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S. 189, 21ST CENTURY NANOTECHNOLOGY RESEARCH AND DEVELOPMENT ACT

HEARING

BEFORE THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDRED EIGHTH CONGRESS

FIRST SESSION

MAY 1, 2003

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

U.S. GOVERNMENT PRINTING OFFICE

97–599 WASHINGTON : 2006

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
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COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED EIGHTH CONGRESS

FIRST SESSION

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S. 189, 21ST CENTURY NANOTECHNOLOGY RESEARCH AND DEVELOPMENT ACT

THURSDAY, MAY 1, 2003

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

The Committee met, pursuant to notice, at 2:35 p.m. in room SR–253, Russell Senate Office Building, Hon. George Allen presiding.

OPENING STATEMENT OF HON. GEORGE ALLEN, U.S. SENATOR FROM VIRGINIA

Senator ALLEN. Good afternoon to you all. Today, the Commerce Committee will examine S. 189, 21st Century Nanotechnology Research and Development Act.

Senator Wyden, my good friend and counterpart and key leader and friend on this issue of nanotechnology, will be here shortly, and he'll have some opening remarks as well.

We're going to look today in this hearing, in both panels, at the progress of the National Nanotechnology Initiative and the issues surrounding the transfer of basic nanotechnology research out of government and university labs into the private sector for commercial applications.

And I do want to especially thank my colleague and friend, Senator Wyden on this issue. Last September, Senator Wyden and I held the first congressional hearing ever on the topic of nanotechnology. And at that time, many of our colleagues thought nanotechnology was too small of an issue to be concerned about to focus on. However, as elected leaders, I'm convinced that we need to focus and recognize that this industry is really at the verge of a tremendous revolution.

There are companies in the private sector, like Hewlett Packard, General Motors, IBM, General Electric, Siemens, Intel, and Dell, all involved in nanotechnology research and development. Furthermore, I think that we all ought to recognize that we are not alone in this country being interested in nanotechnology. Indeed, when one will look at the global picture, we are falling a bit behind, insofar as our research and development in nanotechnology, and we're facing some stiff foreign competition in nanotech research from Japan, the European Union, Russia, Korea, and China. Now, this Nation, the United States, has been at the forefront of almost every important transformative technology since the industrial revolution, and we must continue to lead the world in the nanotechnology revolution, in my estimation.

Now, our role, as elected leaders, should be to create or to foster the conditions precedent for our researchers and innovators to compete and contribute and succeed, both domestically and internationally. I am not here to say that we ought to guarantee anyone's success, but the Government's role is to make sure the field is fertile, our tax policies, our research policies, our regulatory policies, allow the creative minds in the private sector, in our colleges and universities, as well as in some of our Federal Government Agencies, to reach their full potential. And that's really why Senator Wyden and I introduced S. 189, to provide, in an organized and collaborative way, an approach to nanotechnology research and commercial economic development.

Our strategic goal is logical and very clear. We want to leverage the government, academic, and corporate research capabilities and assets this country has currently available, and to allow our whole country, and those involved in it, to compete and succeed worldwide.

Now, the groundbreaking nanotech projects today will mean substantial regional and national job growth in the future. Our legislation authorizes $678 million for grants to support basic, fundamental research and development and establish research centers of excellence that will bring together experts from the various disciplines, agencies, and private sector, as well as universities. This legislation also leverages and recognizes the work taking place at the state-led initiatives, like the ones in Virginia, Oregon, Texas, California, Pennsylvania, and New York.

I'm especially pleased by the Bush Administration—good timing—especially pleased by the Bush Administration's focus and support for nanotech. The President requested $849 million for nanotechnology, which is a 10 percent increase over last year's request. If Congress approves this requested increase, the funding for the National Nanotechnology Initiative will have doubled since fiscal year 2001.

Now, this afternoon we'll be hearing from an eminently qualified panel, two panels, to discuss this measure, Senate Bill S. 189, as well as technology transfer and the progress of nanotech research and development in the United States.

I want to welcome all of our witnesses for being with us. Thank you for your willingness to be here, some from clear across the country and halfway across the country, and some from right around here in this region, but thank you for your willingness to testify before this Committee on this very important subject for our future.

I will introduce each one of you in the panels as we proceed, but before I do that, I would like to ask my colleague, who's been a real partner and teammate in this effort in nanotechnology, Senator Wyden, if he has any opening remarks he may wish to make.

STATEMENT OF HON. RON WYDEN, U.S. SENATOR FROM OREGON

Senator WYDEN. Well, thank you, Mr. Chairman. It's great to team up with you. And suffice it to say, we are going to be busy on the technology front over the next few months with Internet taxes and our legislation to ensure that the Net does not get barraged with a whole new array of taxes. And, of course, today we're focusing on a special priority you and I have had for a number of years. So I'm really pleased that the Oregon/Virginia Tech Alliance is alive and prospering, and I thank you for it.

I would ask unanimous consent, Mr. Chairman, that my statement could be made a part of the record, and maybe I could just highlight a couple of my concerns.

Suffice it to say a lot of Americans still think that nanotechnology is the stuff of science fiction or that it is certainly a fairly exotic discipline with widespread application far off in the future.

I was home just last week in Oregon and met with a whole host of Oregon companies and academic leaders and scientists that certainly made it clear that practical applications of nanotechnology are available today. Nanoscale and microscale technologies, from computer printers to computer inks, have, in fact, already been created by companies in my home state. Companies in Oregon are fusing together the sciences of nanotechnology and microtechnology, which works on a slightly larger scale, and creating a variety of new innovations.

The collaborative effort between Oregon's universities and technology companies, called Micro2Nano, intends to go ever further using nanotechnology to create biosensors, reactors, energy sources, medical devices, and the next generation of semiconductors.

What our legislation, of course, does, as Chairman Allen has touched on, is provide the critically-needed funding not just for Oregon and Virginia that have been leaders in the field, but for programs across the country.

I also think that the last major explosion of technology and information technology, offers a clear and positive precedent for the use of discipline-specific expert advisory panels, as opposed to the use of more general, less knowledgeable counselors. I bring this up only by way of saying that I know that we're going to have some debate with respect to the advisory council and who could handle this. Chairman Allen has been very reasonable in this, and probably out in the real world, nobody gets completely consumed by these kinds of questions. The National Research Council, in this book, an excellent book, "Small Wonders, Endless Frontiers," stresses how important it is that there be an independent advisory council on nanotechnology, because if we're going to have a significant financial investment, it ought to be matched by a significant intellectual investment, and that ensures that we have the best possible people on this job. And Chairman Allen and I have had some more discussions on this with some obviously feeling that the President's Council of Advisors on Science and Technology should be the overseeing body in nanotechnology efforts. And I think virtually all the independent academic experts feel that the language we've got in our bill is appropriate.

But, as I say, Chairman Allen and I have worked out all of these issues and certainly have come up with the resolutions to matters far more contentious than this. And I look forward to working with you, Mr. Chairman, on this and would close simply by welcoming one of our witnesses, Dr. Jun Jiao, of Portland State University. She is a leader in the field of research and development in a variety of nanotechnology disciplines, and I'm just thrilled that one of the great minds in the field is here today and wanted to welcome her. And I look forward to working with you, Mr. Chairman, to move this legislation quickly to the Senate floor.

[The prepared statement of Senator Wyden follows:]

PREPARED STATEMENT OF HON. RON WYDEN,
U.S. SENATOR FROM OREGON

I want to thank my colleague from Virginia for convening today's hearing. I am pleased to count him as a supporter and cosponsor of the 21st Century Nanotechnology Act. In fact, when I formerly Chaired the Subcommittee on Science, Technology and Space and the Senator from Virginia was the Ranking Member, we convened the Senate's first-ever hearing on the subject of nanotechnology. I am as pleased as he is to see the full Committee's attention turn to this subject again.

The field of nanotechnology offers a unique pathway to the medical practices, materials and major innovations of the future. Now is the time not only to fund nanotech, but to marshal this country's efforts into a cohesive drive to lead the world in this field. To do that, this committee will need to ensure both adequate funding and expert advisory resources to the nation's nanotechnology programs.

A lot of folks believe that nanotechnology is still the stuff of science fiction—or that its widespread application is still far off in the future. But on a recent trip home I was encouraged by Oregon companies' practical applications of nanotechnology today. Nanoscale and microscale technologies from computer printers to computer inks have already been created by Oregon companies. Today, companies in my state are fusing the sciences of nanotechnology and microtechnology, which works on a slightly larger scale, to create new innovations. A collaborative effort between Oregon's universities and technology companies called Micro2Nano intends to go farther—using nanotechnology to create biosensors, reactors, energy sources, medical devices, and next generation semiconductors.

The key to all these advances will be adequate funding for research and development. The Wyden-Allen Legislation, the 21st Century Nanotechnology Research and Development Act, will provide that funding to nanotech not just in Oregon and Virginia, but across the country. In addition to providing research and educational grants, our bill establishes the nanotechnology infrastructure America currently lacks. That includes a national program to keep abreast of our global and economic competitiveness, and to consider ethical concerns. Research centers created in the bill would bring together experts from various disciplines to work together for better results.

I want to be very clear this afternoon, however, that I do not believe funding and programs will do the job automatically. Equally essential to America's nanotechnology future is the advice and guidance of a qualified, expert panel of scientists who know this field inside and out. For that reason, I am not satisfied with proposals to make the President's Council of Advisors on Science and Technology the overseeing body for American nanotechnology efforts.

The last major explosion of technology—information technology—offers a clear and positive precedent for the creation of a discipline-specific, expert advisory panel as opposed to the use of more general, less knowledgeable counselors. The Information Technology Research and Development (ITRD) initiative has described their expert advisory committee as quote, "crucial" to its effort to align federal research of science and technology as well as to develop advocates for the program. The expert guidance provided allowed America to move to the forefront of the information technology wave. I want no less for this country when it comes to nanotech.

My legislation calls for an independent advisory panel on nanotechnology, and I intend to stick to that provision. A significant financial investment in nanotechnology must be matched by a significant intellectual investment. Only then can this country reap the full range of rewards offered by this burgeoning field.

As today's hearing begins I would like particularly to welcome one of our witnesses, Dr. Jun Jiao of Portland State University. Dr. Jiao is a leader in the field of nanotechnology research and development. She will be one of the great minds to lead this country into the future with nanotechnology, and I look forward to today's discussion with her.

Senator ALLEN. Thank you, Senator Wyden, for your great leadership and your comments about this hearing and the promise of nanotechnology.

Now we're going to listen to the real experts. We're trying to facilitate and help you all move forward so you're improving our material sciences and biological sciences and life sciences and so forth.

I'm going to first introduce the first panel and then hear from you in the order in which—I've made some brief predicatory remarks about each of you.

First is Dr. James Murday. Dr. Murday is the Acting Chief of Science of the Office of Naval Research. Until recently, he served as Director of the National Nanotechnology Coordination Office, perfect to have you here. From May to August 1997, he also served as acting Director of Research for the Department of Defense Research and Engineering.

Dr. James Roberto is the Associate Laboratory Director for Physical Sciences at Oak Ridge National Laboratory. He is responsible for ORNL's research portfolio in material science, condensed matter, physics, chemistry, and nuclear physics. He is a former president of the Materials Research Society and chair of the Division of Materials Physics of the American Physical Society. Now, is that right? American Physical Society? All right.

And also we have, last but not least, Dr. Clayton Teague. Dr. Teague is the current Director of the National Nanotechnology Coordination Office. The NNCO provides day-to-day technical and administrative support to the National Nanotechnology Initiative.

Gentlemen, thank you all for being with us. We'd now would like to hear your insight and your views, and we'd like to start with you, Dr. Murday. Please proceed.

STATEMENT OF DR. JAMES MURDAY, CHIEF SCIENTIST, ACTING, OFFICE OF NAVAL RESEARCH

Dr. MURDAY. Thank you.

Chairman Allen, Senator Wyden, I'm pleased and honored for the opportunity to share some of my enthusiasm on the National Nanotechnology Initiative. As a scientist at the Office of Naval Research, in the Naval Research Laboratory, I've been engaged in fostering nanoscience since the early 1980s. And in the last two years, I culminated in the privilege of serving as the part-time director of the National Nanotechnology Coordination Office, or NNCO.

Senator ALLEN. Move the microphone a little bit closer.

Dr. MURDAY. Yes, sir. Thank you.

And hopefully that experience over these 20 years has provided some insights that can help accelerate the rate of the science discovery and its transition into innovative technologies.

Concurrent with my involvement in nanoscience, DOD interest dates back into the early 1980s. And by 1997, that interest was sufficiently mature that the DOD created a nanoscience strategic research topic in its basic research program. Thus, the DOD was a natural participant in the 1997 to 2000 year process of creating the national initiative, and that's one of the reasons, my engagement there, that I was asked to serve as the Director of the NNCO.

DOD's interest in nanotechnology stems from its huge potential impact on national security and, by inference form that, homeland security, homeland defense. And its early entry into nanoscience means that we're in a position to enable some transitions, even in this time frame, without looking for 20 years into the future. And I'll highlight one of those for you in a moment.

For simplicity's sake, I tend to organize nanotechnologies as they pertain to national security and homeland defense into about three generic topic areas. One is nanoelectronics, photonics, magnetics—that's basically information-technology devices—sensors to acquire information, logic to process it, memory to store it, communicate and transmit that information, and ultimately to display it. And, from my observations in the electronics industry, I believe that by the end of this decade, essentially every electronic device that you, myself, and Defense acquisition, is going to want to buy is going to be enabled by having a nanostructure. Nanostructure inside will be pasted, or should be pasted, on all those devices. Having the capabilities that will add to those devices is going to be very important for information warfare, metric-centric warfare, for the uninhabited combat vehicles, the added intelligence necessary to take the man out of those immediate vehicles, automation to reduce manning—in fact, we're training through virtual reality, which I think will, in turn, spill down into our schools.

The second generic topic area is what we call nanomaterials by design. And the DOD weapons and platforms frequently require much higher performance than one sees in their counterparts in the civilian sector. And the ability to maneuver things at the nanometer size scale is going to provide much greater capability to give higher performance.

Now, I've got here an example of this. This is a nanostructured coating, the black coating you see. And these parts have been introduced into the fleet now; they're actually out in operation. They're in reduction gears on surface-ship air-conditioning units, they're in hull ball valves on submarines, and in several other applications. And the improved performance that we expect, and we're evaluating now in the field, are expected to yield considerable savings. The nanostructured coatings have a wear resistance that's five times greater than their microstructured counterparts, and they have 10 times the fatigue life. So this is a significant improvement.

Because of these enhancements, this particular coating won an R&D 100 award in the year 2000. That's an award given to one of the top 100 technologies introduced into the marketplace in that year.

The third generic area is in nano-biotechnology. And, by far, the greatest impact of that is going to be in medicine and health, but it relates also to the warfighter. We would be able to monitor physiological status. If you have a man out on point, you want to make sure that he's alert and not going to sleep on you. If you have somebody who's wounded, you'd like to have a system that could detect the status and perhaps start to take some recuperative action. But maybe more importantly, and it leads into the homeland security, as well, as in the area of chemical/biological warfare defense, weapons of mass destruction.

If you think about this, if you work in the nanoscience, you can pick up and manipulate and measure individual atoms. These are very small. The chemical agents and the pathogens that we worry about in chemical/biological warfare are large in comparison. So it's relatively reasonable to expect that we can take those tools we're using in nanoscience and morph them into highly sensitive detection techniques. And, in fact, we're beginning to see that will happen. Further, since these can be miniaturized, you can have arrays of them, and that addresses the selectivity part of the problem.

Dramatic advances in the sensor, you also can expect to see advances in protection, decontamination and therapeutics. Recognizing some of these opportunities, some of the DOD scientists organized a workshop, about a year ago, about nanotechnology innovation for chemical, biological, radiological, and explosive detection protection. That workshop came up with a set of recommendations, which has gone to the national initiative and will be part of the planning process as we go through a revitalization of that in NNI over the next year.

Let me finish with a couple of observations from my tenure at the NNCO. The first is that having sweated the uncertainties in the transition from the Clinton to the Bush Administration and wondering whether we were going to survive as an initiative, I very much appreciate the incorporation of the initiative into law.

The second point is, the Nanoscale Science Engineering Technology Committee is populated by a dedicated group of agency department nanotechnology champions, with Dr. Mike Rocco, of NSF as leader. Those champions are essential to the continued success of the NNI, and they now face a real task of taking a program that is just now leaving its infancy and moving into adolescence and making sure that we do that appropriately and we do it in a way that will help accelerate the transition into commercial products. And I can assure you that the interest and support that you are showing for the initiative is very important to this group of people and will help them accomplish that task.

Thank you for your attention.

[The prepared statement of Dr. Murday follows:]

PREPARED STATEMENT OF DR. JAMES MURDAY, CHIEF SCIENTIST, ACTING, OFFICE OF NAVAL RESEARCH

Mr. Chairman, distinguished Members of the Committee, thank you for this opportunity to discuss Nanotechnology Research. You and the other Members of the Senate Committee on Commerce, Science, and Transportation have been leaders in calling attention, both nationally and in the Department of Defense, to the importance of funding basic research and to bringing new technology quickly from the scientist's bench to our Sailors and Marines.

Department of Defense Interest in Nanoscience

The Department of Defense (DOD) has been investing in fundamental nanoscience research for over 20 years. For instance, one of the early programs dating into the 1980s was Ultra-Submicron Electronics Research (USER). In 1997, the DOD identified several Science & Technology (S&T) topics with the potential for significant impact on military technology; nanoscience was selected as one of those special research area (SRA) topics (see below for illustrative impact examples). A DOD Nanoscience SRA coordinating committee was established; its current membership is: Dr. Gernot Pomrenke, Air Force; Dr. John Pazik, Navy; and Dr. William Mullins, Army. Further, each Service has a coordinating group to guide its nanoscience program.

Nanoscale Opportunities with Potential Major DOD Impact:

Nanoelectronics/Photonics/Magnetics

- Network Centric Warfare
- Information Warfare
- Uninhabited Combat Vehicles

- Automation/Robotics for Reduced Manning
- Effective Training through Virtual Reality
- Digital Signal Processing and Low Probability of Intercept

Nanomaterials "by Design"

- High Performance, Affordable Materials
- Multifunction Adaptive (Smart) Materials
- Nanoengineered Functional Materials (Metamaterials)
- Reduced Maintenance (halt nanoscale failure initiation)

BioNanotechnology—Warfighter Protection

- Chemical/Biological Agent detection/destruction
- Human Performance/Health Monitor/Prophylaxis

Since the DOD nanoscience programs are some 20 years old, one might expect to see transition successes. One example from each Service is illustrated here. Under Army funding Dr. Chad Mirkin, Northwestern University, has invented a way to utilize nanoclusters of gold for the sensitive, selective detection of DNA. This technology has been demonstrated to work for anthrax, has been commercialized by a start-up firm Nanosphere, and is under clinical evaluation. The Air Force is funding Triton Technologies Inc. under an Small Business Innovation Research (SBIR) program to insert nanostructured clay particles in polymers. One benefit of this composite is reduced gas permeability. This new material was marketed by Converse in athletic shoe heels with greater elasticity (He gas bubbles trapped by the low permeability polymer composite); the reduced permeability is also of interest for packages containing food, beverages and pharmaceuticals. The Navy is interested because nanoclay particles increase the fire resistance of organic composite materials for ship applications. Under Navy funding Inframat has developed a thermally sprayed coating of alumina/titania nanopowders. The properties of this coating are far superior to the micropowder equivalent; this product was one of the R&D Magazine selections as an R&D 100 award for the year 2000. The coating is presently under field evaluation on Naval ships.

Each Service has its own laboratory nanoscience programs. The Army efforts in nano-electronics, nano-optics, organic light emitting diodes and displays, sensors, and Nano-Electromechanical Systems (NEMS) are centered at Army Research Laboratory (ARL) Adelphi; the work on organic nano-materials is largely at ARL Aberdeen. The Army's Natick Soldier Center (NSC) also invests in innovative nanotechnology initiatives, including projects in nano-photonics, nano-composites, nano-fiber membranes and photovoltaics. The Air Force nano-materials program is largely centered at Wright Patterson AFB in Dayton. It has work on nano-composites, inorganic nano-clusters, nano-phase metals and ceramics, nanotribology, nanobiomimetics and nanoelectronics. The Navy program is centered at the Naval Research Laboratory (NRL) in Washington DC. NRL has created a Nanoscience Institute with the goal of fostering interdisciplinary research that cuts across the NRL organizational structures. A new NRL Nanoscience Building will come on-line in the fall of 2003; it has been specially designed to minimize those noise sources that would limit the precision of nanostructure measurement / manipulation. To fully exploit this new building capability, NRL will welcome collaborations with external researchers.

