities within the Department of Energy, including DOE's five Nanoscale Science Research Centers (*http://science.energy.gov/bes/suf/user-facilities/nanoscale-science-research-centers/*) providing user access to facilities supporting interdisciplinary research at the nanoscale. The NIST Center for Nanoscale Science and Technology user facility supports the U.S. nanotechnology enterprise from discovery to production by providing industry, academia, NIST, and other government agencies with access to world-class nanoscale measurement and fabrication methods and technology. Furthermore, the NIST Technology Innovation Program (TIP) provides cost-shared funding to speed the development of high-risk, high-reward, transformative research. This research is targeted to key societal challenges that are not being addressed elsewhere. The 2010 TIP competition focused on manufacturing technologies, resulting in awards to small and medium-sized companies producing a range of nanotechnology-enabled products in areas including flexible liquid crystal displays, organic photovoltaics, and lithium-ion batteries.

Question 2. What role do you see for the Federal Government in encouraging regional investment strategies for equipment sharing between university and industry clusters?

Answer. As described in the National Nanotechnology Initiative 2011 Strategic Plan, infrastructure such as national user facilities, cooperative research centers, and regional initiatives will help enable the NNI goal to "foster the transfer of new technologies into products for commercial and public benefit." A number of nanocenters are supported by NNI member agencies, including DOE and NSF, and in many cases these are co-located to draw on regional synergies such as technical expertise and manufacturing facilities. The NIST Center for Nanoscale Science and Technology (CNST) national user facility stands out in this regard. The NanoFab, a critical component of the CNST, promotes research by providing streamlined, rapid access to a suite of world-class nanoscale measurement and fabrication methods and technology.

Proposed in Fiscal Year 2012, the NIST Advanced Manufacturing Technology (AMTech) program is intended to support industry-led consortia to develop industry roadmaps and support precompetitive research at universities, following on the successful model of the public-private Nanoelectronics Research Initiative. The AMTech program aims to fill a critical gap for early-stage technology development by supporting precompetitive R&D and enabling technology development, and creating the infrastructure necessary for more efficient promotion of knowledge and technology. This strategy has the potential to drive economic growth, enhance competitiveness and spur the creation of jobs in high-value sectors of the U.S. economy. AMTech is modeled on NIST's successful interactions with the semiconductor industry via a partnership with the Nanoelectronics Research Initiative.

Public Outreach

Question 3. Public understanding of nanotechnology will affect both the level of government investments in nanotechnology R&D and the consumer willingness to accept nanotechnology products. In many cases the American public may be unaware that basic products like sunscreen can contain nanoparticles. Is the American public sufficiently familiar with nanotechnology to judge its potential benefits and risks appropriately?

Answer. Public outreach is a cornerstone of the National Nanotechnology Coordination Office, which performs public outreach and engagement on behalf of the NNI as well as serving as a central point of contact for Federal nanotechnology R&D activities. Outreach and informal education programs to foster a public that is well informed about nanotechnology are highlighted in the 2011 NNI Strategic Plan as a path to NNI goal 3, "Develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology." Furthermore, the Nanotechnology Public Engagement and Communications (NPEC) Working Group provides a forum to bring together agency representatives to identify opportunities for public outreach. NIST's measurement and standards efforts for nanotechnology environmental health and safety (NanoEHS) are providing necessary information and data for researchers, regulators, the public, and industry, helping to assure the responsible development of nanotechnology. NIST's mission-centric work in the area of NanoEHS advances measurement science, standards, and technology to provide critical measurement science, tools, and information that enable science-based assessment and management of NanoEHS risk.

Question 4. Are you concerned that a campaign to improve public understanding might, in fact, result in a backlash against nanotechnology R&D due to the potential safety implications?

Answer. Coordination and communication of clear information that identifies potential risks and benefits of nanotechnology among Federal agencies, the public, and other stakeholders is part of the foundation for Federal oversight of nanotechnology and nanomaterials described in the June 9, 2011 memorandum "Policy Principles for the U.S. Decision-Making Concerning Regulation and Oversight of Applications of Nanotechnology and Nanomaterials" (*http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/nanotechnology-regulation-and-oversight-principles.pdf*). This memorandum also recognizes that consumer trust and confidence in a sound regulatory regime is integral to fostering innovation and promoting the responsible development of nanotechnology applications. NIST's NanoEHS research program is developing the necessary measurement methods and standards to underpin informed assessments of nanomaterial risks and benefits.

The National Nanotechnology Coordination Office continues to explore best practices for public engagement on nanotechnology issues. As described in the 2011 NNI Strategic Plan, the NNCO will continue to solicit diverse public input and is planning outreach activities including activities such as interactive webinars, workshops, and other educational events.

Maximizing Return on Investment from the NNI

Question 5. Since the original authorization for the NNI expired in 2008, numerous attempts have been made to authorize the program. What do you think is needed in a reauthorization to improve the program overall and increase its return on investment?

Answer. The collaboration, coordination, and communication engendered by the NNI has created a fruitful forum for NIST to interface with other agencies across the Federal Government, enabling NIST to prioritize and coordinate research in numerous areas, most notably in nanolectronics; nanomanufacturing; energy; and environmental, health and safety aspects of nanomaterials. For example, activities within NNI groups such as the Nanotechnology Environmental and Health Implications Working Group help NIST to gather input from a broad range of stakeholders on the critical measurement science and measurement tools that are needed for the responsible development of nanotechnology.

A reauthorization should continue to provide support for the efforts of the NNI. Achievement of the objectives identified in the NNI Strategic Plan would serve NIST and the other NNI member agencies well as they work toward the NNI vision of a future in which the ability to understand and control matter at the nanoscale leads to a revolution in technology and industry that benefits society.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARK PRYOR TO DR. CHARLES H. ROMINE

Question 1. What does "nanomanufacturing" mean to you?

Answer. NIST reports its investments in nanomanufacturing using the NNI Program Component Area 5—Nanomanufacturing. In this context, nanomanufacturing is research and development aimed at enabling scaled-up, reliable, and cost-effective manufacturing of nanoscale materials, structures, devices, and systems. This includes R&D and integration of ultra-miniaturized top-down processes and increasingly complex bottom-up or self-assembly processes (2011 NNI Strategic Plan, available at *http://nano.gov*).

Question 2. You mentioned that NIST is working with the Nanoelectronics Research Initiative as part of a public-private partnership and that NIST is also engaged with industry consortia working on flexible electronics and neutron-based measurement for the manufacture of soft materials. How did NIST get involved in these public-private partnerships?

Answer. In carrying out its mission, NIST is charged by statute to work in partnership with industry to develop measurement solutions and standards and promote technologies that address innovation and facilitate trade and commerce. The broad authorities given to NIST by Congress provide the agency with a high level of agility in working with industry, standards organizations, academia, and other stakeholders. Exploiting our status as a technical, non-regulatory agency, NIST convenes communities around common measurement science and standards needs and provides funding and technical assistance to firms and institutions using a wide variety of formal arrangements.