In 2002, the Army established a University Affiliated Research Center (UARC), the Institute for Soldier Nanotechnologies (ISN), at the Massachusetts Institute of Technology (MIT), awarding a 5-year $50M contract for the development of nanoscale technologies for soldier performance and protection. ISN works in partnership with industry to produce revolutionary technologies to enhance soldier survivability in the battlespace. The industrial partners working with the ISN provide needed core competencies, expertise in transitioning technologies from the laboratory to the real world, and cost sharing.

DOD contributions to National Nanotechnology Initiative (NNI) Planning/ Reporting

The DOD has been an active participant in the initial Interagency Working Group on Nanostructures and its successor body, the Nanoscale Science, Engineering and Technology (NSET) committee. I, while a staff member at the Naval Research Laboratory, served as the first director of the National Nanotechnology Coordination Office. In addition, several workshops have been executed by DOD scientists/engineers in support of revisions to the NNI implementation plan.

Nanoscience shows great promise for arrays of inexpensive, integrated, miniaturized sensors for chemical / biological / radiological / explosive (CBRE) agents, for nanostructures enabling protection against agents and for nanostructures that neutralize agents. The recent terrorist events motivated accelerated insertion of innovative technologies to improve the national security posture relative to CBRE. Since DOD has considerable experience in this topic, DOD scientists led the effort to redefine a NNI Grand Challenge to address this important topic. They also organized an AVS (formerly the American Vacuum Society) hosted workshop on Nanotechnology for CBRE Protection and Detection. The report for that workshop is available at: *http://www.wtec.org/nanoreports/cbre/*

In the National Defense Authorization Act of 2003, Section 246, addressed the Defense Nanotechnology Research and Development Program. It states that the Secretary of Defense shall carry out a defense nanotechnology research and development program. The purposes of the program are stated as:

(1) To ensure United States global superiority in nanotechnology necessary for meeting national security requirements.

(2) To coordinate all nanoscale research and development within the Department of Defense, and to provide for inter-agency cooperation and collaboration on nanoscale research and development between the Department of Defense and other departments and agencies of the United States that are involved in nanoscale research and development.

(3) To develop and manage a portfolio of fundamental and applied nanoscience and engineering research initiatives that is stable, consistent, and balanced across scientific disciplines.

(4) To accelerate the transition and deployment of technologies and concepts derived from nanoscale research and development into the Armed Forces, and to establish policies, procedures, and standards for measuring the success of such efforts.

(5) To collect, synthesize, and disseminate critical information on nanoscale research and development.

The report directs the DOD Director of Defense Research and Engineering to submit to the congressional defense committees an annual report on the program. The report shall contain the following matters:

(1) A review of——

(A) the long-term challenges and specific technical goals of the program; and

(B) the progress made toward meeting those challenges and achieving those goals.

(2) An assessment of current and proposed funding levels, including the adequacy of such funding levels to support program activities.

(3) A review of the coordination of activities within the Department of Defense, with other departments and agencies, and with the National Nanotechnology Initiative.

(4) An assessment of the extent to which effective technology transition paths have been established as a result of activities under the program.

(5) Recommendations for additional program activities to meet emerging national security requirements.

The DOD will prepare these reviews, assessments, and recommendations in conjunction with the related efforts for the NNI as a whole.

In closing, the Department of Defense investment in basic research over the last 20 years is paying off in transformational capabilities to the DOD. I have mentioned only a few examples within the DOD nanoscience Science & Technology program. I believe the Department of Defense successes in nanotechnology are significant, and I appreciate the opportunity to come before you today to tell you about them.

Thank you.

Senator ALLEN. Thank you very much, Dr. Murday, for your insight, and I also like your enthusiasm. Some people may look at this and think, “Well, what is that? It’s a piece of pipe,” or whatever. But the specifics of it and the specifications and its longevity do mean a great deal, and it is—the way that we’re going to have to compete and succeed in the future, is with these sort of, while seeming mundane, very, very significant improvements. And thank you very much.

Now we’d like to hear from Dr. Roberto. Dr. Roberto?

STATEMENT OF JAMES ROBERTO, PH.D., ASSOCIATE LABORATORY DIRECTOR FOR PHYSICAL SCIENCES, OAK RIDGE NATIONAL LABORATORY

Dr. ROBERTO. Chairman Allen, Senator Wyden, I'm the Associate Laboratory Director for Physical Sciences at the Oak Ridge National Laboratory, which is a Department of Energy multi-program laboratory managed by UT/Battelle, a partnership of the University of Tennessee and the Battelle Memorial Institute. It is an honor to appear before the Committee in support of the 21st Century Nanotechnology R&D Act.

In my role at Oak Ridge, I oversee the physical sciences, which includes nanoscale science and technology. This includes the development of ORNL's Center for Nanophased Materials Sciences, one of DOE's five planned nanoscale science research centers. These centers are state-of-the-art user facilities that we have located at Argonne, Berkeley, Brookhaven, Los Alamos, and Sandia, and Oak Ridge National Laboratories. Each center will focus on nanoscale research and development that leverages the unique capabilities of the host laboratory, including major synchrotron, neutron, and microfabrication facilities. The DOE nanotechnology centers will help fulfill a presidential priority of providing American researchers with the foremost capability in this breakthrough technology. Not only DOE researchers, but also other agencies, U.S. industry and universities will benefit from these centers.

The excitement surrounding nanoscale science and technology is real. Recently, we held a DOE Nanoscale Science Research Centers workshop in Washington. We attracted more than 400 scientists and engineers from 94 universities, 40 industries, and 15 federal laboratories. More than 2,000 researchers have attended regional and national workshops for these centers. In fact, it's difficult to find a month without a national or international meeting in this field.

Nanoscale science and technology crosscuts the traditional disciplines of material science, chemistry, physics, biology, computational science, and engineering. It occupies the frontiers of these fields and includes some of the most challenging research problems. The solution to these problems offer a line of sight to technical advances of enormous potential in materials, information technology, health care, and national security. Many see nanotechnology as the basis of the next industrial revolution.

For the Department of Energy, the opportunities that are afforded by nanoscale science and technology are unprecedented. Research on the synthesis and properties of nanoscale systems consisting of tens to thousands of atoms underpins progress in a multitude of high-impact fields, including catalysis science, photovoltaic, sensor technology, high-performance alloys, and advanced materials for fuel cells and hydrogen storage. Applications include low-cost, high-efficiency solar cells, materials that are 10 to 100 times stronger than steel at one-sixth the weight, energy-efficient smart coatings for windows, high-efficiency solid-state lighting, and new catalysts for energy conversion and chemical processing. These applications offer enormous energy, national security, environmental, and economic benefits.

John Marburger, the Director of OSTP, describes the nanotechnology revolution as one in which the notion that everything is made of atoms has a real operational significance. This has been made possible by extraordinary tools, such as synchrotron light sources, neutron sources, electron microscopes, scanning probe microscopes, and high-performance computers. These tools have enabled the atomic scale characterization, manipulation, and simulation of complex assemblies of atoms and molecules. This bottoms-up view of the physical world embraces breathtaking complexity and seemingly endless possibilities.

We are now at a crossroads in the physical sciences. The boundaries between the scientific disciplines are disappearing at the nanoscale. The study of simple isolated systems is giving way to complex assemblies. We are moving from atomic-scale characterization to atomic-scale control, from miniaturization to self assembly. This paradigm shift for the physical sciences rivals other revolutions in science, such as the revolution in biology following the discovery of the molecular structure of DNA.

It is this opportunity and the technological impact that will result that underpins the 21st Century Nanotechnology Research and Development Act. This act is an important element of the strategy to strengthen the physical sciences in the United States. Other components include the Nanotechnology Research and Development Act, the Energy Research Development, Demonstration, and Commercial Application Act, and Energy Science Research Investment Act.

The traceability of advances in the physical sciences to economic growth, new medical technology, energy independence, and enhanced national security is very strong. As you know, the President's Council of Advisors on Science and Technology has given high priority to strengthening the physical sciences, including nanoscale science and technology.

I appreciate the committee's leadership in this area. I firmly believe that the future of our Nation depends on continued leadership at the scientific and technological frontier, a frontier that includes nanoscale science and technology.

Thank you.

[The prepared statement of Dr. Roberto follows:]

PREPARED STATEMENT OF JAMES ROBERTO, PH.D., ASSOCIATE LABORATORY DIRECTOR FOR PHYSICAL SCIENCES, OAK RIDGE NATIONAL LABORATORY

Mr. Chairman and Members of the Committee:

My name is James Roberto, and I am the Associate Laboratory Director for Physical Sciences at Oak Ridge National Laboratory (ORNL). ORNL is a Department of Energy multiprogram laboratory managed by UT-Battelle, LLC, a partnership of the University of Tennessee and Battelle Memorial Institute. It is an honor to appear before the Committee in support of the 21st Century Nanotechnology Research and Development Act.

In my role at ORNL I oversee the physical sciences, including nanoscale science and technology. This includes the development of ORNL's Center for Nanophase Materials Sciences (CNMS), one of DOE's five planned Nanoscale Science Research Centers. The Nanoscale Science Research Centers are state-of-the-art user facilities for nanoscale science and technology that will be located at Argonne, Berkeley, Brookhaven, Los Alamos and Sandia, and Oak Ridge National Laboratories. Each Center will focus on nanoscale research and development that leverages the unique capabilities of the host laboratory including major synchrotron, neutron, and microfabrication facilities. The DOE nanotechnology centers will help fulfill a Presidential priority of providing American researchers with the foremost capability in this breakthrough technology. Not only will DOE researchers benefit from these centers, but also other agencies, U.S. industry and our universities will benefit from these new capabilities.

The excitement surrounding nanoscale science and technology is real. The recent DOE Nanoscale Science Research Centers Workshop and National Users Meeting in Washington, DC, attracted more than 400 scientists and engineers from 94 universities, 40 industries, and 15 federal laboratories. More than 2000 researchers have attended regional and national workshops for the DOE Nanoscale Science Research Centers. It is difficult to find a month without a national or international meeting in this field.

Nanoscale science and technology crosscuts the traditional disciplines of materials science, chemistry, physics, biology, computational science, and engineering. It occupies the frontiers of these fields and includes some of the most challenging research problems. The solutions to these problems offer a line-of-sight to technical advances of enormous potential in materials, information technology, healthcare, and national security. Many see nanotechnology as the basis of the next industrial revolution.

For the Department of Energy, the opportunities provided by nanoscale science and technology are unprecedented. Research on the synthesis and properties of nanoscale systems consisting of tens to thousands of atoms underpins progress in a multitude of high-impact fields including catalysis science, photovoltaics and thermoelectrics, sensor technology, high-performance alloys, advanced materials for fuel cells and hydrogen storage, and membrane technology. Applications include low-cost high-efficiency solar cells, materials 10–100 times the strength of steel at 1/6th the weight, energy-efficient "smart" coatings for windows, high-efficiency solid state lighting devices, and new catalysts for energy conversion and chemical processing. These applications offer enormous energy, national security, environmental, and economic benefits.

John Marburger, Director of the Office of Science and Technology Policy, describes the nanotechnology revolution as one in which "the notion that everything is made of atoms has a real operational significance." This has been made possible by extraordinary tools such as synchrotron light sources, neutron sources, electron microscopes, scanning probe microscopes, and high-performance computers. These tools have enabled the atomic-scale characterization, manipulation, and simulation of complex assemblies of atoms and molecules. This is a "bottoms up" view of the physical world—Mother Nature's view—that embraces breathtaking complexity and seemingly endless possibilities.

We are at a crossroads in the physical sciences. The boundaries between scientific disciplines are disappearing at the nanoscale. The study of simple, isolated systems is giving way to complex assemblies. We are moving from atomic-scale characterization to atomic-scale control, from miniaturization to self-assembly. Change is opportunity, and this paradigm shift for the physical sciences rivals other revolutions in science, such as the revolution in biology following the discovery of the molecular structure of DNA.

It is this opportunity, and the technological impact that will result, that underpin the 21st Century Nanotechnology Research and Development Act. This Act is an important element of the strategy to strengthen the physical sciences in the United States. Other components include The Nanotechnology Research and Development Act of 2003 (H.R. 766), the Energy Research, Development, Demonstration, and Commercial Application Act of 2003 (H.R. 238) and the Energy and Science Research Investment Act of 2003 (S. 917 and H.R. 34). The traceability of advances in the physical sciences to economic growth, new medical technology, energy independence, and enhanced national security is strong. As you know, the President's Council of Advisors on Science and Technology (PCAST) has given high priority to strengthening the physical sciences, including nanoscale science and technology. I appreciate the Committee's leadership in this area, and I firmly believe that the future of our Nation depends on continued leadership at the scientific and technological frontier, a frontier that includes nanoscale science and technology.

Senator ALLEN. Thank you, Dr. Roberto, and we'll have questions for you later, because I'm all intrigued by some of those great advancements you're talking about there at Oak Ridge.

Now we'd like to hear from Dr. Clayton Teague, director of the National Nanotechnology Coordination Office.

Dr. Teague?

STATEMENT OF E. CLAYTON TEAGUE, PH.D., DIRECTOR, NATIONAL NANOTECHNOLOGY COORDINATION OFFICE

Dr. TEAGUE. Yes, thank you.

Mr. Chairman, Senator Wyden, and Senator Sununu, I am pleased and honored to have this opportunity to appear before you today to address the plans for the National Nanotechnology Coordination Office and the Nanoscale Science Engineering and Technology, or the NSET Subcommittee, of the National Science and Technology Council.

I believe strongly in the potential and the importance of nanotechnology for the security, the economic prosperity, and the welfare of our Nation. I also share this Committee's belief that federal support for nanotechnology R&D is essential for the nation to realize the full benefits of this emerging field.

I've submitted my written testimony for your consideration, so here I would just emphasize three important points from that record.

The first one, nanotechnology is practically limitless in its potential for creating new materials, new devices, and systems. The initial commercialization and economic impact that we're just beginning to see is only a hint of what I think is to come. Let me illustrate.

There are 6,720 ways to permute the six different letters among the eight characters or places in the name of the Chairman's State, Virginia. There are 6,720 ways to permute the six different letters among the eight characters or places in the name of the Chairman's State, Virginia. So if you took the six different characters and you looked at all the possible ways that you could relocate them, you would find there are 6,720 different ways that you could do that.

So now if you imagine the huge number of possible permutations of the 91 atoms that make up the periodic table among the millions of places in a small nanostructure, what we can build, if you think about all of those possibilities, will really be limited more by our creativity and our imagination than by the laws of physics. However, the great promise that we've just talked about, in terms of that rich area, must be tempered with the realization that our nanotechnology capabilities are in a very embryonic and infant stage, as Dr. Murday had talked about.

As someone who was involved in it for many years, it's sort of surprising to realize that it's taken us 20 years to progress from the ability to see atoms, and then to manipulate them, and finally, a few years ago, to build a simple three-atom structure. Twenty years. So to build a nanostructure large enough to observe in an optical microscope, about one micrometer, would require assembling millions of atoms. I hope that talking about that in that sense would give you a sense of the amazing potential that nanotechology has and also a sense of the tasks remaining for us to realize that potential.

My second point, nanotechnology research has potential applications in all the multiple-agency mission areas, and the NNI and the NCET were created to ensure coordination to ensure federal funding and to engender the rapid development of nanotechnology in the United States.

Technology transfer and commercialization have been the key elements of the NNI plan from its inception. The NCET and members agencies have responded by designing industry outreach activities into their NNI-related programs. Some specific examples are given in my written testimony, and I believe if you examine those that you will see that their impact is evidenced by the exponential growth over the past several years in the number of technical papers and articles that have been written on nanotechnology, the number of U.S. patents that have been filed, nanotechnology companies formed, and products brought to the market.

Nanotechnology-based products that have become available, just even over the last year, range from water filters for removing harmful microorganisms to protective and glare-reducing coatings for eyeglasses and cars to stain-free clothing and mattresses. For the future, nanotechnology promises a lot of the things you've already heard about today, but breakthroughs in biomedicine, sensor technologies, and energy production and storage.

My third and final point, the NNI has grown in scope and scale over the last four years, and it's now in a stage for refocusing and strengthening, including a review by the President's Council of Advisors on Science and Technology, the PCAST.

PCAST will serve as the independent-standing nanoscience and nanotechnology advisory board called for in the recent NRC report that Senator Wyden mentioned. The PCAST is well-suited to conduct this review since its members have extensive expertise in technological developments, the operation of federal R&D programs and technology transfer. The PCAST panel also has the seniority and the visibility that will assure that its findings have impact. PCAST and co-chair Floyd Kvamme have already begun their review and planning processes.

PCAST's work plan focuses on first refining the grand-challenge topics to guide the NNI program; and, second, assisting in the development of an NNI strategic plan that was also called for in the NRC report. These two tasks are complementary to the activities of the NCET toward formulating a new NNI strategic plan.

In summary, nanotechnology is still at a very early stage of development, and there are tremendous opportunities and challenges before us. The NNI has, for almost five years now, served as an effective means for coordinating federally funded activities in nanotechnology. As this initiative matures and grows, the NNCO is scaling up to meet the additional responsibilities that this entails.

We greatly appreciate the endorsement of the NNI's achievements and potential that was implicit in the language of the proposed 21st Century Nanotechnology Research and Development Act.

Mr. Chairman and Senator Wyden and Senator Sununu, we thank you, again, for your support in bringing this bill forth. The NNCO staff and I look forward to working with the other members of the NCET, PCAST, and the legislative branch to move the NNI, hopefully, into the next stage of the maturing era of the nanotechnology program.

Thank you.

[The prepared statement of Dr. Teague follows:]

PREPARED STATEMENT OF E. CLAYTON TEAGUE, PH.D., DIRECTOR, NATIONAL NANOTECHNOLOGY COORDINATION OFFICE

Chairman Allen, Senator Wyden, Members of the Committee, I am pleased and honored to have this opportunity to appear before you today in behalf of the National Nanotechnology Coordination Office (NNCO) and the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the National Science and Technology Council (NSTC). I, and all agency representatives on the NSET Subcommittee, believe strongly in the tremendous potential and importance of nanotechnology for the security, economic prosperity, and general welfare of our nation. We also share this Committee's belief that federal support for nanotechnology R&D is essential for efficient development of the scientific understanding, advanced facilities, education, and standards necessary for timely translation of R&D in nanotechnology into true economic development.

As the National Nanotechnology Initiative (NNI) has defined it, nanotechnology is the ability to work—to see, measure, and manipulate—at the atomic, molecular, and supramolecular levels, in the length scale of approximately 1–100 nm range, with the goal of understanding and creating useful materials, devices, and systems that exploit the fundamentally new properties, phenomena, and functions resulting from their small structure. So, nanotechnology is not just the study of small things. Nanoscale research and development is the study of materials, devices, and systems that exhibit physical and chemical properties quite different from those found in larger scale systems. Take the semiconductor cadmium sulfide as an example. In its large-scale form, it is typically used as a material for constructing detectors of light. But, when it is formed as small crystals of less than 10 nm—termed quantum dots—the material as a nanostructure has the property of fluorescing with a color dependent on the size of the crystal. In a demonstration accompanying this testimony, I would like to show the Committee this nanoscale size-dependent phenomenon. When illuminated with near-ultraviolet light, five vials of liquid containing cadmium sulfide quantum dots ranging in size from 3 nanometers to 7 nanometers will be shown to fluoresce with colors ranging from blue to red, the blue light being produced by the 3 nanometer quantum dots and the red light being produced by the 7 nanometer quantum dots. Such size-dependent quantum dots and nanorods promise to have a wide range of applications in improved solar cells, biological imaging of cells, and faster DNA testing.

This NSET focused definition of nanotechnology, along with the NNI vision and program elements, were carefully prescribed in the basic research directions document for the NNI, drafted in 1999. The definition, vision, and program elements have served the program as guiding principles for the NNI since that time. More than thirty other countries have also modeled their nanotechnology programs on the NNI.

As a scientist who has worked for over twenty-five years in some of the fields now included in nanotechnology, I'd now like to offer my perspective on how this technology is developing. Then, I'll describe plans for the NNCO and the interactions underway between the NNCO, the NSET Subcommittee, and the President's Council of Advisors on Science and Technology (PCAST).

I had the privilege early in my career of observing the phenomenon of quantum mechanical tunneling between two small gold spheres spaced about one nanometer—ten atomic diameters—apart. In classical physics no current flow would occur between metals not touching. But in quantum mechanics, the electrons "tunnel" through this potential energy barrier produced by the physical gap. With a small voltage applied between the spheres, changing the spacing between them by only one atomic diameter would cause the current flow to change by a factor of ten, an extraordinarily large change. This characteristic of quantum mechanical tunneling between two closely spaced metals—known and predicted by theory—proved to be the basis for the totally unexpected discovery later by Gerd Binnig and Heinrich Rhorer that by carefully moving a sharpened metal tip about one nanometer above a surface one could resolve and draw images of the individual atoms constituting the surface. For the first time in scientific history, we could virtually reach down and touch the very rudiments of all matter—the atoms! Nothing in my career has generated as much sustained excitement and stirred as much imagination and creativity as did this discovery. That was twenty years ago, and I still marvel at the beautiful and refined images of atoms obtained with this instrument, the scanning tunneling microscope.

About ten years later, Don Eigler and colleagues demonstrated that using a scanning tunneling microscope they could not only reach down and touch the atoms but, in addition, could controllably move individual atoms around on a surface and build atomic structures they designed—atomically precise letters of the alphabet and quantum corrals for electrons. There have been many other developments since then leading to the current rapid development of nanotechnology, but these two demonstrations are clearly the events that energized the scientific community to begin thinking seriously about the real possibility of atom-by-atom structuring of matter.

Parallel to these developments in the direct mechanical manipulation of atoms with the scanning tunneling microscope, similar exciting things were taking place in other fields now included in nanotechnology. The discovery of fullerene molecules—buckyballs and nanotubes—sprang from the study of small clusters of carbon; ultra miniaturization of microelectronics produced the burgeoning field of thin film superlattices and quantum dots; DNA and other biomolecules emerged from biotechnology as unique building blocks; the study of very large or supramolecules produced surprisingly efficient catalysts. This is only a small number of the fields overlapping with the field now termed nanotechnology; each has its own exciting story of discovery and rapid development over the last ten years or so.

With all these approaches and processes, just imagine the astounding number of structures one can build with the 91 atoms of the periodic table. The rich possibilities may be appreciated by considering the large number of atoms in typical nanoscale sized structures. Nanoscale structures with dimensions of 1 nanometer can contain up to about 100 atoms; those with dimensions of 2 nanometers, up to about 1000 atoms; and those with dimensions of 100 nanometers, up to about 100 million atoms. The number of possible structures within this nanoscale size range isn't infinite but it is huge. The structures that we can build will be limited more by our creativity and imagination than by the ultimate bounding of possibilities posed by the laws of physics.

So where are we in our abilities to realize all these wonderfully rich possibilities, and why is there a need for so much research and development? First, even with the rapid progress made in scanning probe techniques for assembling atoms, the first assembly of atoms involving true molecular bonding was only achieved in 2000 and that was assembling a three-atom structure. Currently, we have an inadequate degree of control at the nanoscale and our tools and processes for assembling atoms are very slow. We still do not have the understanding, the tools, and processes for the full control of assembling reasonably large numbers of atoms into desired structures. As an example, we cannot form single wall nanotubes with a known twist or chirality. This is critical because depending on the twist of the nanotubes; they may be metals or semiconductors. Speed in forming a macroscopic quantity of these nanostructures, say enough for a drug tablet, is critical because it requires assembling about a million, billion, billion, atoms! Innovative combinations of top-down tools such as lithography with methods of directed self-assembly of atoms and molecules have provided means to overcome some of the speed limitations yet with some resultant loss in ultimate control of the atomic and molecular form of the resulting structures.

This gives you a sense of the task remaining before us and the amazing potential for making new materials, devices and systems as we continue to engage the challenges.

In the Marketplace Today

Relative to the long-range potential just outlined, nanotechnology is truly in its embryonic stage of development. Yet, many important nanotechnology-based products are already in use today. Few people are aware of these first commercial nano products because they are more incremental than revolutionary.

Some applications of nanotechnology have been in use for many years, and we can now begin to appreciate their economic impact. The U.S. oil industry saves an estimated 400 million barrels of oil each year, representing some $12 billion, through the use of nanoparticles called zeolites, which act as molecular sieves. Zeolites extract up to 40 percent more gasoline from crude oil than the catalysts that were previously used. Recently, the automotive industry was able to substantially reduce the amount of precious metals used in its catalytic converters and extend the longevity of the converters, in part due to advancements in nanostructured catalysts. These examples show how significant a contribution nanotechnology can make to our economy, environment, and natural resources management.

Other nanotechnology based products that have become available over the last year or two include:

- Nanoparticle filters for removing viruses, bacteria, and protozoa such as hepatitis A, *E-coli* and *giardia* from water

- Nanocomposites in running boards and bumpers on automobiles to decrease weight and improve corrosion resistance
- Thin layers engineered at the nanoscale to produce protective and glare-reducing coatings for eyeglasses and cars
- Transparent sunscreens with superior UV protection
- Longer-lasting tennis balls due to decreased gas permeability of nanoclay coatings
- Stain-free clothing and mattresses due to nanostructured fiber coatings. In addition, exciting new applications are in the product pipeline, with patents already licensed, and partnerships sealed between product developers and manufacturers. But these near-term applications are modest in comparison to the potential applications of research now being conducted under the auspices of NNI funding. Examples include the following:
- Microcantilever arrays incorporating nanostructured coatings that will enable detection of multiple chemical warfare agents, explosive vapors, and biological agents on a single chip (A. Majumdar, U.C. Berkeley)
- Dip-pen Nanolithography: Use of atomic force microscopes as "ink pens" for use in nanolithography for low-cost, ultra high resolution chip manufacturing (C. Mirkin, Northwestern University)
- A variety of potential applications of carbon nanotubes, including electrical interconnects for nanoscale electronics, hydrogen storage, and even structural applications such as nanotube-reinforced composites (R. Smalley, Rice University)
- Digital logic and memory devices manufactured on the molecular scale from rotaxane molecules using nanowire interconnects (J. Heath, Caltech)
- Novel antibiotics based on peptide nanotubes that punch holes in bacterial cell walls (A. Olson, Scripps Research Institute)
- Low-cost, ultra lightweight, and flexible nanorod-polymer photovoltaic cells (P. Alivisatos, UC Berkeley)
- Metallic iron nanoparticles for low-cost, high-efficiency remediation of groundwater contaminated with heavy metals (W. Zhang, Lehigh University)

Nanotechnology is highly interdisciplinary. It is not just chemistry, molecular biology, medicine, physics, engineering, information science and metrology; it is all of these fields at once. R&D efforts, accordingly, require extraordinary coordination and cooperation within the scientific community, among federal, state, and local agencies, and with industry. Further collaboration with industry in particular is necessary to commercialize scientific discoveries.

Technology transfer and commercialization have been key elements of the NNI plan from its inception. NSET member agencies have responded to this challenge by designing industry outreach activities into many of their funding programs within the NNI. Some examples are included below:

1. Several agencies (e.g., NIH, NSF and DOE for example) have put out special nano SBIR solicitations or have included language specifically encouraging nanotechnology-related SBIR proposals. NSF hosted an NNI SBIR workshop in March 2002 reporting on the results of initial FY01 SBIR funding in nanotechnology. Six agencies (NSF, NIST, NIH, USDA, EPA, and NASA) presented information on nanotechnology-related SBIR funding activities at that workshop. In data later provided to NNCO, these agencies reported a total of over 65 nano-related SBIR awards made in Fiscal Year 2001, with a total funding of over $11 million. This figure is not known in Fiscal Years 2002 and 2003, but the overall NNI budget has grown dramatically since FY 2001.

2. While some NSET agencies are restricted from funding R&D activities in companies (SBIR excepted), other agencies do not have such restrictions. Within the NNI, agencies that primarily fund academic research are partnering with agencies that can fund industrial development to assure the timely transfer of basic research developments into industry. For example, the Department of Defense plays a key role in carrying nanotechnology innovations all the way from basic research funded at agencies such as ONR and DARPA into industrial practice. Thus, ONR was able to accelerate the application of wear-resistant nanostructured coatings developed under its basic research funding, and these coatings are now deployed in some Navy ships, reducing wear in turbine shaft bearings, in turn reducing the need for major propulsion systems overhauls, and thus reducing costs and increasing readiness of the Navy fleet. DOD research agencies frequently work with NSF and other basic research agencies to co-fund promising academic research, and DOD can pick up the

results and promote the accelerated development of military applications through development work funded at major defense contractors.

3. The Department of Energy's Nanoscale Science Research Centers (NSRCs) are designed to be "user facilities" open to researchers from U.S. industry. Depending on intellectual property rules the industry researchers may be working under, the use of the DOE facilities may be free, or may entail the payment of a modest fee. DOE held a large meeting on Feb. 26–27, 2003, to formally initiate the NSRC program; the first annual users' meeting was held on Feb. 28. Members of Congress, nanotechnology researchers, and industrialists participated in the meeting, which was designed to highlight the opportunities that the new DOE facilities will afford to researchers from both academia and industry.

4. Nanoscale Science and Engineering Centers funded by NSF require industrial interest and effective plans for cooperation with industry. The focus for FY 2003 is on manufacturing processes at the nanoscale, so industrial participation is all the more important as NSF reviews the new proposals that will be submitted in response to this year's solicitation.

5. Industry participation is required in the NSF program entitled, "Grant Opportunities for Academic Liaison with Industry (GOALI)." Several of the GOALI awards that were made by NSF in FY02 were closely related to nanotechnology.

6. The U.S. Army's Institute for Soldier Nanotechnologies at MIT reflects a partnership among MIT, the Army, and private industry. Currently active industrial partners include Dupont and Raytheon.

7. Similarly, the DARPA/DMEA Center for Nanoscience Innovation for Defense (University of California at Santa Barbara) maintains close industrial ties, with industry representation on the technical advisory committee and with participation by Rockwell Scientific and Motorola.

8. NSF's National Nanofabrication Users' Network (NNUN) provides nanofabrication and other research infrastructure at 5 universities around the country, available for use by either industrial or academic researchers. Each year industry researchers conduct hundreds of research projects that involve use of NNUN facilities. NSF plans to re-organize and roughly double the size of the NNUN program in the coming year.

9. The Department of Commerce has assisted the NNI in organizing workshops in Los Angeles and Houston aimed at building local and regional alliances between researchers, local businesses, and entrepreneurs and investors to promote the commercial development of nanotechnology. Additional workshops are planned in the coming year for the Boston and Chicago areas. Reports from these and many other nanotechnology-related workshops are available at *http://wtec.org/nanoreports/*.

10. NSF held a special workshop for public and industry outreach at the Reagan Bldg. in Washington, DC on March 19, 2002. Entitled, "Small Wonders: Exploring the Vast Potential of Nanoscience," the meeting featured presentations on promising applications of nanotechnology in a wide variety of economic sectors, including materials, medicine, instrumentation, and electronics. Industrial participation included representatives from IBM, Lucent, Eastman Kodak, the Semiconductor Research Corporation, Motorola, the California Molecular Electronics Corporation, and Digital Instruments.

11. For the past two years running, the NNI has co-sponsored a large annual NNI meeting at which representatives of NSET agencies have explained the NNI programs, and at which leading NNI-supported researchers present their most promising findings. There has been significant industry participation in these meetings, which have provided yet another forum for building connections between researchers and industrial practitioners.

12. NNCO is now planning a workshop to enhance coordination between federal NNI and state and regional nano initiatives that target economic development and commercialization. Key objective of this workshop are to find ways to better promote economic development through commercialization of nanotechnology breakthroughs, and to leverage the expertise and resources of existing state and local nanotechnology efforts. Another objective is to assure the broadest possible geographical distribution of the benefits of nanotechnology development—the meeting will feature presentations from states that have established nanotechnology initiatives for the benefit of states and local governments that are hoping to establish such programs in the future. We have been working closely with Dr. Nathan Swami of the Virginia Nanotechnology Initiative, Sean Murdoch of Atomworks, and Mark Modzelewski of the Nanobusiness Alliance to plan and carry out this activity.

13. Industry leaders are participating in a series of workshops being organized this year by the NNCO to help establish detailed research plans corresponding to the NNI's nine grand challenge topics. One example is a workshop held in September of 2002 entitled, "Vision 2020 for the Chemical Industry." A chemical indus-

try group manages the Vision 2020 exercise in cooperation with the DOE/Office of Industrial Technologies. This workshop was particularly targeted at identifying nanotechnology research opportunities that would benefit the chemical industry. Not all of the grand challenge workshops planned for the coming year will be industry-led in the way Vision 2020 was, but all will include representation from key companies in the relevant industries affected by the respective grand challenge topics.

14. A new research and education theme on "manufacturing at the nanoscale" has been added to the NSF's Nanoscale Science and Engineering (NSE) program solicitation in Fiscal Year 2002, and the program element "Nanomanufacturing" has been established in the Directorate for Engineering. NSF invested about $22 million in manufacturing research and education in Fiscal Year 2002, and two Nanoscale Science and Engineering centers with a focus on nanoscale manufacturing will be funded in Fiscal Year 2003. Also, SBIR nanotechnology investment has reached $10 million in Fiscal Year 2002.

Because of the complexity, cost and high risk associated with nanotechnology research, the private sector is often unable to assure itself of short- to medium-term returns on R&D investments in this field. Consequently, industry is not likely to undertake the basic research investments necessary to overcome the technical barriers that currently exist. The traditional government role of supporting basic research is thus particularly important in this case. Additional basic research will be needed to make these innovations ready for industry to develop and market.

The National Nanotechnology Initiative

The National Nanotechnology Initiative is a critical link between high-risk, novel research concepts and new technologies that can be developed by industry. Since the creation of the NNI in October 2000, federal funding for nanotechnology has been coordinated through the NNI. The NNI has continued to the present time as a successful interagency program that encompasses and promotes relevant nanotechnology R&D among the participating federal agencies. The federal agencies currently participating in the NNI research budget are as follows:

- National Science Foundation
- Department of Defense
- Department of Energy
- National Institutes of Health
- Department of Commerce
- National Aeronautics and Space Administration
- Department of Agriculture
- Environmental Protection Agency
- Department of Homeland Security
- Department of Justice

Funding for the NNI provides support for a range of activities, which include: basic research on fundamental nanoscale science; focused efforts aimed to achieve major, long-term objectives of high significance—so-called "grand challenges;" and building research infrastructure (instrumentation, equipment, facilities) and centers and networks of excellence (larger, centralized facilities intended to provide sites for cooperative and collaborative efforts among distributed networks and groups of researchers at multiple affiliated institutions). Depending on the agency, funding supports research and applications of nanotechnology in support of the respective agency missions, research at national laboratories, and research at academic institutions and other research institutes. A portion of the funding is also dedicated to addressing non-technical research problems in a broader context, including societal implications and workforce and training issues.

The NNI has benefited and grown under this Administration's strong commitment to furthering nanotechnology research and development. Support for the NNI is evidenced by significant funding increases for this interagency initiative in each of President Bush's proposed budgets. That trend continues this year, with a 10-percent increase over last year's request for nanotechnology (to $849 million) in the President's FY 2004 Budget. In addition, last year the Director of the Office of Management and Budget and OSTP Director Marburger issued a memo to the heads of executive departments and agencies identifying nanoscale science and technology as one of six interagency research and development priorities.

Nanoscale Science and Engineering Technology Subcommittee

The research agenda for the ten agencies currently participating in the NNI is coordinated by the NSET Subcommittee of the National Science and Technology Council (NSTC). As you know, the NSTC is a cabinet-level interagency body through which interagency science and technology issues are discussed and coordinated. The NSET Subcommittee is staffed by representatives of the participating agencies, OSTP, and OMB. It also includes other federal agencies that do not fund nanotechnology R&D but nevertheless have an interest in these technologies—agencies such as the Food and Drug Administration and the Department of the Treasury. There are now 17 agencies participating in the NSET Subcommittee. NSET members meet on a monthly basis to measure progress, set priorities, keep abreast of nanotechnology R&D being proposed and conducted in the agencies, plan and organize workshops, and plan for the coming year. The agency representatives to the NSET, typically program officers, and researchers, have extensive knowledge of and experience with nanoscale R&D. This expertise has been of critical importance to the success of the initiative, providing a necessary link to nanotechnology researchers in industry and academia.

Because the cost of nanotechnology instrumentation, equipment and facilities is rather high, government funding of such research infrastructure can provide a great benefit to both academic and industrial research. An important focus of the NNI, for instance, is to develop measurements and standards, research instrumentation, modeling and simulation capabilities, and R&D user facilities. Current examples of how this type of funding is used are the National Nanofabrication Users Network (NNUN), the modeling and simulation Network for Computational Nanotechnology sponsored by NSF, and a group of five user-facility Nanoscale Science Research Centers being created by DOE.

The need for this type of infrastructure is so great that federal agencies are committing additional resources to support the NNI's efforts. These include a dedicated nanoscience facility at the Naval Research Laboratory (NRL) and portions of the new Advanced Measurement Laboratory at the NIST.

The National Nanotechnology Coordination Office

The National Nanotechnology Coordination Office (NNCO) assists NSET-participating agencies by: (1) serving as secretariat to the NSET Subcommittee, providing technical and administrative support, (2) supporting the NSET Subcommittee in the preparation of multi-agency planning, budget, and assessment documents, (3) acting as the point of contact on Federal Nanotechnology activities for government organizations, academia, industry, professional societies, foreign organizations, and others for technical and programmatic information, and (4) developing and making available printed and other communications materials concerning the National Nanotechnology Initiative including maintaining a Web site for the Initiative. As part of this support, the NNCO produces annual supplements to the President's Budget explaining the NNI portion of the budget request. It also coordinates and assists in the conduct of regular workshops based on grand challenge areas. The NNCO assists and coordinates the conduct of regional workshops that explore commercialization opportunities for nanotechnology discoveries. These conferences bring together scientists, entrepreneurs, venture capitalists and large businesses for discussion and exploration of partnerships. Reports produced by the NNCO provide a permanent record of conference proceedings and are used by those not in attendance to learn more about developments in the field. Under the auspices of the NSTC, the NNCO also contracts for periodic program reviews to provide feedback on the NNI.

The annual budget of the NNCO is approximately $1 million. Three years ago, the NSET subcommittee and NNCO coordinated the efforts of six agencies involved in nanotechnology R&D. Today, through the NNI, the NSET and NNCO coordinate the efforts of 17 participating agencies. The scale of the workload for the NNCO parallels this increase in participating agencies. The NNCO staff is coordinating an increasing stream of workshops proposed by the agencies, and prepares the post-conference reports. Planning and administrative functions have expanded, as will reporting requirements resulting from the pending legislation.

With an increased number of discoveries and acceleration of commercialization activities here and abroad, staff tracking and reporting to the scientific community and government agencies must keep pace. Increased activity at the state and regional levels has brought welcome support for commercialization and another level of involvement for the NNCO.

Current high-priority NNCO projects include the following:

(a) NNCO is working with OSTP and OMB to finalize a supplement to the President's FY 2004 Budget to explain the NNI activities within the request.

(b) NNCO will follow this with a more detailed report this year, the revised Implementation Plan for the NNI. This will be an update of a similar detailed plan that was submitted in July of 2000.

(c) An interagency workshop being led by the Environmental Protection Agency will address environmental implications as well as applications of nanotechnology. The purpose of this September workshop is to define the future research agenda for EPA and other agencies in the NNI that support nanotechnology research aimed to enhance environmental quality through pollution detection, prevention, treatment, and remediation.

(d) The National Institutes of Health is taking the lead in organizing a workshop to explore opportunities for supporting more research at the intersection of nanotechnology and biology, as recommended in the NRC report. This is tentatively scheduled for October.

(e) Another workshop scheduled for September will facilitate collaboration and best practices among state and regional initiatives.

(f) NNI and the Semiconductor Research Corporation (SRC) are organizing a workshop this Fall on nanoelectronics.

(g) A workshop is tentatively scheduled for this December to assess broader societal implications, including ethical, economic, education/workforce, medical, and national security implications. This is follow-on to a workshop held in September 2000 on these same subjects.

(h) A project is underway to produce a brochure for industry, explaining the state of nanotechnology, R&D opportunities and resources toward commercialization of nanotechnology discoveries.

(i) Following from all the above activities, NNCO will be coordinating a large workshop in early 2004 to integrate inputs from all the grand challenge workshops, PCAST suggestions, new legislation, and recommendations of the NRC report and produce a new "crisp, compelling plan" for the NNI. This will be a reprise and 5-year update of the January 1999 workshop that produced the first detailed technical plan, the report entitled, Nanotechnology Research Directions.

Recognizing the growing complexity of this multi-agency effort, OSTP asked me to begin serving on April 15 of this year as the full-time Director of NNCO. (In the past, Dr. James Murday had served as the Director of the NNCO in a half-time capacity.) Among my specific charges are increasing communications between the OSTP, NNCO and the NSET; promoting a higher level of coordination of nanotechnology R&D among the Departments and agencies participating in the NSET; and providing an increased level of support for the NSET Subcommittee in preparation of planning, budgeting, and assessment documents. Recognizing the increasing need for public outreach for greater understanding of nanotechnology and its societal implications, the NNCO has hired a full-time communications director and will be undertaking an array of communication tasks, including enhancing the NNI Web Site.