There are many scenarios in which NIST interfaces with industry to accelerate outcomes, including: rapid transfer of technical expertise; in response to a call from industry; or to develop unique measurement capabilities in partnership with industry. NIST continues to engage with the flexible electronics industry through discussions with industry consortia in order to identify strategic measurement and standards needs for the success of the electronic display and printed electronics industry. As another example, NIST is underway in launching a new consortium, nSoft, to develop neutron-based measurement solutions for manufacturers of soft materials (*e.g.,* plastics, pharamaceuticals, solar cells, and battery membranes). nSoft is planned as a NIST-led consortium of industrial, government, and academic members designed to advance measurement science and reduce barriers for industrial research programs at peer-review based user facilities such as the NIST Center for Neutron Research (NCNR) by developing rapid and reliable facility access and training. A workshop in June of this year brought together key industry representatives and academic researchers to determine key research and measurement areas of impact on soft materials manufacturers and researchers (*http://www.nist.gov/nsoft/*).

In 2007, as part of a competitive process NIST selected the Nanoelectronics Research Initiative (NRI) as partner with which NIST could accelerate research in electronics that goes beyond today's technology to meet future demands. Achievements of this program to date, as noted in my written testimony, include:

- NIST funding of research ($2.75M/year) has been leveraged by $5M/year from industry partners and $15M/year from states to support projects at over 30 universities to work in 4 regional centers.
- The NIST/NRI partnership has attracted over $110M over five years in state and private funding to support business development and commercialization NIST/NRI interactions are currently supporting over 100 graduate students and dozens of post-docs through the four regional centers
- Outputs of the NIST/NRI partnership include dissemination of research in scientific publications and filed patents based on work sponsored by the NIST/NRI.

Question 3. What other Federal Agencies are involved?

Answer. The NRI has teamed up with the National Science Foundation (NSF) to fund research projects at existing NSF Nanoscience centers and networks at universities across the country (for example, see *http://www.src.org/program/nri/nri-nsf/*).

Question 4. Why should the Federal Government want public-private partnerships in nanotechnology?

Answer. Public-private partnerships provide a framework to accelerate industry outcomes. As described above, NIST has a rich history of partnering with industry across a range of sectors to leverage resources and meet technical industry needs in measurement science and technology development. Public-private partnerships in nanotechnology hold much promise, in part due to the inherently interdisciplinary nature of nanotechnology and the anticipated breadth of future nanotechnology-based applications. Public private partnerships such as the NRI and NIST's proposed AMTech program can help position industry for success by filling a critical gap by providing resources to conduct directed basic research and measurement research that is generally seen as outside the scope for large industry.

In their March 2010 review of the NNI, the President's Council of Advisors on Science and Technology noted the NRI's success, stating "It [NRI] all looks straightforward in hindsight: companies pooling resources to encourage pre-competitive university research in the hope of revitalizing their industry, state governments promoting regional development of R&D talent and infrastructure, and Federal funding agencies investing in forward looking research that is in the national interest." (*http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nano-report.pdf*).

Question 5. What other industries or technology sectors have, or could, develop nanotechnology roadmaps that could become the basis for additional public-private partnerships?

Answer. This very question is currently being asked as part of a Request for Information in the *Federal Register* on the topic of NIST's proposed AMTech Program (*http://www.gpo.gov/fdsys/pkg/FR-2011-07-22/pdf/2011-18580.pdf*). First described in the President's Fiscal Year 2012 budget request for NIST, the AMTech Program is a proposed public-private partnership initiative that would provide Federal grants to leverage existing consortia or establish new ones focused on long-term industrial research needs. The grants would fund development of research road maps and enhance research productivity through improved coordination and efficiencies. The program's goal is to accelerate the innovation process—discovery to invention to development of new manufacturing process technologies. Successful innovation as you are aware is what—creates skilled, high-wage manufacturing jobs. In the Request for Information, NIST seeks input on a variety of programmatic questions surrounding the development of this program, including whether AMTech consortia should focus on developments within a single existing or prospective industry, or should focus on broader system developments that must be supplied by multiple industries.

The importance of public-private partnerships and technology roadmaps is noted in the 2011 NNI Strategic Plan as a pathway toward NNI Goal 2, "Foster the transfer of new technologies for commercial and public benefit." Specifically, the plan calls for the NNI to increase its focus on nanotechnology-based commercialization and related support for partnerships, through activities such as working with U.S. industry across sectors to develop technology roadmaps in support of nanotechnology signature initiatives or new public-private partnerships.

Question 6. What do users pay to access the Nanofabrication Facility in Gaithersburg?

Answer. There are three types of hourly rates charged to every NanoFab user to recover the costs of performing the work: Specific Tool Use, Cleanroom Use, and Process Assistance (when applicable). Each rate is computed for full cost recovery, including the cost of the NanoFab staff time required plus the operating costs, and reviewed and approved by the NIST Budget Office. The operating costs include the costs of any maintenance contracts, routine maintenance and repairs (both scheduled and unscheduled), and accessories and consumable supplies. After a full cost recovery rate is computed, for projects that hold the promise of furthering the development of nanotechnology, a reduced cost percentage is applied to compute the reduced rates charged to those projects. As a matter of NIST policy, proprietary projects are not eligible for the lower rates and must pay the full cost for work performed in the NanoFab. The charges for every NanoFab project are based on the same rates, including projects led by NIST employees (CNST research staff included) and are available on the NanoFab website (*http://www.cnst.nist.gov/nanofab/nanofab.html*).

Question 7. What percentage of the operating cost of the NanoFab is covered by user fees?

Answer. As stated above, 100 percent of the operating cost of proprietary projects is paid by the users. Non-proprietary projects are eligible for reduced rates (discounted by 60 percent), with the balance of the full cost paid by the CNST from its appropriated research budget. All applicants, including those from NIST, can request consideration during the application process, and each project is rated on the extent that it will contribute to the development and/or application of nanoscale measurement and fabrication methods to further the development of nanotechnology. All such requests are decided on a case by case basis, typically within 10 days of an application being submitted, following review by a CNST committee and final approval by the CNST Director. This cost-sharing approach is similar that used for academic researchers using NSF-supported nanofabrication facilities within the National Nanotechnology Infrastructure Network.

Question 8. What is NIST's policy on intellectual property when the NanoFab is accessed by a private company?

Answer. NIST does not claim any inherent rights to inventions made solely by employees of a private company in the course of a NanoFab project. The rights will be determined by any intellectual property agreements the inventors may have with their employer(s) or other parties. If an employee of a private company co-invents something with a NIST employee in the NanoFab, NIST will jointly own that invention, and the sharing of those rights will need to be negotiated between all the rights holders.

Question 9. There are several international standards setting organizations and committees on nanotechnology. Often the best people are not able to participate in the standards development process because of lack of travel funds. How is the United States represented on these committees?

Answer. The various international standards setting organizations currently engaged in developing nanotechnology standards have different models of participation. Some rely on a direct participation model where an individual participates in standards setting through an individual or institutional membership and pays a nominal participation fee. In such a model, each individual (or organization) has one vote. Other international standards setting organizations rely on national body representation. In these instances, U.S. experts are convened in a U.S. technical advisory group (or mirror committee) to develop consensus positions, which representatives then take to the international organization and use as the basis for discussion with their counterparts from other countries. In such models, each individual/organization has one vote at the U.S. committee level, and the United States has one vote at the international level.