NSET and NNCO Interactions with PCAST

Relevant to the legislation before the committee is the report of the National Research Council (NRC) following their study of the NNI. Entitled *Small Wonders, Endless Frontiers: A Review of the National Nanotechnology Initiative*, the report, published in the summer of 2002, highlighted the strong leadership of the NNI, praised the degree of interagency collaboration, and lauded the early successes of the research programs.

As you know, the National Research Council (NRC) recommended that the federal nanotechnology research program would benefit from an outside review. As noted in the President's FY04 Budget, the Administration concurs that an independent review is warranted, and has asked the President's Council of Advisors on Science and Technology (PCAST) to undertake this effort.

PCAST has already begun its work in this regard, and the NNCO staff is excited to be working with the PCAST membership on this task. PCAST is well suited to conduct this review, as its members have extensive experience and expertise in technological developments, how federal R&D programs operate, and how R&D effectively translates to the economy. This type of broad experience offer perspectives on how nanotechnology can address key issues facing industries today (e.g., the "red brick wall" referred to in the recent "International Technology Roadmap for Semiconductors" report).

The preliminary PCAST work plan for its role in advising the NNI, approved at the March 3 PCAST meeting, sets out as one of its first tasks the review and assessment of the NNI's "grand challenges"—the nine areas where nanotechnology can make significant contributions to national goals and priorities outlined in the current NNI program plan. The industrial backgrounds of many PCAST members are particularly appropriate to this role, providing a broader perspective beyond laboratory research.

PCAST also offers the benefits of timeliness and effectiveness. PCAST already exists, and has already begun its nanotechnology work with the intent on providing some recommendations by late summer, in time for the FY05 budget process. Importantly, too, PCAST is an established and well-regarded entity within the Administration. Its advice will be well-received.

The PCAST review of the NNI will be an ongoing project that provides continuing recommendations to the President on how to improve the program. PCAST will work in coordination with the National Science and Technology Council, as well as the NNCO. PCAST's initial effort will be assisting in the development of a crisp, compelling and overarching strategic plan, and refining the list of specific "grand challenge" topics to guide the NNI program. NSET and NNCO are working with OSTP already in organizing a series of workshops aimed at setting specific objectives within those grand challenge topics and clarifying the research agendas for NSET member agencies that will lead to the achievement of those objectives. PCAST then intends to explore additional issues, such as program metrics, and also to monitor the response to the guidance it provides.

To assist in these activities, PCAST has formed three internal task forces—one on materials, electronics and photonics, one on energy and the environment, and one on medical, bio and social issues. In addition, PCAST is forming an external technical task force to gain input on technical nanotechnology issues as may be needed. Additional consultations will naturally occur as well. At its March 3rd meeting, for example, PCAST met with three leading nanotechnology scientists—Richard Smalley, Richard Siegel, and Samuel Stupp (who led the NRC review). PCAST co-Chair Floyd Kvamme also met with the NSET members at NSETs last meeting in early April and I, as the new NNCO coordinator, have already met with Mr. Kvamme as well.

The NNCO is pleased to have PCAST's experience available for counsel, and looks forward to working with PCAST in the months and years to come.

In another structural change, the OSTP has proposed that the NSET Subcommittee be re-constituted with higher level agency membership to enable enhanced coordination and priority setting. We at the NNCO recognize the importance of high-level agency involvement in the NNI. For the active support of planning and conducting workshops and generally tracking technological innovations, we will rely on the current membership of the NSET, which under the OSTP plan would be reformulated as an interagency working group. The members' extensive knowledge of and experience with nanoscale R&D has been and will continue to be of critical importance to the success of the initiative, providing a necessary link to nanotechnology researchers in industry and academia.

Summary and Final Comments

In summary, nanotechnology is still at a very early stage of development, and there are many challenges and opportunities before us. The NNI has for almost five years now served as a very effective means for coordinating federally funded activities in nanotechnology. As this initiative matures and grows in scope and scale, the National Nanotechnology Coordination Office is also scaling up to meet the additional responsibilities that this entails. We greatly appreciate the endorsement of the NNI's achievements and future potential implicit in the language of the proposed 21st Century Nanotechnology Research and Development Act.

Mr. Chairman and Members of the Committee, thank you again for your support. The NSET, NNCO staff and I look forward to continuing to work with you and your staff to refine and improve the program and the legislation currently under consideration.

Senator ALLEN. Thank you, Dr. Teague.

Thank you, all doctors, here. I'll go, perhaps, a line of questioning here. I'll begin and then turn it over to Senator Wyden, and Senator Sununu may also, I'm sure, have some insightful questions of you, as well.

Listening to you all, you all talked about all these different developmental levels. They're something tangible, which is good. A lot of this, again, is very early. There is much research and development going on in a variety of ways, some at colleges and universities, clearly in the private sector, some in your variety of perspectives in governmental agencies.

I'd ask each one of you, what—and I was thinking, looking at each of you is—what are the greatest barriers today for the application for the variety of these very exciting opportunities of nanotechnology and a variety of disciplines and getting the applications of this into the commercial sector? Now, some of it is research. But, more importantly, could you share with me, and share with the Committee, what's the biggest barrier, what is, let's say, the greatest challenge for the transfer of these advances of nanotechnology to the commercial sector?

And I'll go with you, Drs. Murday, Roberto, and Teague.

Dr. MURDAY. Okay, you've identified a problem that I'm sure you're well aware is not unique to nano——

Senator ALLEN. Right.

Dr. MURDAY.—how you get something out of science and discovery into technology is a never-ending challenge, and so this is just one variant on it.

There are a couple of things that I think that need to be addressed. One is, we are just now opening up these nanostructures that Dr. Teague talked about. Their quality factor, to be able to manufacture on the large scale in a cost-effective fashion is still somewhat limited. We've got to address manufacturability, especially to get the reliability and cost improvements that are necessary.

Second, we've got to look to moving ideas out of universities, since most of the funding out of the NNI is in the universities, by intent. We have the science discoveries happening there and the mechanisms to move the ideas out of the universities and into the commercial sector is the challenge, as it is for the other discoveries in science, as well. But we're trying to work with the States and local bodies to help that process to create, through NSF, in particular, the NSECs, which have university involved directly with industry. Within the DOD, there has been a UARC, a university affiliated research center, for soldier nanotechnologies up at MIT. So deliberately reaching out into the university community and helping them form alliances with companies.

We've also tried to pay attention to the SBIR programs, because that is a mechanism to reach out and push new ideas into new businesses. And a number of the State, both private and public, universities are creating science parks where you can get these SBIRs nurtured and the SBIR provides some of the funds that's appropriate to it.

Finally, we're trying to reach out into the venture-capital community, as well, keep them aware of what are the true opportunities, trying to be careful not to over-hype the area to lead to unrealistic expectations. But I have a viewgraph that I sometimes use that says "nanotechnology is the real dot-com," as opposed to the bust of 10 years ago.

Senator ALLEN. Thank you, Dr. Murday.

Dr. Roberto?

Dr. ROBERTO. I guess I'd like to say three things. First of all, the line of sight from the scientific discoveries in nanotechnology and applications is a lot clearer than many other areas of science, and so, in this sense, I think that a very difficult job is made a little bit easier in this field.

Second, certainly coming from a DOE national laboratory, I'm aware of the level of effort that goes into technology transfer and into bringing in the university partners and to identifying opportunities into the effort to get technology out into the marketplace. I'm also aware that many research universities have similar efforts underway. And my general feeling is that, in the area of nanoscale science and technology, that we are finding there's a very significant interest, and we are making those partnerships in a more productive or easy fashion, not that it is ever an easy task bringing these various parties together.

Finally, the DOE Nanoscale Science Research Centers really are developed to help enable this process. These will be state-of-the-art centers. They will be located at laboratories. We've already made a billion-dollar level investments in neutron sources or synchrotron sources or micro-fabrication equipment. And they will be available to universities and industry, and will provide an opportunity for labs and universities and industries to work together in areas that can help bring the science into the marketplace.

Senator ALLEN. Thank you.

Dr. Teague?

Dr. TEAGUE. I guess I'd like to comment on it, first, from a scientific standpoint, in terms of taking things from the research laboratory to the commercialization. But I think one of the things that you probably have heard some other people say, but just to re-emphasize it, is that I think that, following up on Dr. Murday's comments about the manufacturability and the manufacturing process, is that one of the things that is so needed, in almost all the different many processes that you were referring to when you talked about how we make nanotechnology products, is the degree of control of the processes that are being used.

Probably you've heard many times about nanotubes and how important and how valuable the nanotubes are. And it's hard to realize that as much as we had them and as much as you hear about them being manufactured as products and things like that, we have a very, very loose control over the properties of the nanotubes which are manufactured.

If you've looked at—maybe you saw that there's a pencil that some people have that has the nanotube structure printed on the surface of the pencil, and it shows you two different ways in which you can construct a nanotube. One of them is called the way that you—it's made out a sheet of carbon, and if you roll up a sheet of carbon, you have a nanotube. And depending upon the twist that you put into it as you roll it up, it totally changes the properties of the nanotube. In one way of it being twisted, it's almost like a conductive of metal. If you twist it a slightly different way, it's like semiconductor. If you twist it a slightly different way, it's an insulator.

Professor Smalley, several times he said, "If I had one big challenge right now, it would be how could we manufacture nanotubes with a known twist so that I could predict, when I made a nanotube, that it would be a metal, a semiconductor, or an insulator?" And if you look at a lot of the other products that are nanotube-based, their structure and their properties are so dependent upon the exact atomic structure of the materials, until that degree of control is absolutely essential for being able to produce, in quantity and at low cost, the wonderful things that we can produce in ones and twoseys in the laboratory and say, "Look at these neat things." Until you can have control, it's hard to go from ones and twos in the laboratory to something that you can produce as a manufacturable product at a good cost.

And how do you get that better control over the processes? I think that that's the essential part of the federal funding for R&D. I think one of the absolutely key parts of the whole nanotechnology program in the United States is a very firm realization that there's a lot of investment and a long time of R&D, probably as long of an R&D investment to bring something to this high degree of control as has been with almost any other technology. So I think one of the ways to bring something to market is to realize that it's going to take good support at the federal level to carry out and complete the really underlying fundamental research and development so that companies can pick it up at a level that is economically viable for them to move into the marketplace and make good production.

Senator ALLEN. First to Dr. Murday. The answer to my question really is nothing new. That's the—basic economics, commercial application, no matter what's coming out of universities, the commercialization or obviously protecting the intellectual property, whatever the method of—or whatever the nanotech application may be, venture capital opportunities, all of that really is just basic economics that we've seen before with any sort of advancement in any new idea or process.

The same applies to what you were saying, Dr. Roberto, although you're saying that the applications are more clear in nanotech, and to the extent that those applications are more clear, that does help with the venture capital. It all then comes back to standard and, probably by analogy, making sure that the methods or standard or control of processes——

Dr. ROBERTO. Yes.

Senator ALLEN.—in what you talk about. Again, I guarantee you there's some analogy. This is not the first time. This is not an issue of first impression.

Dr. ROBERTO. Right.

Senator ALLEN. And I'm sure this applies to extrusion and the manufacturing of all sorts of material——

Dr. ROBERTO. Yeah.

Senator ALLEN.—plastics, metals, and films, where there needs to be that standard or that grading or the method of production that has that quality that is desired by whomever the ultimate user may be.

So, fortuitously, we're at the early stages, but none of these are never considered problems. Again, you may have to just use some common sense and creativity. And the best of all with this is that we're only limited by our imagination. All of the challenges you all brought up here are easily—I shouldn't say easily surmountable, but have been faced before and certainly can be—the challenges can be surmounted in the future.

Thank you all. Thank you so much.

And I'd like to turn it over to Senator Wyden.

Senator WYDEN. Thank you, Mr. Chairman. That was really excellent. That was almost like a teach-in on nanotechnology, and I thank you for it.

The panel is just terrific, and I thank you all. And let me get into a couple of nuts-and-bolts issues that we're going to have to work out to wrap this up.

Dr. Teague, on the advisory panel you were quite passionate about PCAST, in effect, being the lead, and Senator Allen and I have already had all kinds of people lobbying us and jockeying with respect to this whole issue. And let me get a sense, a bit, of your reaction to how I come at it.

I mean, if you look at the President's Council of Advisors on Science and Technology, this is an extraordinary group. I have worked with many of them myself. This is not—in questioning, I mean, people like Dr. Healy, Floyd Kvamme—I mean, these are people I've known for years and I have looked to for help on technology questions. That is not what's at issue.

What is at issue is, at first impression, this does not look like a group that has a history of involvement in the nanotechnology area. This looks like a group of incredibly dedicated, thoughtful people, who are going to be coming to nanotechnology for the first time.

So what we did in the last Congress, when I put this legislation together with Chairman Allen again now, is we said, what we need to do is follow the recommendations of the National Research Council, which is, from the get-go, go out and find the very best people who, on day one, are going to have some history and some involvement with respect to nanotechnology.

My question to you is—I'd like to hear your reaction to, sort of, how I approach this and also your thoughts on how we figure out how to work this out and get it resolved, because it—I mean, this is a terrific bill. Chairman Allen and I have spent a ton of time on it. I've already gotten the sense from the House, there's been a dust-up a bit on this issue, and we're not going to let that happen. Chairman Allen and I have worked out much tougher issues than this. So let us see if we can have your great minds give us your insight on this, and your thoughts, Dr. Teague, with respect to how I've come to my assessment of this, and what you think we might do to make sure we just get this to the President's desk quickly.

Dr. TEAGUE. Well, I could certainly concur with that last sentiment. And relative to PCAST, and one of the reasons I guess I was very enthusiastic about it is, is that I think that there are members, and some of the ones you mentioned, certainly, who have some experience with nanotechnology——

Senator WYDEN. Tell me who, of the PCAST membership now, has experience with nanotechnology. I'm not aware that they do, and that's what's in question, and we need experts like you—I mean, just, if you would, Charles Arntzen, Norm Augustine, Carol Bartz, Kathleen Behrens, Eric Bloch, Stephen Burke, Wayne Clough, Michael Dell, Raul Fernandez, George Scalise, Luis Proenza, Steve Papermaster—tremendous group. Who has background today in nanotechnology?

Dr. TEAGUE. Well, the two, I guess, that would come to mind most immediately would be the president of the Georgia Institute of Technology, Wayne Clough, and the president of MIT, Charles Vest. I think certainly both of those have a lot of nanotechnology-related activities within their universities. Certainly they are the highest level of the administration of their institutions. But I think both of them would have a great deal of knowledge of what would be going on in the field of nanotechnology, just from interacting with, I would say, the physics departments, the chemistry departments, the material-science departments within their respective institutions. So I would think they would be quite informed relative to that.

Gordon Moore, certainly in terms of looking at the ultra-miniaturization of microelectronics, I would think is definitely familiar with the extreme miniaturizations that one might achieve down to the nano-electronics and the molecular-electronics level. I would think that he, in his many years of experience with electronics, would have a very good perspective on the basic understanding of what would happen to electronics at the nanoscale level.

So some of the other ones, I think even if you look at—I forget one of the Members of the Committee also had a lot of background in the bio area, and I think that the biotechnology aspect and its heavy overlap with nanotechnology is going to be very crucial in, again, having the proper perspective on what's happening in the area of nanotechnology.

Finally, I guess, relative to that, the PCAST itself is—they've decided, in their proceeding of their assessment, that they're going to obtain additional technical expertise through the formation of different technical task forces to assist them in their assessment. So they're not going to do it just on their own; they're going to be actually forming and pulling task forces of experts in the field, very much as you're indicating is being needed, and I would agree that there are some additional possible inputs needed onto it.

I guess two other points that I think are so important about PCAST. The first one is that relative to the question that Mr. Chairman was asking, in terms of the technology transfer, I think the business acumen and the experience of many people on the PCAST would be tremendously valuable in understanding the transition of the technology out into the commercial and into the economic factors that would be involved in that.

And, finally, I guess, from my perspective, one of the greatest assets of the PCAST so far is that they've become engaged, and they are taking—they're really taking action relative to trying to understand and to do some real assessment of the NNI. I think that, to me, is one of the most important aspects of any kind of council or any kind of Committee of this nature, is that they really do engage with whatever their charge is. And, so far, PCAST has indicated very good interest and very good action in tackling the problem.

Senator WYDEN. Well, again, I can't say enough good things about PCAST, generally. This is not what the discussion is about. But there are 25 people on there, and you mentioned three who you thought had some involvement in nanotechnology, and I want to make sure that, on day one——

Dr. TEAGUE. Okay.

Senator WYDEN.—we've got everybody with some proven expertise and a track record in this area, and we're going to work this out. This is too important, and the bill is too good to have this be an issue it flounders on. And, by the way, I agree with your point with respect to technology transfers——

Dr. TEAGUE. Yes.

Senator WYDEN.—as well. We're going to hear from another witness—I noted, Mr. Chairman, we have another private sector witness who points out something you and I have talked about, which is that Bayh-Dole has not worked as well as it needs to, neither for industry, universities, or taxpayers. And the point that Dr. Teague is making with respect to how important it is to improve tech transfer is one that I very much share, and that involves getting the private businesses in early with their suggestions for how to do it.

A couple of other quick questions, and then I know Senator Sununu's got a great interest in this, too. I want to let him get at it.

Gentlemen, how are we doing with respect to the global competition? Last year, Japan spent $650 million on nanotechnology research. Europe was at $400 million. A host of other countries have spent substantial sums. Really the two areas that I want to touch on—maybe you can talk about them together—one was, how do we fare with respect to global competition? And the second is, what needs to be done with our universities and particularly the multidisciplinary approach that's going to be so important. And so perhaps, in the interest of time, maybe you could take both of those two together for our other witnesses.

The question, global competition, where we stack up, and what do we need to be doing with our universities to foster a multi-disciplinary approach?

Perhaps, you start Dr. Murday.

Dr. MURDAY. Okay. With respect to the global competition, I did take a quick look earlier this year at the science literature. There's about 18,000 articles that came out in 2002, to put some numbers behind your concern. They're roughly divided; one-third in the Asian theater, one-third in the U.S., and one-third in Europe. That says, in terms of quantities, we are one-third.

Then there is always the concern that maybe the quality—maybe we're ahead on quality, if not quantity. So I did another search on some key journals that are considered high-impact journals and looked at that. And there, if you look at it, the U.S. has got about 50 percent of the articles. So we're fairing a little better in the quality war, if you want, but there is a clear trend for the other nations to be growing. So we're presently at 50, but that's a diminishing fraction.

So the concern about global competition is a real one, and one of the aspects that we need to be very careful—as we go in this process of developing a crisp, compelling strategic plan, one of the recommendations from the NRC is, part of that has got to be, how do we incorporate the global perspective and invest more smartly? We're clearly not going to outspend any longer, so we have to spend more smartly. And that's part of what's got to be built into this strategic process.

It's quite clear—you had asked about multi-disciplinary, and Jim Roberto commented on it, and maybe at this high a scale essentially all the disciplines sort of blur into one. But it's important to get these different perspectives, because it's the boundaries between traditional perspectives where you get the most frequent and scintillating advances.

Now, there, I believe the U.S. has still got a clear lead, compared to other nations. Where I would be more concerned in our university environment, not can we out-compete them in that aspect of it, but, rather, we're drawing a significant fraction of our students, our graduate students, from other nations. And as their research investment goes up, as their capabilities grow, there will be less likelihood we're going to attract those students here to the U.S. That means we'd better have our own pipeline stoked to replace them. And that is a very daunting challenge for us, and it goes—as we commented in terms of being able to transfer into technology—this is not unique to nano—getting American students into science and engineering is not unique to nano, but maybe nano's enough interesting, enough scintillating that, you know, we can get some people really excited about it. I know I am.

Senator WYDEN. Well, without letting the hearing divert, Senator Allen's been very supportive to me on another one of my crusades, which is getting more women into these fields, and even looking at Title IX, which many people think is a sports statute, but was—its origins are really academics, using Title IX as a lever to do it. So your point about students is a good one, as well.

Dr. Roberto?

Dr. ROBERTO. Yes, I think that we are in a tough fight. I think the kind of investments that you all are talking about making in the various bills that I talked about in my remarks are, sort of, what's needed in order to keep us abreast and moving ahead. I don't think there is a clear leadership in the world now in this field. I think that the leadership is ours, in many respects, to win or lose, depending on the kind of investments that we make as a nation. This is a field that I think is very important to have leadership, because I think it is going to be the basis for a new industrial revolution.

With respect to the issue of whether we're going to have the scientific person-power for the future, I guess I'd like to add that I go out in the community and give a lot of talks at schools and in public forums, and often those talks are on nanotech. And the response that I usually get, whether it's the third grade or whether it's the grandmother, is, "Can I come work for you?" I mean, they really get excited when we talk about nanoscience.

And I think that one thing that we could do is, we could use nanoscience as a way to catalyze interest in our secondary-school students in science and technology. And I think the kinds of investments that we're talking about making provide a path that can then keep them interested in science as they go through college and graduate school.

So I think there's an opportunity here not only on the technology-transfer side, but also on the human-capital side.

Senator WYDEN. Thank you, Mr. Chairman.

Senator ALLEN. Thank you. They're very good questions, Senator Wyden.

At the outset, I was talking about competition, and I guess the summary is, we're in competition, and we were more preeminent than we are now.

Again, the issue in the science—and we've run into this in a lot of areas in technology, in the H1B visas and the issues associated also in aeronautics—there's a lot of areas where we do need to somehow motivate and excite more Americans, whether they're—all genders, all races, all ethnicities, all Americans, regardless of their background, to get involved in it.

So thank you all.

I'd like to turn it over to Senator Sununu, who may have some questions, I suspect.

Senator ALLEN. Senator Sununu.

STATEMENT OF HON. JOHN E. SUNUNU, U.S. SENATOR FROM NEW HAMPSHIRE

Senator SUNUNU. Thank you, Mr. Chairman.

I'm pleased that you're having the hearing. This is obviously an extraordinary area of investigation and research, just as evidenced by the amount of resources that have already been dedicated, at least at the federal level, toward this type of research across a number of different agencies. I think well in excess of $500- or $600 million last year, over $800 million proposed in the President's budget across a good handful of different research areas. NSF, even the Department of Commerce, HHS, have their own initiatives investigating opportunities in nanotechnology. So it's an exciting area. It really does require some continued support and investment.

I want to begin by talking a little bit about the exchange between Dr. Teague and Senator Wyden on the advisory group. But, first, I think it's important to note that—Dr. Teague mentioned three or four people with some background, experience, expertise, knowledge about nanotechnology, its potential applications, even some of the scientific principles, and I would venture that the list goes even a little deeper than that. I mean, we have individuals that were former directors of the National Science Foundation, that were directors of the Brookhaven and National Laboratories. We have—Mr. Kvamme, in his role as a venture capitalist, you know, if he doesn't have experience working with people that are interested in laying out their own risk capital in areas involving nanotechnology, then we can certainly find a venture capitalist that has. But I think that Kleiner Perkins has dealt with more than one potential application involving nanotechnology.

So I think there's a wealth of experience and understanding of how this technology may affect research in scientific institutions or institutions of learning. You mentioned Georgia Tech, and another smaller school in Cambridge, I think——

[Laughter.]

Senator SUNUNU. MIT, that was it.

But this is, from my perspective, very much the kind of background we would want, for a couple of reasons. One is the understanding of how this technology can fit into these different areas—

education, research, of course, the business world, you mentioned Intel, there's a representative from—who's done some work with IBM, Lockheed—not that these companies are any more unique than many others, but there's that private sector perspective, as well.

But if you look at the other side of the coin, I would also like to have, ultimately, a review board, an advisory board, that doesn't have an interest that is vested solely in nanotechnology.

Now, academics are wonderful people, but I'm sure that once in a while you can find an academic that's a little bit parochial, you know, that is very particular about funding for their area of interest. I saw a few of those, you know, as an undergraduate trying to do research. And they don't necessarily have the best perspective when it comes to allocating scarce resources into different areas of interest or research.

The same principles may be at stake in nanotechnology, but, as was pointed out, some of these fundamental areas of investigation might affect biotechnology, they might affect material science, they might affect construction. And I think it serves us very well to have a slightly broader perspective on the advisory board.

Naturally, there's also the concern about creating yet another layer of bureaucracy. There's nothing wrong with bureaucracy when it's properly utilized, but advisory boards are—it's the bureaucracy. And the more advisory boards you have, the more layers of advice and consent and review. Obviously, that carries with it an expense; not necessarily in dollars, but in time and certainly in effort of those that are involved.

And I note, given the background of some of our witnesses today, we already have a National Nanotechnology Coordination Office. I think that's important to have an office that's focused in a professional way on trying to make sure information is appropriately shared, that there's some coordination going on. We have the Subcommittee, the NSTC, that is also fulfilling an important role. And, of course, then we have PCAST.

I would be very concerned about creating another layer of bureaucracy and then not taking advantage of a board that already exists and that I think can lend a great deal of value and substantive advice when it comes to these issues of nanotechnology.

A few other concerns that I have, or caveats, and not specifically with the legislation. Obviously, this is an issue that the Subcommittee Chairman and the ranking Member are aware of, and I trust you to work this through, not just here in the Senate, but with our counterparts in the House, so that we end up with a structure that works. But I do have a couple of other concerns where this kind of research is—where we make investments in this kind of research. And I want to share that with the panel and with my colleagues here, as well.

I noticed, first, with regard to applications, that we come to these hearings, and we want to talk about the future and about the potential growth and economic benefits and returns and job creation and such. But I always get nervous when I hear anybody in government talking about doing scientific research with the express objective of creating a certain number of jobs or a quantifiable benefit to the economy. Because if you can tell me what the economic value of your research is, then I'll ask you to leave the room, and I'll call Mr. Kvamme, because he can, as well as anyone, evaluate what the net-present value of that—if you can tell me what the net-present value, the economic benefit of your research is, he certainly can, and he'll go out and find somebody to put $1 million or $10 million or $50 million or whatever the warranted investment is.

I believe, as a society and as a country, we should be investing in research, because, societally, it creates very significant benefits. But the kind of research that we should be investing in is precisely that research for which the time horizon is so long or the benefits are spread over such a large number of areas that you cannot quantify the economic benefits. Physics and chemistry, computational mathematics, obviously the very areas that I hope the bulk—I would hope that all of our National Science Foundation funding is being invested in. And nanotechnology is one such area. You know, nobody knew what a Bucky ball could be used for when the concept was first developed and there wasn't a venture capitalist that was looking at this, you know, wringing their hands and excited about the prospects.

That's where we should be making investments. So I look at the list of products that have become available over the last year or two, and this is certainly interesting, but I guess, in clearest terms, the caveat is, we should not be making investments with the specific goal of strengthening our nation's tennis ball industry or mattress industry or sunscreen industry or automotive industry. Those are great industries and great companies that populate them, and I'm pleased that nanotechnology has provided them with exciting and lasting benefits to their product-development areas. But that's not why we invest the money, that's not why we do the research; not for any specific benefit, but because we know that, in the long-run, the scope and the breadth of the benefits will be significant even if we can't quantify them today.

And, finally, with regard to global competition, I think that the last point that was touched on is an extraordinarily important one, and that is the strength of our Nation's education system. And one way to measure that is the number of advanced degrees in science and mathematics that we're turning out. And the statistics have probably been touched on in here before by this Subcommittee, and I won't belabor them. I think that's extremely important.

But there was another discussion about the global competition and some interesting statistics given about this. You could look at patents or papers published or—I like the quality measurement, too. And I believe that to be absolutely accurate. But we shouldn't allocate funds to any area of research just because some other country is doing the same. Now, if there's significant value, long-term value, societal value, to the area of research, I'm sure there are many countries that will be pursuing it. But if just did what all of our competitors do—in fact, the notion that we should do what our global competitors are doing is what nearly drove our Government to invest several billion dollars, maybe $10 billion, in the HDTV market and HDTV technology about, oh, 12 years ago now. We chose not to do that, and that was $10 billion or so that was very, very well spent on other things in this country.

So, you know, the Japanese, I think, in retrospect, made an enormous mistake in thinking that they needed to, you know, make this investment so that they could keep their television industry healthy. I love the television industry, too. They make good products, and I've used them from time to time. But we need to be very careful about just making an investment because somebody else is putting money in the same area.

So this is a wonderful opportunity. I'm excited that we've made so much progress over just a few years with the Nanotechnology Coordination Office, that we have senior Members of the Senate here that are great advocates for these programs, with a President who has put in his budget over $800 million, and I think, with this legislation, as it's developed and as it's refined, we can be confident that the programs will remain strong. And I do hope that the money will be put to very good use.

Thank you, Mr. Chairman.

Senator WYDEN. Mr. Chairman?

Senator ALLEN. Yes, thank you, Senator Sununu.

Senator Wyden?

Senator WYDEN. Just so I can make one quick point very clear, since we're having this discussion, about the advisory panel. The advisory panel was never, neither as originally envisioned or today, to be made up solely of academics, and that's made very clear at page 17 and 18 of the bill, where we call for those with a reasonable cross-section of views and expertise and make it clear that recommendations from industry are invited, which is at the top of page 18. So just since we're talking about the nature of the advisory—having this debate, I want to be clear that, as the lead author of this now for two sessions of Congress, with the help of Chairman Allen, it has never been my desire to just go off and bring together a handful of academics and to have them go sit in a corner, but to make sure that we are getting the cross-section of views that I think's important to develop this, and that's outlined on page 17 and 18 of the bill.

Thank you.

Senator ALLEN. Thank you, Senator Wyden.

As a practical matter, it's going to be PCAST anyway, who we're seeming to evolve to in that respect.

I want to thank all our doctors. Thank you so much for your expert advice, your enthusiasm, and your leadership in this area in a variety of ways. You're articulate, you're smart, and I also like the fact that you're competitive and recognize that it's just basic market forces and issues that none of us in government can solve, nor should we, but make sure that those creative, innovative ideas can start improving our lives, whether it's in health care, materials sciences, energy, or a variety of other ways.

So, again, thank you all so much for your testimony and answering our questions.

I'd like to have our second panel please come forward.

Thank you, Doctors.

I want to thank our second panel for joining us today. We look forward to your testimony. I'll make a brief introduction of each of our witnesses on the second panel.

First, Dr. Davis Baird, who's a professor and chair of the Department of Philosophy at the University of South Carolina, a fine institution. My wife is a graduate of the University of South Carolina, the real USC.

[Laughter.]

Senator ALLEN. And Dr. Baird is now leading a National Science Foundation-funded interdisciplinary team of Researchers from 10 Departments in 6 colleges at USC and is working in cooperation with USC's Nanocenter on the societal implications of nanotechnology. One of the concerns are that a lot of the limits we have here are simply in our imagination, but ethical limits and values still do apply; legal, as well. And so we look forward to hearing from you.

And then we have Dr. Jun Jiao—am I saying it close enough?

Dr. JIAO. Yes.

Senator ALLEN. Senator Wyden got to meet Dr. Jiao just before the meeting, and she's a wonderful doctor and person. She's co-director of the Center of Nanoscience and Nanotechnology and a professor of physics at Portland State University. Dr. Jiao's principal research interests concern nanoscale materials and the application of analytical techniques of electron——

Dr. JIAO. Microscopy.

Senator ALLEN.—microscopy, thank you. These are not words we normally use, but I guess we will as we become more familiar.

[Laughter.]

Senator ALLEN. In the last 10 years, Dr. Jiao has proposed and conducted several studies on the preparation and properties of carbon-related nanometer-scale materials, including carbon nanotubes, which we heard about earlier, and carbon-coated magnetic nanoparticles.

Next, we have Dr. Kent Murphy, who is the founder and president of Luna Innovations. Luna Innovations is located in Blacksburg, Virginia. They have over 180 employees working in the technology sector in biotechnology, nanomaterials, optical-fiber telecommunications and instrumentation, and control and predictive-based maintenance, as well as other key technologies of the future.

Thank you for being with us, Dr. Murphy.

And, finally, James Von Ehr II, is the founder and Chairman and Chief Executive Officer of Zyvex Corporation, which I've had the invigorating pleasure of visiting. As we were talking about where employees are coming from and where the talent is, I did observe that I think you had employees that must have been—you might not have had anybody from Australia, but you certainly had them from every continent of the world, as it seemed. You may have had an Australian in the midst. No Australian, all right, every continent except Australia.

[Laughter.]

Mr. VON EHR. We have a New Zealander on our advisory board.

Senator ALLEN. New Zealander, close.

[Laughter.]

Senator ALLEN. Well, I will say Mr. Von Ehr is also the founder of the Texas Nanotechnology Initiative, a nonprofit organization dedicated to establishing Texas as a world leader in the discoveries, development, and commercialization of nanotechnology. Mr. Von

Ehr is also co-founder of the Feynman Grant Prize, a $250,000 prize for a particular embodiment of nanotechnology.

I welcome all these esteemed witnesses, and we look forward to hearing your testimony this afternoon.

If you'll please proceed, we'll start with you, Dr. Baird.

STATEMENT OF DR. DAVIS BAIRD, PROFESSOR AND CHAIR, DEPARTMENT OF PHILOSOPHY, UNIVERSITY OF SOUTH CAROLINA

Dr. BAIRD. Well, thank you, Chairman Allen, Senator Wyden. I wish to thank you both, and the Committee, for inviting me to testify about the need for social and ethical dimensions research on nanotechnology.

At the University of South Carolina, I'm leading a broadly interdisciplinary team of researchers working in cooperation with the Nanocenter. Our mission is to examine the societal implications of nanotechnology. It's a topic I feel strongly about, and I'm happy to speak to you about it here.

And this is my primary point. It's essential that research into the societal and ethical dimensions of nanotechnology be undertaken. It's essential because nanotechnology presents itself as a transformative discipline. So these are the words of the 2002 National Nanotechnology Initiative Report, and I quote, "The impact of nanotechnology on the health, wealth, and lives of people could be at least as significant as the combined influences of microelectronics, medical imaging, computer-aided engineering, manmade polymers developed in the century just past." We would be foolish not to investigate the human implications of such a fundamental technology.

Research into the societal and ethical implications is essential also because of the nano size that we're dealing with. Immediately, privacy issues come to mind, but there are also important issues concerning toxicity, about environmental uses and abuses of nanotechnology. Possible military uses of nanotechnology raise concerns.

Beyond these concerns about specific nano-size products, we need to think carefully about how nanotechnology is framed. Ray Kurzweil, in testimony to the House on their version of this bill, about, oh, a few weeks ago, spoke of conquering aging. Were we to do so, it would be a societal nuclear bomb, and we need to think this through.

Ideas about nanotechnology come to the public through two main avenues, science fiction—Michael Crichton's "Prey," for instance—and what I call "science faction," meaning more than fiction, but less than fact—for instance, Bill Joy's "Why the Future Doesn't Need Us." If we're not careful, we'll have a real political football on our hands. Already, we can see resistance building.

For all of these reasons, I think it's imperative that we undertake research under the societal and ethical dimensions of nanotechnology.

Targeted funding is necessary here. Funds for research into the societal and ethical implications of nanotechnology need to be targeted to those with the expertise, training, and interest to focus on these issues. If they're not, the funds will be gobbled up, reasonably enough, by hungry scientists and engineers. This much has been said by the recent National Research Council's 2002 Review of the National Nanotechnology Initiative, the "Small Wonders" book that's been referred to.

A center for research is necessary. In order for the promise of the work on societal and ethical implications of nanotechnology to have a significant impact, the work needs to be concentrated in one or, preferably, more than one center. There are numerous science and technology centers, a veritable juggernaut. Such centralization is needed for the societal and ethical voice to be heard above the roar of the scientific and technological excitement. In addition, a center can help coordinate and assess the various approaches to these problems that we attempt. So I was pleased, and I underline that Section 4 (c)(5) of the bill you're considering, S. 189, is very important.

Interdisciplinary research is necessary. The research must be done in a broadly interdisciplinary way. We need to draw on the full spectrum of voices—the humanities, arts, social sciences, the legal and medical professions, and, of course, the scientists and engineers.

Productive work on societal implications needs to be engaged with the research from the start. Ethicists need to go into the lab to see what's possible. Scientists and engineers need to engage with humanists to start thinking about this aspect of their work. Students need training now that will take their understanding of nanotechnology from laboratory to society. These students today, trained in the right interdisciplinary setting, will become a cadre of scientists, engineers, and scholars used to working together, thinking about the societal and technical problems side by side. Only thus, working together in dialogue, will we make genuine progress on the societal and ethical issues that nanotechnology poses.

We have a real opportunity here. Instead of calling on ethicists to patch things up as best they can after the fact, if we start now, bringing social scientists, humanists, legal and professional scholars to the table, our understanding of the social and ethical dimensions of nanotechnology can co-evolve with the technology itself. This will make for better, more socially responsive work in nanotechnology and for few problems to patch up later on. Nanotechnology can avoid the fate, most recently, of the genetically modified organisms.

Thank you for considering my testimony. In my written comments, I map out, in somewhat more detail, the kind of interactive interdisciplinary model that we're building here at USC. I should also note similar work being done at the University of Virginia. But it's a big country and there's lots to do. And I welcome any questions you may have.

[The prepared statement of Dr. Baird follows:]

PREPARED STATEMENT OF DR. DAVIS BAIRD, PROFESSOR AND CHAIR, DEPARTMENT OF PHILOSOPHY, UNIVERSITY OF SOUTH CAROLINA

I wish to thank the Committee for inviting me to testify about the need for research on the social and ethical dimensions of nanotechnology. At the University of South Carolina I am leading a broadly interdisciplinary team of researchers working in cooperation with the USC NanoCenter. Our mission is to examine the societal implications of nanotechnology. It is a topic I feel strongly about, and I am happy to speak to you about it.

I have one primary point, and three follow-up clarifications.

Primary point: It is essential that research into the societal and ethical dimensions of nanotechnology be undertaken.

Targeted Funding Necessary: Adequate funding for this research must be *specifically targeted* for investigating nanotechnology's societal and ethical dimensions.

Center for Research Necessary: It would be more productive for some of the research to be concentrated in one—or preferably more—centers.

Interdisciplinary Approach Necessary: This research should be conducted in a broadly interdisciplinary way that includes humanists, social scientists legal and medical professionals and nano scientists and engineers.

Primary point: Research into the societal and ethical dimensions of nanotechnology is essential for many reasons:

(1) Nanotechnology presents itself as a fundamentally transformative technology, with changes promised in nearly every important sector of human endeavor. According to the 2002 report of the National Nanotechnology Initiative: "The impact of nanotechnology on the health, wealth, and lives of people could be at least as significant as the combined influences of microelectronics, medical imaging, computer-aided engineering, and man-made polymers developed in the century just past."[1] We would be very foolish not to research carefully the potential societal and ethical consequences of nanotechnology.

(2) In virtue of its defining characteristic—nano size—nanotechnology immediately raises several social and ethical concerns. Privacy comes quickly to mind, but also the human and environmental toxicity of manufactured nanoparticles. Nanotechnology will be important for other environmental issues including waste disposal and the remediation of natural sites. Potential military uses of nanotechnology raise concerns.

(3) Beyond concerns about such concrete products of nanotechnology, we need to consider how the goals of different segments of society for the use of nanotechnology are framed. In oral testimony to the House of Representatives Ray Kurzweil said, "Nanotechnology and related advanced technologies of the 2020s will bring us the opportunity to overcome age-old problems, including pollution, poverty, disease, and aging."[2] Problem or not, "overcoming" aging would be a societal nuclear bomb. Such goals need careful reflection, not "damn the torpedoes, full steam ahead" technical pursuit.

(4) Information about nanotechnology is coming to the public through two main avenues science fiction—Michael Crichton's *Prey*—and, what I call "science faction" (more than fiction, less than fact)—Bill Joy's "The Future Doesn't Need Us." Without some serious reflection on the genuine opportunities and risks posed by nanotechnology, this field could very easily become a political football. Already one can see resistance building in, for example, the efforts of the ETC group.[3]

For all these reasons, and others as well, it is imperative that we undertake research on the societal and ethical dimensions of nanotechnology.

Targeted Funding Necessary: Funding for this research needs to be specifically targeted to societal and ethical work. When this doesn't happen hungry scientists and engineers—reasonably and appropriately enough—gobble up all the funds. They may add some words to a largely scientific or engineering grant application that suggest an interest in societal implications, but if the work is not organized and led by those for whom societal and ethical concerns are the focus, the words will only be window dressing. This much has been reported in the National Research Council's 2002 review of the NNI.[4] Philosophers, ethicists and social scientists are

[1] National Science and Technology Council 2002, *National Nanotechnology Initiative: The Initiative and its Implementation Plan. http://www.nano.gov/nni2.pdf, p. 11.*

[2] House of Representatives, Committee on Science, Hearing, April 9, 2003, on H.R. 766, "The Nanotechnology Research and Development Act of 2003," (the House version of S. 189). The quoted material is from the transcript p. 3.