In general there is good participation by U.S. experts in international standards setting organizations that are developing nanotechnology standards. Such participation is important in that it helps ensure that U.S. perspectives are represented in the increasing number of nanotechnology related standards setting activities, and that U.S. leadership in contributing to the development of nanotechnology standards can be maintained.

Question 10. Should the Federal Government reimburse academics and NGOs for travel so that they can more fully participate in these committees?

Answer. Academics and NGO representatives provide an important perspective in standards setting, and are already playing an important role in international standards setting for nanotechnology. With the various grants and funded projects that academics in particular, receive from Federal agencies, academics could potentially include participation in standards setting as part of their project/grant proposal to enable technology transfer and commercialization of their findings. Thus approval of project/grant proposals from Federal agencies would permit academics to use these funds to support their participation in international standards setting in a manner that is analogous to the current practice of academics traveling to domestic and international technical conferences to present the results of their projects. Federal agencies such as NIST can conduct outreach to funding agencies to convey the strategic importance of standards setting, and help funding agencies with defining milestones and metrics that can be used to judge the effectiveness of standards participation activities that may be supported by such grants.

Any Federal Government program to support participation of private sector U.S. technical experts in standards setting activities should be need-based, fair, open, transparent, designed to address specific national priorities and structured in a manner that is consistent with the private-sector led model of the U.S. standards system, where the public-private partnership is a key aspect of the system.

Question 11. Are these committees creating international standards that in some cases are not acceptable to the U.S.?

Answer. The open nature of standards setting activities provides everyone an equal opportunity to propose new standards development activities. Through their extensive participation in these activities, U.S. technical experts are able to monitor and participate in these activities. Working with like-minded experts from other countries, U.S. experts have been successful in ensuring that new standards proposals and resulting international standards are based upon and reflect broad technical merit, rather than individual narrow interests or regional policy or political considerations. In select areas, such as nanotechnology related labeling, where work is underway in a European regional standards organization, and non-European members have limited participatory rights, U.S. experts are utilizing all existing tools and mechanisms of engagement and dialog to ensure that the resulting specifications or standards do not unfairly disadvantage U.S and non-European exporters.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARK WARNER TO DR. CHARLES H. ROMINE

Question 1. Nano-medicine and nano-biology hold significant promise to improve human health. How is the National Nanotechnology Initiative (NNI) supporting this critical area?

Answer. There are many current and planned activities in support of nanotechnology for human health. Some agency priorities and programs are described in the 2011 NNI Strategic Plan and the annual NNI supplements to the President's budget (available at *http://nano.gov*). The National Nanotechnology Coordination Office can provide additional details and insights into work to address this critical area.

Question 2. Public-private partnerships between universities, government, and industry are key methods to ensure that promising research is developed into useful new technologies and products. One example of such a partnership is the new Virginia Nanoelectronics Center, a partnership of several Virginia Universities, the Commonwealth of Virginia, and Micron Technologies. How does the NNI plan to incentivize, facilitate, and further leverage these kinds of public-private partnerships?

Answer. The importance of public-private partnerships and technology roadmaps is well understood by NIST and is consistent with NIST's mission to promote U.S. innovation and industrial competitiveness. Partnerships are noted in the 2011 NNI Strategic Plan as a pathway toward NNI Goal 2, "Foster the transfer of new technologies for commercial and public benefit." Specifically, the plan calls for the NNI to increase its focus on nanotechnology-based commercialization and related support for partnerships, through activities such as working with U.S. industry across sectors to develop technology roadmaps in support of nanotechnology signature initiatives or new public-private partnerships.

First described in the President's Fiscal Year 2012 budget request for NIST, the AMTech Program is a new public-private partnership initiative that would provide Federal grants to leverage existing consortia or establish new ones focused on long-term industrial research needs. The grants would fund development of research road maps and projects in advanced manufacturing and enhance the research productivity of consortia members through improved coordination and efficiencies. The program's goal is to accelerate the innovation process—discovery to invention to development of new manufacturing process technologies—that creates skilled, high-wage manufacturing jobs. NIST is currently soliciting public input into the development of AMTech through a notice in the Federal Register (*http://www.gpo.gov/fdsys/pkg/FR-2011-07-22/pdf/2011-18580.pdf*).

Question 3. I have heard some concern from nanotechnology researchers regarding the current state of technology transfer for nanotech research. Given that nanotech requires sophisticated manufacturing processes, for instance, to what extent is NNI focused on potential barriers to widespread use of nanotechnology-based products? Do we know, for instance, if printing and imaging technologies used in consumer electronics can be transferred to nanotechnology?

Answer. The promise of high-value nanotechnology-based industries requires suitable technologies that can economically and reliably manufacture products on a commercial scale. The NNI nanotechnology signature initiative "Sustainable Nanomanufacturing" establishes a path for the development of cost-effective nanomanufacturing such as high-throughput, inline metrology to enable process control and quality assurance of nanomaterials. Researchers are working on adapting traditional roll-to-roll manufacturing processes, the workhorse of flexible electronic printing and imaging technologies today, to produce new lightweight, high-strength materials for a wide range of applications including personal body armor and solar energy harvesting. User facilities such as the NIST Center for Nanoscale Science and Technology provide needed access to technology developers for rapid prototyping and experimentation of various nanomanufacturing protocols.

Question 4. Some scholars have raised ethical concerns about nanotechnology research and its applications. What are the dual use implications of nanotechnology?

Answer. The NNI has openly engaged with leading ethicists and social scientists, most recently as key participants in a number of recent workshops held in support of the development of the NNI Strategic Plan and the NNI Environmental, Health, and Safety Research Strategy. For example, an ethicist from the University of Virginia School of Engineering and Applied Science described some of the ethical issues surrounding nanotechnology during her plenary presentation at the July 2010 NNI Strategic Planning Stakeholder Workshop (*http://nano.gov/sites/default/files/pub_resource/nni_strategic_plan_stakeholder_rpt.pdf*). Research activities to inform the assessment of potential implications of nanotechnology, such as NIST's NanoEHS research program, provide the scientific basis to support the safe and responsible deployment of nanotechnology. The National Nanotechnology Coordination Office performs public outreach, regularly engaging with stakeholders, and can provide more details on the dual use implications of nanotechnology.

Question 5. Should we be paying more attention to the ethical implications of this field and its products? If so, what should we be doing to prevent the possible erosion of public trust in nanotechnology research?

Answer. Paying attention to the ethical implications of nanotechnology and its product is important as nanotechnology products will impact the public both directly through the products that contain nanotechnology, and also through products that are made possible due to nanotechnology (but may not contain any nanomaterials, in turn). The 2011 NNI Strategic Plan calls for agencies to identify and manage the ethical, legal, and societal implications of research leading to nanotechnology-enabled products and processes. An appreciation of the ethical implications of this technology will also help us be better stewards of this technology.

Our still early, but evolving understanding of the benefits and risks of nanotechnology and nanomaterials reiterates the importance of communication, education and outreach to policy makers and the public. Such outreach highlighting benefits, risks, safe use, technology limitations etc., can help the public better understand the technology and make their own decisions regarding how they choose to use the technology (or the products dependent on this technology), while also judging for themselves the hyperbole or fear that may be associated with the technology.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. ROGER F. WICKER TO DR. CHARLES H. ROMINE

Question 1. Currently, NIST supports efforts to accelerate development of transformational technologies through small companies and joint ventures to support high-risk transformational R&D. Recent awards produced a range of nanotechnology-enabled products in areas including flexible liquid crystal displays, organic photovoltaics, and lithium-ion batteries. How does research on nanostructured materials for the development and improved performance of organic photovoltaics complement the efforts that NIST supports?

Answer. The NIST Technology Innovation Program (TIP) has a number of active awards, one of which is to Polyera Corporation for the area of "Novel Nanomaterial Synthesis Processes to Enable Large-Scale, High-Performance, Flexible Solar Module Manufacturing in the U.S." Research on nanostructured materials in this technical area (*e.g.,* conducted at NIST laboratories, other Federal laboratories, universities, or within industry) helps to advance the state of technology.

Question 2. Are the efforts at academic institutions to leverage expertise in polymer science and engineering consistent with NIST's goals to accelerate transformational technology?

Answer. Academic institutions certainly may play a role in the acceleration of transformational technologies such as nanotechnology. Expertise in polymer science and engineering is needed for advances in a variety of application areas, including advanced photovoltaic cells for solar energy and flexible display technologies. Public-private partnerships with academic institutions, industry, and government, such as the Nanoelectronics Research Initiative, can be a powerful tool to accelerate new technology developments.

Question 3. How does NIST support and promote the development of research that combines contribution to the NIST Solar Energy Collection Initiative with the larger energy goal of improved conversion efficiency for solar cell materials and applications?

Answer. NIST efforts in the area of solar energy have largely been focused on the development of measurement tools, methods, and models to evaluate Photovoltaic performance. NIST is also looking to develop new metrology tools to support the development and manufacture of third generation photovoltaics. In 2010, NIST hosted an externally-led workshop to identify photovoltaic measurement grand challenges in four major third generation photovoltaic technology areas: crystalline silicon devices, thin film devices, III–V multijunction devices, and excitonic devices. (A full report can be found at: *http://events.energetics.com/NISTGrandChallenges 2010/pdfs/Opps_Solar_PV_web.pdf*). This workshop identified a number of strategic opportunities and measurement challenges in the following areas:

- Enabling Science and Engineering
  - Three-dimensional (3–D) analysis from nanoscale through macroscale
  - Multi-scale modeling for simulating materials growth, structure, optical and electronic properties, and device performance
- Reliability
  - Measuring and predicting the degradation of materials
  - Accelerated lifetime and reliability testing for thin films, concentrating PV, and quantum-scale technology
- Sustainable markets
  - Application of fundamental knowledge to increase efficiency in excitonic and quantum-structured cells

NIST is developing efforts to apply its current suite of optical, electrical, chemical and physical measurements to deliver advanced measurement and modeling tools that will enable researchers to understand optimize the intrinsic electronic and optoelectronic processes that govern the efficiencies of third-generation photovoltaics.

Question 4. NIST has external partnership programs designed to meet manufacturing challenges and the Administration's goal of advancing a world-class nanotechnology research and development program. How are partnerships with universities, particularly those in Experimental Program to Stimulate Competitive Research (EPSCoR) jurisdictions such as Mississippi, leveraged to carry out this goal?

Answer. As noted throughout the National Nanotechnology Initiative (NNI) Strategic Plan, partnerships area critical component to achieving the NNI vision of a future in which the ability to understand and control matter at the nanoscale leads to a revolution in technology and industry that benefits society. The three Nanotechnology Signature Initiatives, described in the NNI Strategic Plan and the NNI Supplement to the President's FY 2012 Budget (both available at *www.nano.gov*) identify research thrust areas and desired outcomes, including the formation of industry and academic partnerships. Though not explicitly stated in the initiative descriptions, the inclusion of Experimental Program to Stimulate Competitive Research (EPSCoR) universities as appropriate would be consistent with the spirit of the education and outreach goals expressed in the NNI Strategic Plan.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN D. ROCKEFELLER IV TO DIANDRA L. LESLIE-PELECKY, PH.D.

Manufacturing

Question 1. Nanomanufacturing is the bridge that connects nanoscience with nanotechnology products and is essential if we are to realize the economic returns on this technology. However, nanomanufacturing infrastructure and techniques are in their infancy. How significant a barrier to nanotechnology commercialization is the absence of nanomanufacturing infrastructure, such as equipment, tools, processes, and systems?

Answer. The lack of nanomanufacturing infrastructure represents the loss of researchers dedicated to the 'development' part of R&D. Developing a technique for making a specific material or device is the research part of R&D. The issues involved in learning how to scale up a technique and improving process efficiency used to be done in industrial research labs, few of which still exist.

We need programs that bring researchers in academia together with industry to identify and overcome specific barriers to progress. The Industry/University Cooperative Research Center (I/UCRC) program at NSF makes direct links between industries and universities—but they receive more high-quality proposals than they can fund. On a smaller scale, SBIR/STTR programs provide excellent opportunities for researchers, in collaboration with industry, to extend their work and solve some of the development problems that would otherwise remain barriers to adaptation.

Question 2. To make sure the United States is the global leader in nanomanufacturing, what should the Federal investment be in infrastructure development? And in what areas should we invest?

Answer. The amount of work being done in nanotechnology is enormous. Coordinating the vast numbers of researchers, facilities and amount of information is critical to ensure efficient progress. These networks also help bring together experts to identify and develop solutions to overcome the most significant barriers.

For example, the National Nanomanufacturing Network (*http://www.internano.org/*) unites academic, government and industry partners, including four NSF-funded nanomanufacturing NSECS (Nanoscale Science and Engineering Centers) and nanocenters at Sandia National Laboratories and NIST. These types of cooperative efforts require funding to develop, but the investment can produce a great payoff by concentrating resources and ideas.

Workforce training and education

Question 3. Dr. McLendon's testimony indicated that the nanotechnology workforce should reach 800,000 by 2015. This sort of job growth would go a long way toward economic improvements. How can the United States make sure we have an adequate supply of engineers and technicians to support nanomanufacturing and the overall job growth projected for the field?

Answer. Improving STEM education is a huge issue for the Nation in general. The question of whether we have "enough" scientists and engineers is debated (as is the numerical meaning of "enough"); however, the changing demographics of the country demand we find better ways to inspire a larger cross-section of Americans to pursue STEM study. The growth of women, minorities and persons with disabilities in science and engineering has been embarrassingly slow.

Microsoft recently released survey results supporting the importance of getting students interested in STEM as early as possible. Seventy-eight percent of STEM college students said they decided to study STEM in high school or earlier. One in five made that decision in middle school or earlier. More than half of the students surveyed attributed their STEM interest to an inspiring teacher or class—including 68 percent of the female students surveyed.

We need to revamp our approach toward teaching math and science at the K–12 level. Instead of focusing on disjoint disciplines, we need to prepare students to think more holistically. Interdisciplinary thinking can't start in college. We need to focus STEM education on essential themes that impact people's everyday lives, like energy and the environment. We need to show students that science and engineering have profound effects on the world and that they have an opportunity to shape the future by choosing these occupations.