[3] An April 14, 2003 news release from the Action Group on Erosion, Technology and Concentration [ETC Group]: "Size Matters: New Information Provides More Evidence for Mandatory Moratorium on Synthetic Nanoparticles," available for download at *http://www.etcgroup.org/search.asp?theme=11.*

[4] In the National Research Council's words: "There appear to be a number of reasons for the lack of activity in this [societal and ethical] area. First and foremost, while a portion of the NNI support was allocated to the various traditional disciplinary directorates, no funding was allocated directly to the Directorate of Social and Behavioral and Economic Sciences, the most capable and logical directorate to lead these efforts. As a consequence, social science work on societal implications could be funded in one of two ways: (1) it could compete directly for funding with

Continued

trained—variously in different ways—to think through ethical and social issues. Furthermore, they are well situated to mediate between the scientists and engineers working on nanotechnology and the broader public.

Center for Research Necessary: In order for research on the societal and ethical implications of nanotechnology to have significant impact, some of this research needs to be concentrated in a center—or better several centers. Already there are numerous well-funded state and university centers for the pursuit of the scientific and technical challenges posed by the nanoscale. NSF has funded six nanoscale science and engineering centers [NSECs]. Similar centers have been funded by NASA, DOE and DOD. There is a scientific and engineering juggernaut here, and some concentration will be necessary for the societal and ethical dimensions voice to be heard. Section 4 (c)(5) of the bill you are considering, S. 189, is important.

Interdisciplinary Approach Necessary: Investigations into the ethical and societal implications of nanotechnology must be done in an interdisciplinary collaborative way, drawing into dialog the full spectrum of perspectives on this work—the humanities, arts, social sciences, the professions and, of course, the various scientific and engineering disciplines that are jointly pursuing nanoscale research. Productive and useful social and ethical considerations of nanotechnology cannot occur outside the research and development itself. We will be much better off integrating such concerns into the research from the ground up. To do this we need to establish channels of communication between and among the various stakeholders in nanotechnology. We need to bring humanists and social scientists into the lab so they can begin to grasp what is genuinely possible at the nanoscale, *and* then it will be possible for the scientists and engineers to hear and to begin to engage social and ethical concerns. Students, who will be developing the nanotechnology for the next generation need to be broadly educated *now* in the whole picture of nanotechnology, laboratory to society. None of these groups has a monopoly on what is right and true, and only through careful open dialog can we hope to make meaningful progress reconciling different viewpoints and building societal and ethical concerns in at the beginning.

Let me close by saying we have a real positive opportunity here. In contrast to the typical case where ethical and social consequences are dealt with after the fact, patching up problems as best as we can, in this case research into the social and ethical dimensions of nanotechnology can co-evolve with the technology itself. This will make for better, more socially responsive work in nanotechnology and for fewer problems to patch up. Nanotechnology can avoid the fate of genetically modified organisms.

Thank you for considering my testimony. In my written comments I sketch out in somewhat more detail the kind of interactive interdisciplinary model I have in mind. I would be happy to entertain any questions you may have.

Appendix 1: USC NIRT "From Laboratory to Society: Developing an Informed Approach to Nanoscale Science and Technology" as a Model for Developing a Center of Ethical and Societal Implications of Nanotechnology

1. Background

On June 15, 2001 the NanoCenter at the University of South Carolina was founded. But the pursuit of nanoscale research here—and elsewhere—takes on a particular intellectual risk. Gary Stix characterizes it in a recent issue of *Scientific American*: "Any advanced research carries inherent risks. But nanotechnology bears a special burden. The field's bid for respectability is colored by the association of the word with a cabal of futurists who foresee nano as a pathway to a technical utopia: unparalled prosperity, pollution-free industry, even something resembling eternal life." Caught between nano-visionaries and nano-skeptics, "the nanotech field struggles for cohesion" and a clear definition. Even serious publications and reports about the totally new promise of research at the nanoscale echo many of the nanovisionaries' predictions. Though they indirectly profit from, and are to some extent inspired by the "hype" surrounding nanotechnology, the serious scientists at USC

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physical science and engineering projects through a solicitation that was primarily targeted at that audience or (2) it could be integrated within a nanoscience and engineering center.

There are a number of reasons both funding strategies failed to promote a strong response from the social science community. First, given the differences in goals, knowledge bases, and methodologies, it was probably very difficult for social science group and individual proposals to compete with nanoscience and engineering projects in the NIRT and NER competitions. (*Small Wonders, Endless Frontiers: A Review of the National Nanotechnology Initiative,* 2002, p. 34).

need to distance themselves from such overreaching claims. They need to do so not only for reasons of intellectual honesty, but also because overstated technological promise has a flipside: It can easily engender irrational fears that undermine public acceptance. The field's bid for respectability therefore concerns not only its standing in the larger scientific community but also its perception by those who shape public understanding of science and technology.

In July 2001, a number of humanities scholars at the University of South Carolina formed a Working Group for the Study of the Philosophy and Ethics of Complexity and Scale [SPECS]. Their goal is to develop a scientifically, philosophically and ethically informed understanding of the critical developments of the sciences and technologies that are set to define and transform the 21st century: nanoscience and nanotechnology, robotics, genetic engineering, earth systems science, the study of complex and autocatalytic systems. One of the group's first topics for discussion was Bill Joy's "Why the Future Doesn't Need Us." Joy moves far too hastily from contentious predictions to a sweeping call for a moratorium on many kinds of basic research. Nonetheless, his dystopian vision should stimulate careful scrutiny of how basic research takes shape in the wider context of the university, the economy, and contemporary culture. This is SPECS's task. A search of databases in the history and philosophy of science and technology revealed that nanoscale science and technology had received only limited attention. This also held in the area of legal studies. The March 2001 NSF report, *Societal Implications of Nanoscience and Nanotechnology,* produced a template for discussion but left particular investigations for the future. SPECS was therefore the first university-based interdisciplinary initiative to bring close scrutiny to this new area of science and technology. In August 2001 SPECS received seed funding from USC's Office of Research for AY 2001/02. By December 2001 SPECS had consolidated as a Nanoscale Interdisciplinary Research Team, and had submitted an application to NSF for a NIRT grant. Our NIRT grant was partially funded for 2002/03, and we were encouraged to reapply in 2002 for a full four-year award, which we did with a research proposal entitled "From Laboratory to Society: Developing an Informed Approach to Nanoscale Science and Technology." The final decision is still pending, but we are optimistic that our project will be recommended for an award.

In the following I provide an outline of our research fields as well the infrastructure that we use to perform research in a truly interdisciplinary manner, with currently 17 faculty members from 10 departments involved. I suggest that this might be taken as the beginning structure of a model for a Center of Ethical and Societal Implications of Nanotechnology.

2. Research Fields

Our interdisciplinary research team is divided into four smaller sub-teams, each devoted to a specific Task Area of research. These Task Areas are structured to focus attention on how our understanding and control of nanotechnology moves from the laboratory to society. Before we debate the ethics of "assemblers," for example, we should be clear just how understanding and control is achieved at the level of basic research, and then how this hard-won mastery can structure and inform a broader public and political understanding and control of nanotechnology. Three kinds of collaboration result from the manner in which we have structured these research Task Areas: (1) collaborations among the members of each Task Area as they prepare joint seminar presentations, workshops, publications; (2) collaborations between these sub-teams and members of USC's NanoCenter; and (3) the collaboration among the participants of all four Task Areas as the results of various researches are brought together and presented for general discussion. Underlying the research in all of these Task Areas is an interest in working out a shared language, a joint appreciation of the scientific and cultural/societal issues involved, and a desire to articulate the background assumptions and models used to address these issues.

Task Area 1: Ideas of Stability and Control in the Theory and Practice of Nanoscale Research

Otávio Bueno (Philosophy, USC) joins *Davis Baird* (Philosophy, USC) and *R.I.G. Hughes* (Philosophy, USC), who continue here an earlier collaboration. They undertake a systematic philosophical examination of nanoscale research. To this end, the projects in this task area examine nanoscience from three different philosophical perspectives. Two projects provide complementary analyses of nanoscale research as it is currently practiced. Baird examines the instruments that allow nanoscience to exist, and Hughes the theoretical tools that the science employs. What Ian Hacking said about science in general applies also to nanoscience in particular: "In nature there is just complexity, which we are remarkably able to analyze. We do so by distinguishing, in the mind, numerous different laws. We also do so by presenting, in the laboratory, pure, isolated phenomena." In other words, as the sciences mature, theory and instrumentation work together to produce stable facts and a stable grasp of the facts. Stable facts trump fantastic visions and defeat skeptical doubts. In their collaboration (which involves close interaction with the scientists at USC's NanoCenter) Baird and Hughes explore the various ways in which nanoscale research can itself become the inherent source of stability and trust. In contrast, Bueno's project deals with one of the forerunners of nanoscience, John Von Neumann. Not only does it add a historical dimension to our understanding, but it also provides an exploration of the limits of physical and mathematical possibility within nanotechnology.

The members of task areas engage in a close collaboration with Alfred Nordmann and his collaborators at the Technical University of Darmstadt, Germany. Together they produce a monograph on "The Philosophy of Nanoscience." This includes chapters on (1) nanoscale research between science and technology, (2) the role of instrumentation in the development of nanoscale research, (3) experimental and technological control of interventions at the nanoscale, (4) historiography and the self-definition of the nanoscale research community, and (5) disciplinary issues of nanoscience. This collaboration furthers the establishment of the Center for the Philosophy and Ethics of Complexity and Scale [CPECS] at the University of South Carolina and a corresponding program on the Philosophy and History of the Technosciences at the Technical University of Darmstadt. The long-term interdisciplinary collaboration between these two Centers serves researchers and students alike.

(1) Extending Eyes and Hands to the Nanoscale: Bringing previous experience developing a philosophy of scientific instruments, *Davis Baird* (Philosophy, USC) here focuses on the instruments used in nanoscience, in particular on the scanning tunneling and atomic force microscopes [STM and AFM]. These instruments establish a central node in a network of relations between scientists and engineers from various disciplines. USC's NanoCenter represents one such network, but the USC Electron Microscopy Lab represents a different node. Baird investigates how data are produced in these overlapping networks and how data are then differently interpreted in their various "home disciplines." To borrow a metaphor from Peter Galison, data move in and out of "trading zones," they are framed differently by people working in different institutional and disciplinary contexts. But the instabilities produced by these differences are counterbalanced by the stability of the phenomena observed and produced by these instruments. Baird is pursuing three specific areas of research. (1) According to a widely reported "standard story," nanoscience has been propelled by improvements in microscope technology, in which early electron microscopes were supplanted by STM and AFM. This story is examined to see if it is accurate and, if not, why it remains so compelling. (2) How has the commercialization of the STM and the AFM impacted their development? (3) The relation between two different kinds of imaging used in nanoscience—electron microscopy and probe microscopy—is explored. One is analogous to seeing, the other analogous to feeling—though even in the latter case the data obtained is made to yield a visual representation (see also Task Area 2).

(2) The Disciplinary Reconfiguration of Nanoscience: Having recently finished a manuscript on theoretical practice in science, *R.I.G. Hughes* (Philosophy, USC) adopts a complementary approach. Instead of focusing on instrumentation and experimentation, he considers how theoretical representations are reconfigured in the newly emerging "trading zone" of nanoscale science and engineering. Theoretical practice at the nanoscale uses a great diversity of theoretical tools. The NSF description of them lists "techniques such as quantum mechanics and quantum chemistry, multi-particle simulation, molecular simulation, grain and continuum-based models, stochastic methods, and nano-mechanics," and there is no reason to think that this list is exhaustive. Investigators study: (1) the tasks that these various tools perform, and the sub-disciplines within nanoscience that employ them; (2) the extent to which different theoretical approaches are integrated, and the problems that can make such integration difficult; (3) the interaction between theoretical and experiment work; and (4) the narratives that nanoscientists employ, and which make interdisciplinary communication possible. Additionally, (5), the topic of theoretical representation provides a bridge to Task Area 2.

(3) Precursors to Nanotechnology, Feynman and Von Neumann: Otávio Bueno (Philosophy, USC) focuses on the forerunners and immediate antecedents of nanoscale research. He is investigating the limits of both physical possibility and mathematical possibility in this domain, examining how the interaction between what is physically and mathematically possible has shaped the constitution of nanoscale phenomena. In "There's Plenty of Room at the Bottom," Richard Feynman

outlined a vision for the development of nanoscience, advancing for the first time the idea that it should be possible to build objects atom-by-atom. Not surprisingly, the nanoscience community has taken this work as a founding document. In it Feynman was concerned with what it was *physically possible* to do at the nanoscale, and he outlined the benefits that should be expected from such a research. In contrast, in a series of seminal papers on the theory of automata, John Von Neumann explored what was *mathematically* and *logically possible*—but also what was *mathematically impossible*—to do in the process of building reliable organisms from unreliable components. Although there has been a considerable amount of research on Feynman's contribution, especially by those in the nanoscience community, Von Neumann's work has received significantly less attention. A focus on Von Neumann's contribution sheds light on nanoscience in two ways. (1) It provides a better understanding of the emergence of the theory of automata and self-reproduction, and in this respect, Bueno's work connects with the work undertaken in Task Area 3. (2) It allows a new perspective on the role played by this theory in the constitution of the field.

Task Area 2: Imaging and Imagining the Nanoscale: From Atomic Force Microscopic Topographies to Science Fiction Utopias and Dystopias

Task Area 2 aims at developing a comprehensive understanding of how images and imaginings of the nanoscale work, and how they might work better. How we see the nanoscale, both with our (aided) eyes and in our mind's eye, has a powerful impact both on the science and technology of the nanoscale and on the public reception to nanoscale research and its fruits. Indeed, it is widely argued that the development of our ability to produce images of nanoscale objects has been the *sine qua non* of any serious understanding and control of the nanoscale. The concerns of Task Area 2 thus reflect back on those of Task Area 1. But our ability to image and imagine the nanoscale drives more widely held popular understandings—and misunderstandings—of the nanoscale, and it is here that debate over the societal impact of technology takes place. For this reason Task Area 2 concerns also reflect forward to the concerns of Task Areas 3 and 4. It is through the images and imaginings of the nanoscale that understanding and control of the nanoscale moves from the laboratory to society.

The issues raised in Task Area 2 do not fit any single discipline, and our approach to these issues is multi-disciplinary and collaborative. Five team members work in Task Area 2, two philosophers, *Davis Baird* and *Otμvio Bueno* (both Philosophy, USC), an engineer, *Richard Ray* (Civil Engineering, USC), an expert on science fiction, *Steven Lynn* (English, USC) and a conceptual artist, *Chris Robinson* (Art, USC). Together they examine the variety of ways we image and imagine the nanoscale. They approach the concerns that Task Area 2 embraces in four areas of study.

(1) A Taxonomy of Kinds of Representation of the Nanoscale: The first area of study, fundamental to the rest, aims at articulating the nature and domain of application of the various different kinds of representation of the nanoscale. Furthermore, it aims to identify the gaps that exist between the different levels of representation:

- Quantum mechanical representations of individual atoms;
- Molecular models (of various sorts);
- STM/AFM/EM images of nanoscale material;
- Scientific representations of bulk matter;
- Nano-visionary designs (e.g., for "molecular assemblers");
- Artist renderings of the nanoscale;
- Science fiction that uses textual descriptions of the nanoscale;
- Creative works of art inspired by the nanoscale.

These different ways of representing the nanoscale differ from one another, both logically and rhetorically, and these differences need to be articulated. Only then can we begin to appreciate how different ways of representing the nanoscale should be used in the various contexts in which they are needed, how, for example, an image of the nanoscale developed for one context may be misleading or ineffective in another context.

Work at this first stage, crossing as it does from largely technical issues—about quantum mechanical and molecular models of atoms—to largely cultural issues—about science fiction and visual art—involves a collaboration of all Task Area members. Bueno brings a background in the philosophy of physics to bear on quantum mechanical and molecular models of atoms. Baird brings a background in the philosophical study of scientific instrumentation to bear on the STM/AFM/EM images of the nanoscale. Ray, with a background in computer-aided design for structures, joins Baird and Bueno to examine how scientific representations of bulk material can work with nano-visionary designs. Robinson, with a background as a creative artist, and Lynn, with a background in the study of science fiction, contribute an understanding of how these more popular genres draw from and contribute to the scientific and technological images, and how the more popular understanding of the nanoscale is thereby established.

(2) Better Images: The second area of study aims at improving images of the nanoscale. The images that we use to "see" the nanoscale are produced using a variety of different technologies. Sometimes the same image combines data from (e.g.) atomic force microscopy, quantum molecular simulations and artist's renderings. These different visual techniques work differently, and these differences need to be appreciated, and ultimately deployed to make better images. Drawing on the work done at the first stage, our team works with scientists and science journalists to develop better images, images that communicate without misleading, and that can do so while moving from one context of use to another. Robinson leads work on this stage, bringing his expertise as a visual and conceptual artist to bear on developing better ways to use the visual medium to communicate ideas.

(3) Scaling Up, Images Crossing from the Nanoscale to the Macroscale: The third area of study examines, first, the gap between the possible manipulation of matter atom-by-atom as it is painstakingly done in the laboratory and as it is rather more easily imagined by nano-visionaries, and, second, the unavoidable engineering difficulties that scaling up to humanly useful dimensions encounters. Here we confront the differences between representations that work in the laboratory and those that work for manufacturing. Ray, with his expertise in computer-aided design for structures, leads work on this stage.

(4) The Nanoscale in Art: The fourth area of study both examines and produces art inspired by the nanoscale. Lynn, with a background in the study of science fiction, examines the history of the incorporation of nanotechnology into science fiction, and relates this history both to simultaneous developments in scientific research at the nanoscale and to cultural aspirations for and concerns with this research. Robinson creates and exhibits visual artworks inspired by his encounters with the research done by members of USC's NanoCenter. This work is open for public viewing, and serves to provoke its viewers to think about how nanotechnology will impact their lives and society.

Task Area 3: Problems of Self-replication, Risk, and Cascading Effects in Nanotechnology: Analogies between Biological Systems and Nanoengineering

Another area of collaboration, involves *Robert Best* (School of Medicine, USC), *George Khushf* (Philosophy & Center for Bioethics, USC), *Loren Knapp* (Biological Sciences, USC), and *Walter Piegorsch* (Statistics, USC), and explores the models and cultures that inform risk assessment of nanotechnology. In both the visionary and dystopian literature are arguments that nanotechnology, genetics, and robotics, when taken together, involve new ethical issues, qualitatively different in scope and character from those associated with previous technologies. The visionaries highlight the potential and promise, and suggest there is an ethical obligation to accelerate development. The anti-utopians argue for a moratorium, fearing a "brave new world." At the heart of the more negative assessment is the assumption that these technologies can produce "cascading effects," which have the potential to alter the environment on a massive and unprecedented scale. The fear is that a new technology such as nanotechnology will introduce a precursor stimulus or hazard, which will lead to other more substantive hazards, and thence to detrimental hazards, catastrophic hazards, on and on. In "Why the Future Doesn't Need Us," Bill Joy speaks for all those who are worried that we will always be one step behind in our capacity to respond.

In order to properly put these concerns into perspective, Task Area 3 team members engage with team members working in Task Areas 1 and 2. Our ability to produce new nanoscale phenomena in the laboratory may unleash a cascade of irreversible hazards that spiral out of control. Task Area 1 considers how stable phenomena and a stable understanding of the phenomena might serve as a deterrent to such risks. Task Area 2 considers how our abilities to image and imagine the nanoscale provide the tools to consider these risks. Members of Task Area 3 take these considerations further to consider the management of risk in three clusters of investigation.

(1) Models of self-replication and self-regulation: Most important is the need to articulate the range of meanings encompassed by self-replication and self-regulation, from a simpler, bench-oriented model to the vision associated with assemblers, and

everything in between. Nanoscientists have already developed a variety of new materials that show promise for nano-engineered products—nanotubes, electrically conducting compounds, quantum dots, etc. Now, they need ways to organize these materials into larger structures that might be useful to society. In order to do this, they have focused upon mechanisms of replication and the regulation of these mechanisms. But, as the complexity of a self-replicating process increases, the possibility of an undesirable medical or environmental outcome seems likely to increase as well, and there are additional concerns about potential mutations of the original process. In order to help anticipate and prepare for such possibilities, Task Area 3 team members seek to identify the multiple models and meanings of self-replication and self-regulation, ranging from current techniques (e.g., for growing nanotubes) to universal assemblers. In between, we consider possibilities on the near horizon (e.g., the use of viruses to engineer at the nanoscale) and the more distant horizon (e.g., limited assemblers, the stated goal of the company Zyvex).