At the college level, we need incentives for more students to pursue math and science degrees. In exchange for scholarships, students might be required to spend two or three years researching an area of need in a national laboratory or university research program.

Equally important are producing people who may not be scientists or engineers, but who are facile with scientific and engineering concepts and techniques. We need knowledgeable people to become technicians, marketing and advertising people, managers, politicians and regulators for the emerging nanotechnology industry.

We need to develop more partnerships with two-year colleges to prepare technicians to work in nanomanufacturing. The "green energy" technical degrees that are growing at two-year colleges can be a template. Some such programs in nanotechnology already exist, such as Penn State's NSF-funded National Center for Nanotechnology Applications and Career Knowledge. This program is part of the NSF ATE (Advanced Technological Education), which supports development of a very broad range of technical preparation. Nanotechnology-focused ATEs could be encouraged to accelerate the development of these programs. There also needs to be funding available for institutions to adapt educational materials that have be proven successful. The traditional emphasis tends to be more on novelty than adaptation of proven methods.

The needs of nanotechnology businesses will be very disparate given that the field ranges from food packaging to security sensors to biomedical devices. Two-year institutions can develop new programs quickly and have a history of adapting to and respecting local needs. Educators need input from local industry as to what skills are desired and feedback from people who work in these new and growing industries as to whether the programs are succeeding.

An important caveat—as the next question points out—is that we need to know that there will be jobs for these people after they graduate.

Question 4. What approaches will help ensure that both nanomanufacturing capacity and a trained workforce grow in tandem?

Answer. This is the canonical chicken and egg problem: We should not train people for jobs that don't exist, but industry won't develop if there aren't qualified workers. At some point, we have to decide to make one happen and then closely follow with the other.

I am less disturbed by industries having jobs they can't fill than I am by people without jobs, so I would prefer an initiative that focuses first on additional aid to businesses overcoming the development gap I referred to earlier. A second string of programs could link industries with educational institutions to jointly develop training programs—which might focus initially on on-the-job training so that industry doesn't have to wait two years for qualified workers.

Business and Job Creation Within Nanotechnology Environment, Health, and Safety

Question 5. Dr. Leslie-Pelecky, in your statement you describe nanomaterials bioactivity as not just a research area but as a potential business opportunity. This seems like an opportunity to enhance public safety while also creating jobs—really, having your cake and eating it too. What role can WVNano play in the development of such businesses in West Virginia? And what can the Federal Government do to incentivize public-private partnerships for business development in this area?

Answer. West Virginia, like many states, made a strategic decision to support nanomaterials as a priority area. Significant resources have been invested in developing the infrastructure to pursue research that will translate into useful products. In low-population states like West Virginia, high-tech businesses are most likely to be initiated by people working at or with a university (including its graduates). Creating more industry requires developing intellectual property and finding dynamic, motivated people to take the lead in the very challenging task of starting a new business.

The university does a good job with creating knowledge, but we could improve our involvement in inspiring people to start businesses and utilize that knowledge. We can develop courses that focus on business issues. We can help them develop the ability to communicate orally and verbally with people of all types, given them an appreciation for the global nature of business, the ability to work as part of team in leadership and membership roles, and a basic understanding of how business works. STEM students at the university represent a pool with very high potential for innovation.

This isn't traditionally part of the way we prepare STEM students. NSF recognized that there need to be resources to initiate these types of programs and created the GOALI (Graduate Opportunities for Academic Liaison with Industry) program. The GOALI at Texas Tech allows students to earn a Masters Degree targeted specifically toward working in the semiconductor industry. The internships that are a required part of the degree have helped many students find employment in the industry—often with their host companies. Similar programs focused on nanotechnology would help develop the workforce and build links between universities and industries.

One of the challenges to programs like GOALI is that they require a critical mass of industry, faculty research interests, and graduate students. Given the diversity of nanotechnology, a graduate research fellowship program that selects participants based on individual applications would provide greater ability for startups—which may only need one person—to participate. Such a model might also help universities without high concentrations of local business build relationships with industries.

We're in a unique situation in terms of nanomaterials bioactivity due to the confluence of having medical, scientific and engineering schools that work well together, plus the collaboration with NIOSH. These projects are simply too complex for one institution to do it all themselves. NIH, FDA and DARPA just announced a $190M program to develop a chip that will allow high-throughput drug testing to identify promising candidates and screen out toxic ones at early stages. If it works, this should significantly decrease the number of failed drug trials due to toxicity. That type of a platform is exactly what we're trying to do to evaluate nanomaterials and their impacts so that we can screen out potentially hazardous materials. There is still a lot of fundamental knowledge that has to be learned before we can think about developing businesses, but we're on that track.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. BILL NELSON TO DR. DIANDRA LESLIE-PELECKY

Nano-Infrastructure

Question 1. The cost and complexity of the infrastructure required for nanotechnology research and commercialization can be a significant barrier to expansion of the industry. What opportunities are available to researchers looking for Federal dollars for infrastructure development and equipment?

Answer. There is more demand than supply for programs funding nanomaterials research and development infrastructure. The Major Research Instrumentation (MRI) program at NSF is my primary source of funding for nanomaterials fabrication and characterization equipment like deposition systems, X-ray diffractometers and electron microscopes. NIH has an instrumentation program to which groups of already-NIH-funded investigators can apply. Most of these programs require groups of investigators to work together to ensure that instruments are maximally utilized.

Few universities in this economic climate have funding for new buildings, especially since nanomaterials research buildings have special requirements, such as low vibration, climate control, and cleanrooms. Opportunities for Federal funding for new buildings or renovation are rare. The ARRA funds that supported scientific research facilities were very important to many institutions. Due to the nature of those funds, the time frame for submission was so short that only universities with plans already completed had a chance at being competitive.

People are an important part of the research infrastructure. Programs like the NSF-Research Experiences for Undergraduates, the NSF–IGERT (Integrative Graduate Education and Research Training) and NIH T32 training grants fund are very important to us for funding students. These programs not only further research, but also prepare the future leaders in the field.

Question 2. What role do you see for the Federal Government in encouraging regional investment strategies for equipment sharing between university and industry clusters?

Answer. Equipment covers a broad range of categories. The highest quality, most specialized instruments (like very high resolution transmission electron microscopes) are not only expensive to purchase, but require one or more dedicated, knowledgeable technicians and expensive yearly maintenance contracts. There is a history of offering these types of resources through national laboratories—for example, the electron microscopy facilities at Oak Ridge National Laboratory. These facilities do a great service in making these one- (or few-) of-a-kind instruments available to researchers from industry as well as academia and national labs. The National Nanotechnology Infrastructure Network supported by NSF has been very successful in providing unique opportunities to university and industry users for the cost of transportation and lodging. Federal support of these user facilities has been a very good investment.

It may be possible to develop a second tier of mid-level instrumentation made available regionally, but it is important to remember that establishing these types of facilities are long-term commitments. In addition to buying the instrument, you have to support people to ensure it runs correctly and to teach people how to use it correctly, and the ongoing costs for utilities, maintenance, repair and updating.

Another consideration is that some essential (but expensive) pieces of equipment really have to be local. A standard transmission electron microscope for routine examination of samples (which is in the $0.5–1M range), is a tool I utilize weekly. Often, the next step of a process has to wait for microscopy results. There is a limit to how much equipment sharing can be done without unreasonably slowing down research progress.