Task Area 3 members approach this work by drawing on analogies between these engineered mechanisms and those found in natural biological systems. In order to appreciate the challenges involved in designing and manufacturing nano-structures capable of self-replication and correction without loss of control, they examine the properties of natural self-replicating systems. What methods does nature use for self-replication? Will nanotechnologies resemble genetic systems in such a way that an understanding of the natural principles governing the latter might guide the development and application of the former in safe and controllable ways? In what ways will they differ? Armed with this understanding we will be able to explore the philosophical and ethical implications of aspects of self-regulation.

(2) Taxonomy of Risk Assessments for Nanotechnology: Scientists know that complex, non-linear, self-replicating systems can produce unanticipated medical and/or environmental harm. In some cases statisticians can quantify risks associated with such systems, but in many other cases the uncertainty is too great, and the best that can be done is to provide a less precise qualitative analysis. Along these lines, Task Area 3 team members develop a taxonomy of the kinds of risk assessment that could be used in ethical debates on nanotechnology. They do so in the following manner.

First, they identify risk paradigms for possible medical and environmental outcomes (e.g., the way a new virus can pose a public health risk). Then they consider whether the associated risks could have been anticipated and quantified in a risk analysis. They examine cases where established methods of quantifying risk worked well and cases where the outcomes could not have been anticipated and quantified. Next they draw on their earlier work, developing the analogy between engineered and natural nanosystems, and they extend this analysis to consider the possibilities of quantifying risks associated with the types of self-replicating, artificially engineered nanosystems identified earlier. The goal is to identify and structure the variety of cases posed by nanotechnology in terms of the degree to which the risks can or cannot be quantified. Finally, within this structure they consider how such risks can and should be incorporated into ethical analysis and communicated to the public.

(3) The literature and culture informing ethical analysis of nanotechnology: There are several new areas of research that involve significant challenges to our understanding of ourselves and our prospects in the world. These include, (1) robotics/cybernetics, (2) genetics, and (3) nanotechnology. In most of this literature, these three technologies are considered in isolation. However, some of the most troubling ethical issues occur where all three technologies intersect. Task Area 3 members explore analogies, similarities, and differences between the ethical discussions in each of these areas and then consider how their combination could raise issues that have been insufficiently considered when viewed in isolation. The focus here is not only on the substance of the issues, but also on the climate and culture that frames the way the issues are addressed and resolved.

All phases of work in Task Area 3 is fully collaborative, bringing together the science (Best and Knapp), probability theory (Piegorsch), and the philosophy/ethics (Khushf). Best is trained as a toxicologist, with research in environmental hazards and genetics; he currently directs USC's program in clinical genetics. Knapp is a developmental and evolutionary biologist. Together with faculty in the USC NanoCenter, they identify the paradigm medical/environmental cases, explore the analogies between natural and artificial nanosystems, and provide the scientific expertise to assure that the statistical and ethical analysis is appropriately scientifically informed. Piegorsch has extensive practical experience in quantitative risk analysis, including work in environmental hazards and toxicology. He directs the development of taxonomies of risk, assessing the degrees to which quantification is possible. Khushf guides the review of the literatures and cultures informing ethical analysis of nanotechnology, exploring the ways risk analysis is integrated into ethical and policy debate, and addressing the conceptual and philosophical issues of complexity, scale, and self-replication.

Task Area 4: Moving Nanotechnology into the Public Sphere

At the end of the day, all the advances in our understanding of nanotechnology that work in Task Areas 1–3 provide are of little value if they are not integrated into the public, political and legal discussions of nanotechnology. Task Area 4 is concerned both with developing models for how to accomplish this, and with bringing the insights from all Task Areas to the public sphere, drawing on the collaborative infrastructure established by our project (see below). In this way Task Area 4 ties together all of the separate strands of work that make the project a conceptual whole.

The first stage of this work is itself conceptual. Each of the five members of Task Area 4 considers how nanotechnology might best be brought to the public. Each of them comes at this issue from a different point of view, and as their collaboration develops over the course of the project, these differences inform each other, as together they model the various ways nanotechnology can be taken up by the public sphere.

(1) Rhetorical Analysis: David Bérubé (English, USC) focuses on the analysis of the structure of discourse about nanotechnology. He brings an extensive background in debate and a long-running interest in the visionary rhetoric found in some work on nanotechnology. He pursues two projects. The first, building on earlier work, is an analysis of the rhetorical place of nanovisionary contributions, mostly that of Eric Drexler and the Foresight Institute, in the development of nanotechnology. The second is an empirical study of how the inclusion into USC's NanoCenter of scholars with a primary focus on the philosophical and societal impact of nanotechnology—the members of our team—alter the structure of discussions at the NanoCenter. This work is pursued in a process of cooperative inquiry aimed at uncovering the dynamics of an organizational culture that facilitate or impede communication across disciplines, and it starts with the assumption that communication between members of the NanoCenter changes when the members our team are part of the mix. The procedure begins with a Likert scale (e.g., 1. Agree; 2. Somewhat Agree; 3. Not Sure; 4. Somewhat Disagree; 5. Disagree) survey of NanoCenter members on a series of questions concerning the societal place of nanotechnology to establish a baseline. As the work proceeds Bérubé develops analyses of communication protocols, observing and recording outcomes. His findings, following the protocols of cooperative inquiry, are added to the dialog among members of the NanoCenter. Follow-up data accumulation may include collection at locations beyond USC and with different populations. Quantitative and qualitative findings will be published.

(2) Science Journalism: Lowndes Stephens (J. Rion McKissick Professor of Journalism, USC) pursues an experimental study of ways to improve science journalism, particularly that covering nanotechnology. The experiment will be conducted during summer 2004 on a group of experienced science writers who have a weeklong training course in *Newsplex*, a $2 million state-of-the-art multi-media, micro newsroom laboratory at the University of South Carolina. Using information from other team members and from members of USC's NanoCenter, the subjects will be asked to research, source and write news stories on several significant advances in nanoscience and nanotechnology. The subjects and their stories will be examined both before and after their experience in *Newsplex*, as a way to determine the degree to which this experience improves their ability to write about nanotechnology. Results will be analyzed during summer 2005. The project contributes to our understanding about how recommendations in the academic literature might be used to improve the quality of science reporting. An important possible outcome of this work may be that we can train journalists in the manner used during the week at *Newsplex* to improve the accuracy of media portrayals of the flaws and promises of scientific innovations in nanoscience.

(3) Politics: Ed Munn (Philosophy, USC). As nanotechnology emerges into the public's consciousness, discussions about the desirability of emerging technologies that nanotechnology is making possible become more common and tendentious. Within a democratic society these discussions are pivotal in setting both public policy and the social and ethical guidelines for the use and pursuit of nanotechnology. Munn studies the emergence of these discussions using the approach favored by the proponents of deliberative democracy. Richard Sclove writes, "If citizens ought to be empowered to participate in determining their society's basic structure, and technologies are an important species of social structure, it follows that technological design and practice should be democratized." Munn explores what this view of democracy implies for the development of nanotechnology. In particular he looks at the

role of "the expert" in both communicating and guiding the development of nanotechnology. Munn argues that the expert's appropriate role is as a facilitator for the creation of an analogue to Jurgen Habermas' ideal speech situation that allows for effective citizen participation in decisions about nanotechnology.

(4) Law: Robin Fretwell Wilson (School of Law, USC) is an expert on the regulation of new technologies. She brings her experience in health law and biomedical ethics, areas in which new technologies challenge traditional notions of regulating behavior, to develop a model for how best to facilitate nanotechnology. The aim is to do so while preserving a role for the incorporation of democratic values input into this emerging technology, and in doing so allowing for appropriate state oversight. Consistent with her examination of past efforts to regulate emerging technologies—ranging from our experiences with allocation of scarce life-saving technologies, like organs, to mapping the human genome and human cloning—she draws on and integrate all of the various insights produced by other members of her Task Area, and those from the other Task Areas into discussions in the policy forum. Because the best possible course for the regulation of nanotechnology necessarily requires deliberative and engaged debate between all the stake-holders involved—journalists, educators, industrialists, scientists, funding and government agencies and citizens, groups—the policy forum brings together these stakeholders and members of the nanotechnology community.

Here, then we reach the second stage of Task Area 4's work: Actually engaging the public sphere in discussions of nanotechnology. The first stage provides three conceptual and two empirical studies of how to take nanotechnology into the public sphere. The results of these studies may differ, but the fundamental assumption of our interdisciplinary research team is that only by bringing such divergent approaches to the study of nanotechnology are we able to find a model for constructive debate concerning nanotechnology in the public sphere. But a model for debate is not enough. Our project aims to produce informed constructive debate itself, and here the key element is the active participation of all the members our project's research team, the members of the NanoCenter, and other members of USC's faculty, student body and staff. The divergent contributions of the members of Task Area 4 are essential to developing genuinely useful discussion of nanotechnology, a discussion that is particularly important in the final conference planned for the project, "Nanotechnology in the Legal and Political Sphere." Wilson will organize this conference. She will structure discussion between national, international and local stakeholders by acting as a reporter for the conference participants, circulating drafts, and mediating between academics and other stakeholders. With this conference we will have taken our understanding and control of nanotechnology from laboratory to society.

3. The Collaborative Infrastructure

A variety of events and publications stimulate informed and integrative dialogue about the significance of nanoscale research, and thereby promote the goal of what we call, "the nano-literate campus."

I. Annual Summer Workshops

These weeklong workshops bring together all investigators. They are joined by scientists at USC's NanoCenter, graduate and undergraduate students, as well as a small group of interested academics and non-academics. Each workshop features contributions by invited experts on various aspects of nanoscience and nanotechnology; these contributions serve to structure the task-oriented collaborations of all participants. Our inaugural workshop took place on August 5–9, 2002: "Reading NanoScience." The next four workshops (2003, 2004, 2005, and 2006) are organized around selected research questions from the four Task Areas:

2003 [TA 2]: "Imaging and Imagining NanoScience,"
2004 [TA 1]: "Self-Assembly and the Construction of Nanostructures;"
2005 [TA 3]: "Biological Machines, Genetic Engineering, and Nanobiotechnology;"
2006 [TA 4]: "Nanotechnology and Its Publics."

II. Annual Spring Conferences & Monthly NanoCulture Colloquia Series

Spring Conferences: The Spring Conferences aim at promoting dialogue between national and international scholars. Since our interdisciplinary research team raises new questions for science and technology studies, these conferences are to foster disciplinary interest in these questions. The first of these, "Discovering the Nanoscale," was held on March 20–23, 2003. Its discussions will be deepened and continued on October 10–12, 2003 in Darmstadt, Germany. Together, both meetings feature about 40 presentations that will be collected in a volume of proceedings. The conferences are free and open to the public. Plans for future conferences are as follows:

2004, organized by Davis Baird: “Tools for Imaging and Imagining the Nanoscale;”
2005, organized by George Khushf: “The Philosophy and Ethics of Emerging Technologies: Nanotechnology, Cybernetics, and Genetics;”
2006, organized by David Bérubé: “Visionary Rhetoric Confronts Real Science;”
2007, organized by Robin Wilson: “Nanotechnology in the Legal and Political Sphere.”

NanoCulture Colloquia Series: Each semester our group organizes and hosts a series of colloquia featuring issues associated with our project’s four Task Areas. The NanoCulture Colloquia Series is open to the public, but our target audience includes scientists at the NanoCenter, other USC faculty, and interested graduate and undergraduate students. Their themes are generated as research on the four task areas progresses.

III. Educational Outreach

Research Based Learning: In coordination with USC’s Honors College, Loren Knapp (Biological Sciences, USC), with the cooperation of other team members, develops a research-based learning course for undergraduate honors students at USC. In a case-oriented manner, it explores the relations between what is theoretically possible, technologically feasible, and ethically defensible. Historically, how has this balance been struck? In the case of a newly emerging science and technology, such as nanotechnology, how can it be found? The course focuses on biological systems and biotechnology as they become fused in the concept of biological machines. It therefore considers how nanoscale science and engineering challenges the traditional separation of nature and culture by using biological systems and processes as models for engineering. Along with an extant course on “Ultramicroscopy,” this new course will be part of our Honors College “Nano Semester” (see below). In addition it will afford several undergraduate research assistants the opportunity to gain the technical skill and theoretical perspective required to produce a research-based Honors Thesis.

Textbook, Understanding Nanotechnology: This volume is aimed at introducing an undergraduate audience to the full spectrum of societal issues raised by nanoscience and nanotechnology. It consists of selected primary readings, with substantial introductory essays for each section, and brief introductions for each essay. Team member, Steven Lynn (English, USC) coordinates the editing of the volume drawing on the efforts of other team members to write all introductory material. The volume has the following structure:

Section 1, Nano Fundamentals: Background readings explaining what nanotechnology is, what its current state of development is, and what it may make possible;

Section 2, Nano Science: Annotated excerpts from science journals that show how the science of nanotechnology is being conducted;

Section 3, Nano Fiction: Short stories that indicate how nanotechnology has been represented in science fiction;

Section 4, Nano Publics: Readings and illustrations from newspapers and magazines that show how nanotechnology is being presented to the public;

Section 5, Nano Politics: Readings the engage the ethics and politics of potential uses and abuses of nanotechnology.

Nano Semester: During the spring of 2005, the Honors College will host a collection of coordinated, interdisciplinary courses, each concentrating on a different aspect of nanoscience and nanotechnology. These will follow the pattern of previous semesters fielded by the Honors College—spring 1999: “Darwin across the Disciplines,” spring 2003: “The Sustainable Futures (on environmentalism).” Catherine Murphy, working in cooperation with other team members, will coordinate this set of courses. In addition to the Research Based Learning course (see above) planned courses include “Ultramicroscopy,” “Chemistry and nanotechnology,” “Post-humanism and nanotechnology,” “Philosophy at the nanoscale: Creating a new reality.” In addition, we will use one or more of these courses to help us develop our reader, *Understanding Nanotechnology*, on the multiple aspects of the cultural significance of nanoscale research.

IV. Publications, Website and Archive

All of the various collaborative ventures involve an exchange of ideas and manuscripts among investigators. These culminates in a collection of papers that brings together the work of the research on the four Task Areas that we will publish in a peer-reviewed academic press. As a matter of course, the preparation of scholarly manuscripts and the participation in the workshops and colloquia leads to a variety of other publications in peer-reviewed academic journals and in other outlets, aimed at a more general readership. Given the current state of the field, we expect the collection of papers that flow out of this project to provide a foundation for this emerging important field of research.

The project's webmaster manages the website and archive of our research team *http://www.cla.sc.edu/cpecs/nirt/*. This website features the general outline, scheduled events and specific projects included in this proposal. It includes a searchable and expanding database of abstracts of research materials for people interested in doing research on the societal implications of nanotechnology. Links to each investigator provide access to their research projects. Website also points to a moderated listserv on the philosophical and social dimensions of nanoscale science and technology, with about 200 subscribers from all over the world. The listserv also allows investigators to present new ideas and arguments for consideration by this audience. The website also includes a collection of "works in progress," available for further public consideration and comment. One team member, Ed Munn, is fluent in Spanish, and is translating much of the website to make our work accessible in Spanish.

V. Engaging USC's NanoCenter

At every stage of our research, we are looking for ways to integrate our critical reflections with the interests and concerns of the scientists and engineers at USC's NanoCenter. Over the course of the grant, the science/humanities collaboration between the NanoCenter and our research team takes a variety of forms: (1) NanoCenter scientists are instructing humanities scholars in the fundamentals of nanoscience and engineering; (2) members of USC's NanoCenter have introduced members of the team to the instruments on which their work relies; (3) the opinions and contributions of NanoCenter researchers are solicited at monthly colloquia; (4) members of the NanoCenter have helped us to compile a collection of classical readings, used in our August 2002 workshop: "Reading Nanoscience." Similar collaborations are envisaged for the future. In addition, (5) claims about the philosophical significance of bottom-up nano-engineering are checked against the insights and assessments of engineers themselves; (6) the laboratory work and disciplinary interactions at the NanoCenter are observed by members of our team; (7) all research produced by the team are made available to the scrutiny and criticism of NanoCenter researchers; (8) members of the NanoCenter are invited to participate in our listserv discussions; (9) in the annual assessment phase, members of the NanoCenter are asked to comment on our activities and to suggest future activities or topics for discussion; (10) Richard Adams, Director of the NanoCenter, is a member of our Advisory Board. Finally (11) we aim to encourage the scientists and engineers at the NanoCenter to more fully examine the hidden societal assumptions behind their research, and to see how the research projects they pursue may be integrated into the broader society they serve.

Appendix 2: Ethical and Societal Implications of Nanotechnology: A Research Agenda

Reflecting the goals of nanotechnology

Nanotechnology is frequently presented as improving wealth, health, environment, and security. While all these four values are, each in their own way, compelling, detailed studies need to analyze (1) if there are possible conflicts between these values, (2) if there are conflicts with other culturally embedded values, and (3) if there are consequences that may arise when the goals would be really achieved. For instance, creating a perfect health control system by nano-bio-information technology may raise issues of privacy and informational autonomy. Or, improving health condition to the state of overcoming aging, as some have promised, would cause radical societal and cultural changes and would also require rethinking individual life plans.

Identifying possible moral issues

Moral issues of new technologies usually arise (1) if the applications have either unintended bad consequences or (2) if the benefits are distributed unjustly. For instance, new kinds of risks might arise from nanoparticles if they have unpredictable catalytic effects in the human body or the environment, or if their built-in capacities to self-assembly or to replicate get out of control. Or, new nanotechnologies, because of their improvement of human performances, might cause or increase a social divide between the privileged and skilled who can use these technologies and the underprivileged and less educated who are not able to use them.

Identifying possible gaps in the legal regulation of nanotechnology

Once moral issues of nanotechnology are identified, juridical analysis is required to check the present regulation system whether it is sufficient to cope with them or not and to develop suggestions for additional regulatory instruments.

Distinguishing the critical from the uncritical fields of nanotechnology

Current definitions of nanotechnology are so broad and vague that a vast field of hardly related scientific and engineering research is included and, given the present trend, much more will be included in the future. Should public concerns about single moral issues ever grow to the condemnation of whatever is labeled nanotechnology, the effect on science and technology could be disastrous. It is imperative, therefore, to clearly distinguish between critical and uncritical fields of nanotechnology and to mediate this distinction to the public.

Analyzing the implicit moral messages of metaphors and images

From media reports to visual images and fiction writing, representations of nanotechnology convey implicit values and moral messages that can powerfully shape the public opinion. It is therefore important to analyze the metaphors and visual images used in communications about nanotechnology, with respect to their normative implications, the fears and hopes they raise, and their cultural roots.

Studying how ideas about nanotechnology transform cultural belief systems

The promises and far-reaching scenarios of nanotechnology, from longevity/immortality to the intimate entanglement of the human body with machines and computers, are able to undermine and transform traditional cultural belief systems, regarding the physical, mental, and social nature of human beings, and the distinction between nature and technology. It is important to study this interaction in order to understand the public reception of nanotechnology, either as extremely conservative reluctance or as quasi-religious embracement, such as in "transhumanism" or "extropianism."

Observing the public attitudes toward nanotechnology

In the long run, nanotechnology will flourish only if the public supports it. It is therefore imperative to understand not only the public concerns but also on what moral basis such concerns are grounded and whether conflicts can be reconciled or not. To that end, a detailed apparatus for sociological investigations needs to be developed and applied, from classical instruments such as questionnaires and oral interviews to more participatory models such as consensus workshops or science cafés.

Studying how nanotechnology transforms the traditional scientific landscape

Nanoscale research is currently about to transform the traditional scientific landscape, in which researchers as a subsystem of the society are involved. The success of nanotechnology will essentially depend on the researchers' willingness to take an active part in that process. The transformation particularly regards the disciplinary structure of the sciences, the science-technology relationship, research values, and methods. Since it is likely that these changes affect our scientific and educational infrastructure overall, it is important to study these impacts in detail and to understand its positive and negative consequences as well as potential obstacles.

Senator ALLEN. Thank you, Dr. Baird.

And every one of our witnesses' written testimony will be put into the record in its totality.

Thank you, Dr. Baird.

Dr. Jiao?

STATEMENT OF JUN JIAO, PH.D., CO-DIRECTOR, CENTER FOR NANOSCIENCE AND NANOTECHNOLOGY, PORTLAND STATE UNIVERSITY

Dr. JIAO. Yes, good afternoon, Chairman Allen and Senator Wyden.

As Chairman Allen mentioned, I have been working in the field of nanotechnology for more than 10 years, and I have made significant advances in this area. So I serve as the co-director of the Center for Nanoscience and Nanotechnology and the Director of the

Electron Microscopy and the Microanalysis facility, both at Portland State University. I have received the fundings from the government agencies and private foundations and high-tech companies for the research, including the development of nanofabrication techniques for carbon nanotubes and nanowires and the investigation of carbon nanotubes and semiconductor nanowires as the new generation of electron emitters.