On the scale of these medium- and small-cost instruments, most universities already operate these instruments within user facilities that are open to internal and external users, including industrial researchers. User fees are charged on a cost recovery basis; however, most universities have to subsidize the fees in order to make them affordable to internal users. Universities have the same challenges in terms of supporting people and maintenance and only larger universities can really afford to operate user facilities.

Public Outreach

Question 3. Public understanding of nanotechnology will affect both the level of government investments in nanotechnology R&D and the consumer willingness to accept nanotechnology products. In many cases the American public may be unaware that basic products like sunscreen can contain nanoparticles. Is the American public sufficiently familiar with nanotechnology to judge its potential benefits and risks appropriately?

Answer. The average person's familiarity with nanomaterials is probably more influenced by Michael Creighton and Prince Charles than by any scientist, engineer or science writer. In some ways, nanotechnologists are at a disadvantage because our field is so fantastic that science fiction writers employ it as a plot device.

People are likely to know the term "nanotechnology", but much less likely to know what it means. Unfortunately, most people don't come away from their K–12 (or even college) education with enough numerical and scientific literacy to accurately judge the potential benefits and risks of any new technology. That won't happen until we move math and science education away from memorization and toward skill development: critical thinking, the rules of scientific evidence, understanding graphs and tables, and understanding the process of how we try to understand the world. It must be noted, of course, that the scientific and engineering communities aren't always good at communicating outside our own boundaries, either.

A major part of the problem is terminology. Talking about "nanotechnology" is like talking about "sports". Baseball or cycling? Soccer or tennis? They share very little in common and you would be hard pressed to make very many meaningful statements that are accurate for all sports. Similarly, "nanotechnology" isn't one thing: it covers drug-impregnated stents, cancer treatments, golf clubs, bike frames, lights, chewing gum, and face cream—and lots more. We do ourselves a disservice by not focusing on specific instances of nanotechnology—and preferably on products that exist and the average person might encounter.

Just as drugs are approved individually—even if they are very similar to already approved drugs—the benefits and risks of each nanotechnology-related product have to be examined and communicated individually. The fact that there are many, many types of nanotechnology might be more important for the public to understand than to have them be in favor of "nanotechnology" *per se.*

Question 4. Are you concerned that a campaign to improve public understanding might, in fact, result in a backlash against nanotechnology R&D due to the potential safety implications?

Answer. The nature of such a campaign would determine the likelihood of a backlash. A well considered informational campaign that carefully frames the issues could do much to help people's eventual acceptance of nanotechnology in their lives.

The first element of such a campaign is helping people understand that 'nanotechnology' covers a vast array of products from health care to food to sports equipment that are so different they cannot be discussed as a single unit. Convincing people of this point would be a major accomplishment that could help prevent a knee-jerk negative reaction to the entire field based on one problem product.

The second element would be focusing attention on applications of nanotechnology that already exist. With over a thousand products that contain nanomaterials or were made using nanotechnology, already on the market, there is a lot of educating to be done. A Swedish study recently showed that people were most antagonistic to nanotechnology when they believe it is used without them knowing. Informing people about the specific benefits and risks of existing products is a much more productive approach.

We cannot deny that some nanomaterials may pose risks to people, animals or the environment, just as we cannot guarantee that a promising new drug won't eventually prove to pose more risks than its benefits justify. Consider DES, which pregnant women were given from about 1940 to 1970 because all the evidence we had at that time suggested that DES could decrease pregnancy risks. Instead, we found that the daughters of women who took the drug experienced a rare vaginal tumor that often left them unable to have children of their own. We have a history of drugs (Celebrex, Fen-Phen) that we thought were safe and only later found out were not. It is absolutely critical that we not make the same mistakes with nanotechnology—and why research into the environmental health and safety effects of nanomaterials must be accelerated.

Maximizing Return on Investment from the NNI

Question 5. Since the original authorization for the NNI expired in 2008, numerous attempts have been made to authorize the program. What do you think is needed in a reauthorization to improve the program overall and increase its return on investment?

Answer. Nanotechnology requires collaboration across scientific and engineering disciplines: It also requires collaboration across funding agencies. There have been some admirable efforts between NSF and NIH, but we need more programs that recognize the need for interdisciplinary and sometimes interagency cooperation. It is important that good ideas—especially in the biomedical applications area—don't fall into gaps between funding agencies. Centralizing funding within one agency would be a mistake: each funding agency has its own area of expertise that is critical to evaluating proposal merits. Fostering collaborative efforts among Federal funding agencies in a way that recognizes their individual expertise is critical.

Our lack of knowledge of nanomaterials bioactivity is a major barrier to making nanotechnology the economic driving force it was promised to be. Economic development and public acceptance of nanotechnologies hinge on improved understanding of nanomaterials bioactivity. Groups of investigators from different disciplines must work together to fully understand how nanomaterials interact with biological systems. Most of the current funding in this area, however, are individual investigator grants. We won't be able to make the necessary progress critical to moving forward this way.

The government has taken the initiative to prioritize research topics by shifting from primarily curiosity-driven, individual investigator research to problem-driven interdisciplinary team-based research. Curiosity-driven research is absolutely critical to continue generating the new ideas that have made us the world leader in nanotechnology; however, we need to expand the funding portfolio to include more targeted proposals that focus on specific barriers to moving forward with nanotechnology. We have seen an increase in directed programs, like NSF's emphases in sustainability and nanomanufacturing, and NIH's focus on translational medicine. There is tremendous power in directing the research focus via the funding opportunities—although which topics are the highest priority must be decided with input from the research community and industry.

The NSF Engineering Research Center (ERC) program supports university-industry partnerships in research across all engineering topics; however, they released in April a focused call for Nanosystems ERCs. NSF Programs like the Centers for Excellence in Materials Research and Innovation (CEMRI) and Materials Research Interdisciplinary Teams (MIRT) are valuable, team-based programs that include nanotechnology. These programs receive many more good proposals than they have the funding to support. The ten-plus-year history of the CEMRI (formerly MRSEC) program has demonstrated that it is a very good investment in terms of creating basic knowledge and applications, and in training graduate students skilled at interdisciplinary research.

We are very appreciative of the resources we've been provided over the last ten years of the NNI. We've made enormous progress in understanding the fundamental properties of nanomaterials and how they can be harnessed to improve the quality of life for Americans. There is much more to do and we appreciate your commitment to making it possible for us to do it.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARK PRYOR TO DR. DIANDRA LESLIE-PELECKY

Question 1. You testified that there is a need to make scientific instruments available on a regional basis. Right now it is difficult for universities to acquire multimillion dollar equipment for nanoscale imaging. The NIST Nanofabrication Facility is an example of a national user facility. Should the Federal Government consider establishing regional nanoscale imaging and characterization centers in each State? If yes, how would it be setup and how would manufacturers use it? Is it better to locate these instruments at a university or at a regional manufacturing center such as an MEP center?

Answer. The equipment necessary for nanomaterials research, development and commercialization varies in scale, complexity and cost (of operation and of continuing support). National user facilities are generally one-of-a-kind (or few-of-a-kind) instruments that require significant infrastructure. The national labs have done an outstanding job with these facilities. They are exceptionally valuable resources for the community.

On the other end of the scale, there is equipment that is expensive ($.5–2M), but so integral to research that it really must be on-site. A lot of our work requires answers from one piece of equipment before we can proceed with the next step of the experiment. Not having this type of equipment on campus makes it very difficult to be competitive researchers.

In the middle are intermediate pieces of equipment that might be appropriate for regional centers based on researcher density. The needs and number of researchers in different states varies widely. Going strictly by state would likely result in redundancy and excess capacity. Once a particular regional need was identified, an open competition to host the facility would be the best way of deciding where it should be located. Some facilities might make more sense at a regional manufacturing center, while others might be easier to host at a national laboratory or university.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN D. ROCKEFELLER IV TO DR. THOMAS O'NEAL

Workforce training and education

Question 1. Dr. McLendon's testimony indicated that the nanotechnology workforce should reach 800,000 by 2015. This sort of job growth would go a long way toward economic improvements. How can the United States make sure we have an adequate supply of engineers and technicians to support nanomanufacturing and the overall job growth projected for the field?

Answer. We need to create more scholarships for domestic students, at the same time we should have a free flowing of talented students outside of USA, which has declined after 911 due to visa restrictions.

Question 2. What approaches will help ensure that both nanomanufacturing capacity and a trained workforce grow in tandem?

Answer. We are lacking in nanotechnology education programs in this country. We need more resources to create such programs and we need them integrated into existing programs in Science Technology, Engineering, and Math (STEM).

Financing

Question 3. Financing is extremely challenging for those attempting to bring nanotechnology to market, because the path from invention to commercial production is often particularly expensive, risky, and lengthy. Dr. O'Neal, you mention in your testimony that a three to 10 year delay is typical in this area of technology. To what extent have capital issues hampered nanotechnology commercialization?

Answer. Start-ups and spin-offs are an important path for commercializing research. New companies require finance to allow them to develop and grow their operations, which should be the point at which venture capital become involved. The best venture capitalists add value to investee companies beyond funding. They provide industrial experience, contacts, and coaching and mentoring. This is especially so in nanotechnology, which often has longer development times and higher costs than an equivalent IT business.

Venture capitalists are investing in nanotech, but not aggressively, due to the long cycles it takes from discovery to commercial viability. Lux Research has identified investments in nanotechnology valued at $792 Million in 2009, 42 percent off their 2008 figure. The largest share of funding (51 percent) went to Healthcare and life sciences, followed by energy and environment (23 percent) and electronics and IT (17 percent). This funding was spread across 91 deals, with an average investment size of $8.6 million.

Question 4. If the venture capital community is focused primarily on short-term funding, what class of institutional investors do you think is most likely to support nanotechnology companies?

Answer. A new breed of Angel investors would need to be developed. It would need to be one that has access to larger amounts of funding that would be more patient for a return. A more feasible approach would be for large corporate investors to step in and fill this gap. They would need to develop a culture of investing in earlier and earlier stage companies and risk losing money of apportion of these investments. We should investigate matching programs with investors and National funding agencies like the German and Japan model.

The SBIR program should increase resources that target nanotechnology. Nanoscience innovation centers should be developed that function as testbeds, proof of concepts centers and business incubators. They should include collaboration areas that provide for shared equipment and facilities.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. BILL NELSON TO DR. THOMAS O'NEAL

Technology Transfer

Question 1. A large share of NNI funding supports research at universities and Federal laboratories. Last year's review of the NNI cited the need to increase the focus on the transfer of technology from the research community to the private sector. How effectively is the knowledge generated by NNI investments being transferred from universities and Federal labs to the private sector?

Answer. My opinion is that it could be much hasn't happened at a level that is making a significant difference. NNI has created great academic papers, but the commercial exploitation is still lagging. Research into the innovation process is merited

Question 2. What mechanisms are Universities using today to facilitate this transfer and which are the most effective?

Answer. Better partnerships and collaboration with industry is the most effective tech transfer. The SBIR is a great example. The Florida High Tech Corridor Matching grants program is another. Universities and industry working together to solve problems that matter to industry promote effective technology transfer. Deals that extend beyond a license are most effective. Faculty startups are effective when combined with business coaching, mentoring, management team development.

Question 3. Dr. O'Neal, as nanotechnology products progress toward the manufacturing stage, what do we need to do to make sure the U.S. captures the production work rather than another country with a strong manufacturing base like China?

Answer. U.S. companies need to be able to compete with companies based in China. The U.S. needs to consider investments in this industry that will return a sufficient return on investment. U.S. companies, Universities, and the government leaders need to work together to address this issue. Research into the innovation process is merited.

Nano-Infrastructure

Question 4. Dr. O'Neal, how is UCF making their equipment available to nanotechnology startups to promote commercialization of the technology?

Answer. We are sharing our facilities on a fee basis. Companies schedule time on the equipment and pay predetermined rates by the hour or month. One company schedules time overnight so as to not interfere with student and faculty usage. They are trained on the equipment ahead of time and recertified if equipment changes.

UCF only has a limited amount of such equipment at this time.

Question 5. What are some of the barriers to these public/private partnerships that you have encountered?

Answer. There needs to be an incentive or mutually beneficial reasons for public/private partners to form. Joint research efforts are one way but if the industry has to be providing all the funding, they may decide to simply do the work internally. Lack of awareness of possible areas of overlap or mutual benefit is also an issue. Creative ways of communicating this should be developed.

Maximizing Return on Investment from the NNI

Question 6. Since the original authorization for the NNI expired in 2008, numerous attempts have been made to authorize the program. What do you think is needed in a reauthorization to improve the program overall and increase its return on investment?

Answer. We need to do more research that addresses important societal issues, develop stronger ties to industry, and support for entrepreneurs to effectively move the technology to the market. Metrics such as patents spin out companies, and jobs created should be included with every program supported by the NNI. Research into nanotechnology commercialization should also be included in the initiative. More efforts into addressing the manufacturability and scalability would also increase the return on investment. We should also invest in nanosafety since safety concerns are negatively affecting investment

---

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARK PRYOR TO DR. THOMAS O'NEAL

Question 1. You testified that knowing how to manufacture and scale-up the production of nanomaterials and products that include nanomaterials is a barrier to commercialization. For example, Boeing may need tons of very pure carbon nanotubes for a plane fuselage. What programs or initiatives should the Federal Government sponsor to help manufactures learn how to scale up their manufacturing capability?

Answer. Create manufacturing centers, Industry-University partnerships using Germany as a model.

Question 2. Should the Federal Government establish "prototyping centers" so that companies can make "proof of concept" products and refine their manufacturing processes?

Answer. This is a great idea. It should include a significant number of students to help with the knowledge transfer aspects.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARK WARNER TO DR. THOMAS O'NEAL

Question 1. Nano-medicine and nano-biology hold significant promise to improve human health. How is the National Nanotechnology Initiative (NNI) supporting this critical area?

Answer. In terms of research, yes, but in terms of product development—no. Consideration should be given to developing more initiatives such as NSF's GOALI program. This provides funding for companies as an incentive to work with Universities. Additionally, funding under this program should be able to be directed to companies for certain activities.

Question 2. Public-private partnerships between universities, government, and industry are key methods to ensure that promising research is developed into useful new technologies and products. One example of such a partnership is the new Virginia Nanoelectronics Center, a partnership of several Virginia Universities, the Commonwealth of Virginia, and Micron Technologies. How does the NNI plan to incentivize, facilitate, and further leverage these kinds of public-private partnerships?

Answer. By investing in both academia and industries and facilitating collaboration. Scientist, engineers, and business people should all be the same room addressing issues.

Question 3. I have heard some concern from nanotechnology researchers regarding the current state of technology transfer for nanotech research. Given that nanotech requires sophisticated manufacturing processes, for instance, to what extent is NNI focused on potential barriers to widespread use of nanotechnology-based products?

Do we know, for instance, if printing and imaging technologies used in consumer electronics can be transferred to nanotechnology?

Answer. Yes. Companies like Intel, IBM, and HP need a business case to become more involved.

Question 4. Some scholars have raised ethical concerns about nanotechnology research and its applications. What are the dual use implications of nanotechnology? Should we be paying more attention to the ethical implications of this field and its products?

Answer. This is a hype, I don't see any real issues. Life sciences have been functioning at the nano-scale for a long time. The issues are the similar with many disciplines. We have good safe guards in place that will protect society. As long as we can prove that nano-products are safe that's what matters. Research into safety should be increased to address this issue. While we understand the nano-toxicity, we should clearly understand and communicate state why they are toxic, to whom, at what exposure, etc. Often the same product can be beneficial or harmful depending on the dose

---

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN D. ROCKEFELLER IV TO DR. GEORGE MCLENDON

Manufacturing

Question 1. Nanomanufacturing is the bridge that connects nanoscience with nanotechnology products and is essential if we are to realize the economic returns on this technology. However, nanomanufacturing infrastructure and techniques are in their infancy. How significant a barrier to nanotechnology commercialization is the absence of nanomanufacturing infrastructure, such as equipment, tools, processes, and systems? To make sure the United States is the global leader in nanomanufacturing, what should the Federal investment be in infrastructure development? And in what areas should we invest?

Answer. There are many barriers for nanotechnology commercialization. Manufacturing in this area is quite diverse as some products would need state of the art lithography labs, while others might need specialty chemical plants. Each of these capabilities exists in nascent form in existing manufacturing infrastructure such as those used for computer chip production or in fine chemicals productions. So the barrier is not that the basic tools are lacking, it is in the difficulty in retrofitting and turning these platforms towards the special needs of nanotechnology. Also, because the U.S. has lost its traditional manufacturing base particularly in semiconductor manufacturing there are significant barriers for those nanotechnology applications that require advanced lithography.

We should invest in programs that help retrofit existing manufacturing enterprises to supply nanotechnology products. Because the U.S. still has active manufacturing for specialty chemicals and medical products, these areas are ideally positioned to benefit from Federal investment. However, incentives for nanotechnology retrofitting must be supported by equal investment in measurement tools and standards for those measurements. One of the most significant retrofitting challenges is in characterizing the quality/purity of nanotechnology products. New instrumentation, that is validated and standardized, has to be available to industry that is moving towards providing nanotechnology products.

Workforce training and education

Question 2. Your testimony indicated that the nanotechnology workforce should reach 800,000 by 2015. This sort of job growth would go a long way toward economic improvements. How can the United States make sure we have an adequate supply of engineers and technicians to support nanomanufacturing and the overall job growth projected for the field? What approaches will help ensure that both nanomanufacturing capacity and a trained workforce grow in tandem?

Answer. The NSF has a traditionally central role in graduate support. It may be deniable to have a specific focus for URP—undergraduate research programs in nanotech to create a pipeline, as well as graduate and/or postdoctoral fellowships in nanotechnology, to insure an adequate workforce.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. BILL NELSON TO DR. GEORGE MCLENDON

Technology Transfer

Question 1. A large share of NNI funding supports research at universities and Federal laboratories. Last year's review of the NNI cited the need to increase the focus on the transfer of technology from the research community to the private sector. How effectively is the knowledge generated by NNI investments being transferred from universities and Federal labs to the private sector? What mechanisms are Universities using today to facilitate this transfer and which are the most effective?

Since the original authorization for the NNI expired in 2008, numerous attempts have been made to authorize the program. What do you think is needed in a reauthorization to improve the program overall and increase its return on investment?

Answer. Maximizing ROI from the NNI: Better focus on transitional research alongside foundational work.

At Rice, we have examples of strategic relationships with companies such as Lockheed-Martin who invest in our more applied research, and have their researchers mentor academic teams to develop ideas so that they can be transferred into corporate labs. However, in tough economic times companies often do not have the luxury to invest in relationships that may need three years or longer to mature. Start-ups are another avenue but also may not always be the best way to let transformative technology have the time it needs to fully develop. Rice has been fortunate to have more than four nanotechnology start-ups that have survived longer than five years.

The most effective approach are strategic relationships with established companies who have the ability to fund nanotechnology development for the long haul; the barriers to these truly transformative technologies becoming effective products are significant—and range from manufacturing challenges to regulatory uncertainties. Larger companies offer the best route for most nanotechnology development at this point, though programs should also acknowledge the unique role that entrepreneurship plays particularly in nanomedicine.

Question 2. On page 91 of the hearing transcript, Senator Nelson says: "Dr. McLendon, give us an example on that Lockheed case where there's a Lockheed scientists with one of your scientists. What are they developing?" Please provide this information for the record.

Answer. Lockheed Martin engineers are working with Rice scientists to develop better-performing rechargeable batteries using electrochemical etching nanochemistry. Steve Sinsabaugh (Lockheed Martin Fellow), and Lisa Biswal and Michael Wong (Rice professors) have created a new material that can store and release more electrons (and lithium ions) than the current graphite material used in lithium-ion rechargeable batteries. The technology breakthrough comes from the recognition that silicon cannot store and release electrons without disintegrating after recharging, but that porous silicon can. Laboratory results at Rice indicate that porous silicon can store and release as much as 10 times more electrons than graphite over many recharge cycles, meaning smaller batteries are possible. Once proved out for real-world operating conditions, this technology may lead to longer-lasting cell phones, cheaper electric cars, smaller computers, and lighter satellites and airplanes. This Lockheed Martin-Rice research is an exciting example of an industry-university partnership successfully resulting in basic science papers, patent applications, and well-trained student and postdoctoral researchers.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. MARK PRYOR TO DR. GEORGE MCLENDON

Set-aside funding

Question. Should the Federal Government, through the NNI, set aside a specific amount of each agencies funding for nanomanufacturing and/or environmental, health and safety?

Answer. Yes. The lack of nanomanufacturing capacity and the uncertainty in EHS regulation for nanomaterials represent significant barriers for commercialization. Both topics fall between multiple agencies and thus are often difficult to both fund and coordinate. However, it is essential to engage industry deeply in the area of nanomanufacturing. For example, in nanomanufacturing Federal dollars could be provided to match industry investments in academic partnerships. In this way, the research outcomes will quickly translate to partners capable of fully scaling up the ideas and processes. For nano-EHS research academic teams must be highly responsive to the needs of regulator policymakers and should engage these end-users directly in their research planning and evaluation.