I'm pleased to appear before you today to discuss nanotechnology and this landmark legislation, S. 189. There is great excitement about nanotechnology on college campuses. Before I could confirm that I would appear today, I asked my students for permission to reschedule a class that I missed on Thursday. They said yes. They want me to tell you how important this legislation is to their future.

Portland State University has made a tremendous commitment to nanotechnology research. We have built a first-class nanocharacterization and nanofabrication facility, which is unique in the Pacific Northwest. This enables researchers to study the materials' properties at the atomic level and to create novel materials, as well as nano-devices.

Nanotechnology research allows us to have unprecedented control over the electronic, magnetic, optical, and thermal properties of nanoscaled materials. Consequently, the resulting nanomaterials are stronger, lighter, and have better quality. This will improve our lives in the future—from safer airplanes to cars and to reduce the power consumption in more miniaturized electronic products, such as cell phones and computers.

I have tremendous excitement about the possibility of new discoveries that can happen as a result of the S. 189. Existing industries, including those not typically characterized as high-tech, will see their production lines and they manufacture influenced by our growing capability in nanotechnology. The business-development progress will be even more rapid as the relative risk from investing in nanotechnology becomes lower.

I wanted to emphasize that the research being done today in nanotechnology is producing exciting results, but the cost of production of innovation is beyond the reach of today's consumers. Therefore, research has to be done to optimize those processes.

As a scientist who has received significant support from our work, I know that federal funding is highly competitive. At the same time researchers in this area are compelled to present their proposals that are, by their nature, high risk, but they have potentials for high gains. The result is that few proposals are funded, thereby limiting the work that can be done in universities throughout the United States.

S. 189 will ensure that U.S. scientists receive reasonable funding for research to compete with their Asian and European counterparts, which has been strongly supported by their nations.

S. 189 supports long-term nanotechnology research and development leading to potential breakthroughs in areas such as materials and manufacturing, medicine, environment, biotechnology, agriculture, information technology, and homeland security. I support this broad-based approach because nanotechnology cannot be advanced without an interdisciplinary focus and federal support.

History has shown us that without the Federal Government providing long-term funding, there are fewer breakthroughs to translate into products and economic prosperity.

Another important aspect of this legislation is that it also focuses on our promising scientists and engineers of tomorrow. These young people know that investment in nanoscale research is the key to their future.

Over the past several years, I have been involved in an outreach program called the Apprenticeship of Science and Engineering organized by the Saturday Academy of Oregon. This program aims at—encourages high-school students to pursue higher education in science and engineering. My experience with those young students suggests that we need an imperative such as S. 189 to ensure that our scientists of the future have a firm training ground with consistent financial support.

In closing, thank you for the invitation to testify today. It is an honor to be asked to participate in this crucial national discussion. My colleagues and I strongly believe that nanotechnology will lead to a new and improved future. S. 189 is the commitment we needed to continue American leadership and innovation in the latest nanotechnological frontier. I urge the Committee to pass this bill.

Thank you very much.

[The prepared statement of Dr. Jiao follows:]

PREPARED STATEMENT OF JUN JIAO, PH.D., CO-DIRECTOR, CENTER FOR NANOSCIENCE AND NANOTECHNOLOGY, PORTLAND STATE UNIVERSITY

Good afternoon, Chairman Allen and Members of the Senate Committee on Commerce, Science, and Transportation. I am Jun Jiao, Assistant Professor of Physics at Portland State University. I have been working in the field of nanotechnology for more than 10 years and have made significant research advances in this area. My original contributions in the area of nanomaterials growth and characterizations have been documented in more than 60 publications. My carbon nanotube work has been granted patent protection. In 1993, I was selected as a Presidential Scholar of the Microscopy Society of America. I serve as co-director of the Center for Nanoscience and Nanotechnology, and director of the Electron Microscopy and Microanalysis Facility both at Portland State University. I have received funding from the National Science Foundation, Petroleum Research Foundation, FEI Company, and Intel Corporation for research including the development of nanofabrication techniques for nanotubes and nanowires and the investigation of carbon nanotubes and semiconductor nanowires as the new generation of electron emitters.

I am pleased to appear before you today to discuss nanotechnology and S. 189. I want to thank Senator Wyden and Members of the Committee for introducing this landmark legislation. There is great excitement about nanotechnology on college campuses and before I could confirm that I would appear today, I asked my students if they would give me their permission to reschedule a class that meets today. They said yes—because they wanted to make sure I told you how important this legislation is to their future. They are excited about the possibilities S. 189 presents and want you to know that they stand ready and willing to be a part of this important national initiative.

Portland State University's Center for Nanoscience and Nanotechnology is Key to Oregon's Economy

Portland State University, Oregon's only urban university, located in the heart of the silicon forest and Oregon's largest economic center, has made a commitment to building a world-class program in nanotechnology. Portland State University has formed an interdisciplinary research center on nanoscience and nanotechnology. The Center involves faculty from Physics, Chemistry, Geology, Biology, Engineering, and Environmental Science. Funding and equipment for the Center has come from the University, industry partners, government, and private foundations. The support PSU has received has allowed it to establish a first class, state-of-the-art electron microscopy and microanalysis facility including an ultra highresolution transmission electron microscope equipped with various analytical capabilities and a high-resolution scanning electron microscope capable of nano-characterization and electron beam lithography nano-fabrication. Both microscopes were made by the FEI Company, which is located in Hillsboro, OR. Portland State University is the only educational institution in the Pacific Northwest having such comprehensive nanostructural characterization and nanofabrication capabilities. This enables researchers to study the materials' properties at the atomic level and to create novel materials as well as nano-devices.

Portland State University has made a tremendous commitment to this area of research in part because it is essential not only to the future of the economy of the Pacific Northwest but to the global economy. The University faculty's research in the areas of carbon nanotubes, quantum dots, ultra high-resolution near-field microscopy, bio-physics, nano-imprinting, and fabrication of nano-devices is strong and carries national and international reputation. Many faculty research groups have engaged in collaborative research endeavors with local high tech industries such as Intel Corporation, FEI Company, LSI Logic, and Boeing Company, to mention just a few.

Academic and industrial research teams know that joint academic-industry partnerships on nanotechnology will make our economy stronger. Nanotechnology as currently practiced by scientists and engineers in the academic sector is not just an exercise in pursuing sophisticated science, it will have a significant impact on industry and society as a whole. The research in these areas allows us to characterize and structure new materials with precision at the level of atoms and to have unprecedented control of their electronic, magnetic, optical, and thermal properties—in fact, any property that we want to enhance. Consequently, the resulting nanomaterials have stronger, lighter, and better quality than conventional materials. This will have innumerable beneficial effects on our lives in the future—from safer airplanes and cars to low-power consumption and higher application efficiency of miniaturized electronic products, such as cell phones, computers, and other instruments.

Additionally, Portland State University is part of a collaborative request to the Oregon State Legislature by the Oregon University System to support a signature research center in multiscale materials and devices development. This proposal involves Oregon State University, the University of Oregon, the Oregon Health and Science University, and Portland State University. It has received favorable support from Oregon's Governor and key legislative committees and is awaiting final approval and funding.

All of this demonstrates that Portland State University and Oregon recognize that the impact nanotechnology currently has on new and existing industries is significant, but the potential for the future will be even greater. Therefore, significant investment in research and development in nanotechnology is essential and especially needed in the academic sector.

Nanoscale Research is the Foundation for the Next Generation of New Scientific Discoveries and Engineering Developments

Nanotechnology is concerned with materials and systems whose structures and components show significantly improved physical, chemical and biological properties because of their nanoscale size. Structural features in the range of a nanometer dimension, which is 10,000 times smaller than the diameter of a human hair, exhibit remarkable novel phenomena as compared to the behavior of bulk materials. We can exploit the novel properties and phenomena of nano-based entities as we learn to manipulate structures and devices at the atomic, molecular and supramolecular levels, and as we develop techniques to efficiently manufacture and use them. Important changes in their behavior are caused not only by the order of magnitude size reduction, but also by new phenomena such as size confinement, predominance of interfacial interaction, and quantum effects. Such new forms of materials and devices herald a revolutionary age for science and technology provided that we can discover and fully utilize the underlying principles.

As a materials scientist, my research focus is on the development of carbon nanotubes and nanowires as new generation of electron field emitters as well as building blocks for nanoelectronic devices. As individual nanoscale molecules, carbon nanotubes are unique. They have been shown to be true molecular wires, and have already been assembled into the first single- molecule transistor ever built. In the future, we will see our current silicon-based microelectronics supplanted by a carbon-based nanoelectronics of vastly greater power and scope. I have developed strong partnerships with local high tech companies such as Intel, FEI Company, and LSI Logic because of their interest in the research developments in these areas.

Some midsize and small size companies are initiating active conversations with Portland State University's Center for Nanoscience and Nanotechnology and exploring partnerships with us for some specific nanotechnology investigations. Portland State University's President Daniel Bernstine has made business development and job creation a key element in our mission. The University is a hub for faculty expertise, specialized facilities, and highly-talented students who become leaders in the workforce.

I believe that current estimates suggesting that nanotechnology will have a one trillion dollar impact on the global economy throughout this century are reasonable. I have tremendous excitement about the possibilities of discoveries and innovations that can happen. For example, existing industries including those not typically characterized as "high tech", will see their product lines and the way they manufacture influenced by our growing capabilities in nanotechnology. Moreover, aspects of nanotechnology will help small companies whose products are developed for niche markets including sensors, bio- and chemical-analytical devices and chemical ingredients expand. These small businesses are not likely to require the multi-billion dollar investments that 'chip' manufacturers must face in re-tooling their plants to the new advances in technology. The progress will be even more rapid as the relative risk from investing in nanotechnology becomes lower. I want to emphasize that the research now being done in nanotechnology is producing exciting results, but the cost of production of innovations is beyond the reach of today's consumers. Therefore, research has to be done to optimize those processes.

The 21st Century Nanotechnology Research and Development Act Will Ensure That the Nation's Work in This Area is Funded, Coordinated, and Focused.

As an active researcher in the area of nanotechnology, I am very pleased by the findings, goals, and programs outlined in the "21st Century Nanotechnology Research and Development Act." This Act will enable our nation to establish a comprehensive, intelligently coordinated program for addressing the full spectrum of challenges confronting a successful national science and technology effort. In particular, those related to funding, coordination, infrastructure development, technology transfer, and social issues. Currently the funding available through government agencies and private foundations and companies is limited. As a scientist who has received significant support for my work, I know that funding from federal programs is highly competitive. At the same time, researchers in this area are compelled to present proposals that are by their nature high-risk—but have the potential for high-gains. The result is that few proposals are funded, thereby limiting the work that can be done in universities throughout America. S. 189 will ensure that U.S. scientists receive reasonable funding for research to compete with their Asian and European counterparts, which have been strongly supported by their nations both financially and politically.

I want to address two specific issues emphasized in the Act. First, S. 189 supports long-term nanoscale research and development leading to potential breakthroughs in areas such as materials and manufacturing, nanoelectronics, medicine and healthcare, environment, energy, chemicals, biotechnology, agriculture, information technology, and national and homeland security. I support this approach because nanotechnology offers great promise in diverse fields and cannot advance without federal support. The foundation of knowledge in this area is incomplete, and significant fundamental research is needed. Particularly, in the current competitive and economically-challenged climate, private sector investment will fall far short of what is needed. Therefore, a strong federal role will be necessary for the field to realize its full potential. Also, history has shown us that each of the critical breakthroughs in science and technology has been based on years of sustained federal funding for research. The breakthroughs funded by the federal government are the foundation that enables subsequent efforts by the business sector to translate that research into products for the marketplace. Without the Federal Government underwriting the long-term funding, there will be fewer breakthroughs to translate into products and economic prosperity.

The Act also requires the Director of the National Science Foundation to collect data about the growth of the workforce that is anticipated as a result of expanded research in nanotechnology. This initiative will provide important information to workforce policy planners about the investment of key economic development and job training funding. I want to speak to this issue because I believe that nanotechnology has strong implications for high-wage jobs and will pay big dividends to communities that make this area of research and development a priority. By this I mean, we need to provide professional development and continuing education for those already working in this field, and make it a priority area of education for tomorrow's workforce. Among three classes I teach each year, two of them are concerning transmission electron microscopy and scanning electron microscopy of nanomaterials. These classes attract students not only from our campus but also from local industry. The classes are full each time they are offered. Most importantly, through these classes as well as the hands-on laboratory experience, students are able to learn state-of-the-art materials characterization skills and are actively involved in the latest nanomaterials research. The students who are already working in the field leave the class prepared to tackle more challenging technical jobs.

A Federal Investment in Interdisciplinary Research Centers Will Leverage Local, State, and Industry Support

S. 189 authorizes $50,000,000 for Interdisciplinary Research Centers and provides grants of up to $5,000,000 to support geographically diverse centers that support the initiative priorities including those addressing the fundamental research, grand challenges, education, development and utilization of specific research tools, and promoting partnerships with industry identified in the legislation. These are exactly the missions that the Center for Nanoscience and Nanotechnology at Portland State University is pursuing. It is our long-term goal to secure additional federal funds and attract foundation and private contributions to expand the work we are doing and to build an internationally recognized multidisciplinary nanoscience and nanotechnology research center.

Additional support from the Federal Government for research in this area will help programs like mine, and those around the country, lead the way for innovations and discoveries. I support the calls for interdisciplinary work and collaboration outlined in the legislation because most of today's challenging problems in science and engineering are complex and will not be solved by investigators working within the borders of their own chosen fields. That is the philosophy that guides the work we do at Portland State University. Federal funding for nanotechnology will assist important interdisciplinary research efforts which may lead to curing cancer and AIDS, reducing reliance on fossil fuels, or building the next-generation of sensors to help safeguard our homeland.

S. 189 is Legislation That Will Resonate With Young People Today—Tomorrow's Scientists and Engineers Know That Investment in Nanoscale Research is Key to Our Nation's Future

My research laboratory is one of the areas of excellence at Portland State University. As a result, I host many visiting dignitaries to campus who are interested in learning about ways the University is addressing the workforce and research needs of the future. Many of those visiting truly understand the research area. Others don't understand the specifics of the work we do, but have enthusiasm for its possibilities. For example, they may have grown up when the nation focused on the imperative of getting man to the moon. Or they have experienced the sophistication and evolution of computers from those that took up whole rooms to the pocket personal computer they carry. So, people of our generation typically have a general appreciation of why this area of research is important.

I want to assure you though that young people today—those in middle school and high school—are truly excited about this area of research. Let me give you two examples. In the past several years, I have been involved in an outreach program called apprenticeship of science and engineering organized by the Saturday Academy of Oregon. This program aims at promoting high school students to pursue higher education in science and engineering. Each summer, I host one or two high school students selected among the high schools in Oregon and Washington to work with me on my nanomaterials research. For one position there are usually more than 40 applicants. In reading their application essays, I was amazed by the depth of the knowledge that young people have about nanotechnology. I was touched by their strong desire to participate in nanomaterials research. In my spare time, I also serve as a judge for the Intel Northwest Science Expo. This is an annual event designed to encourage middle and high school students to apply their interest in science and engineering to real world innovations. Each year, more than 500 students from Oregon and Washington participate in this event. The students present their own research at this event and every year I am encouraged by these young people who I know will become great scientists. These students are excited about nanotechnology, however we need an imperative such as S. 189 to ensure that our scientists of the future will have a firm training ground with consistent financial support.

In closing, I would like to thank the Committee for the invitation to testify today. It is an honor to be asked to participate in this crucial national discussion. My colleagues and I strongly believe that nanotechnology will lead to a new and improved technological revolution. S. 189 is the commitment we need to continue American leadership and innovation in the latest technological frontier. I urge the Committee to pass this bill.

Senator ALLEN. Thank you, Dr. Jiao, for your enthusiastic testimony. I can see why your students enjoy your courses.

Now we'd like to hear from Dr. Kent Murphy, from Blacksburg, Virginia Tech, Hokie country.

Dr. Murphy?

STATEMENT OF KENT A. MURPHY, PH.D., FOUNDER AND CEO, LUNA INNOVATIONS

Dr. MURPHY. Thank you very much. Thank you, again, for the invitation to speak today, Chairman Allen.

Again, my name is Kent Murphy. I'm the founder and CEO of Luna Innovations, a research and development company located in Blacksburg, Virginia. We are a leader in nanotechnology production. We produce the largest, most pure quantities of carbon nano-based materials that there are; but, more broadly, we are a company that is specialized in technology transfer, bringing research to products.

We have been a recipient of several NIST ATP awards, several SBIR programs, and have been able to utilize that to grow Luna to a little more than 200 employees at this point in a rural area in Southwest Virginia. And for that, we'd like to say thank you.

Two major points that I hope to bring to your attention today. One is the importance of commercializing work at the university and government labs; and, two, the crucial role nanotechnology will play in our future.

The investments our country has made in the past 50 years in our university and government-research labs has created an enormous potential. I was very fortunate in the seventies to work for a multibillion-dollar corporation with a team of people who focused on basic research, bringing research to products and handing it over to production crews. Later on, I accepted a position at Virginia Tech as a professor, worked there for 9 years. I was very excited to be in the university environment, but, after a few years of that, began to realize there was an enormous amount of potential—many, many inventions, many publications, many opportunities and important technologies that were just left on the shelf. I took a leave of absence from my position at Virginia Tech, started Luna Innovations, and we began to try to transfer that technology out and, hopefully, create jobs from that.

Our future economic growth in this country is going to be led by collaborative research, development, and commercialization efforts across universities, government labs, and corporations, both large and small. Large corporations have continued to cut back on their R&D budgets, based on quarterly earnings requirements. They're looking more and more towards small companies for those innovations, and we hope to provide that.

We must recognize the importance of these strategic alliances and continue to find ways to improve the efficient use of these national resources that we've created at our universities and government labs. The Bayh-Dole Act has been a great start, but we need to continue to do more.

As we've heard today from many speakers, every facet of human life will be touched by advances in nanomaterial development. We've heard many different areas in medical, homeland defense, power generation and distribution, telecommunications, transportation, and things that we've never dreamed. Luna strongly believes this proposed legislation will help secure our country's position as a leader in nanotechnology by funding this basic research and also the technology-transfer programs required to make them a reality. With this funding, we'll also be able to move the discoveries of our greatest researchers to the marketplace and create high-quality jobs in the U.S. more rapidly.

Nanotechnology, as we've heard, is not a specific technology or discipline. Instead, it's a broad term used to define work conducted on the nanometer scale. True breakthroughs are often just accidental discoveries that happen when basic research has been funded, as Senator Sununu pointed out, but the majority of the progress towards problem solving is usually incremental work done on a collaborative effort across many different fields of expertise.

We have listed, in the written testimony, many different applications that we, personally, are working on and others, and I'd like you to try to imagine the different areas of scientific and business expertise that will be required to bring some of the products from the laboratory to the consumer in a timely fashion.

We are currently working on radio-pharmaceuticals, with cell targeting, that will deliver therapies directly to a cancer cell. They are carbon nanocages filled with radioactive materials functionalized with ligands that are searching out a particular cancer cell. Just in that alone, we need chemists, materials scientists, manufacturing experts to be able to manufacture these in large quantities, biologists, radiologists, oncologists, toxicologists, long lists, it goes on and on, of the experts that will be required to bring these products to a reality.

Again, Luna Innovations' business model is to license patents, we've licensed dozens of patents from universities in the U.S. and government labs and created a wide variety of products. We've currently licensed patents from Drs. Dorn and Stevenson, of Virginia Tech, who discovered a way to put materials inside of a buckyball.

The fellow that discovered the buckyball and won the Nobel Prize actually wrote an article just last year and said—the title of the article was, "Why, After 18 Years, Is Bucky Still Out of a Job?" Well, it was basically because the carbon cage doesn't interact with much. We've figured out a way to put things inside those cages and make products that will increase contrast agents for MRI scans, to diagnose disease, and other things

I'd like to point out also that Virginia is a leader in collaborative nanotechnology research and development, with the CIT and the Secretary of Technology, the first of their kind in the country, also, INanoVA and VRTAC, who have also testified here before, and point out that the Federal Government must take a leadership role in funding these nanotechnology research and coordination efforts, and also point out that the economic success of our Nation is at stake. We must remain in a leadership position. And this legislation is necessary for the United States to ensure our future health and well-being and safety in this rapidly advancing global economy.

And, again, thank you for the opportunity to speak.

[The prepared statement of Dr. Murphy follows:]

PREPARED STATEMENT OF KENT A. MURPHY, PH.D., FOUNDER AND CEO, LUNA INNOVATIONS

Mr. Chairman, and Members of the Committee, thank you for the opportunity to testify today regarding the 21st Century Nanotechnology Research and Development Act. I am the Founder and CEO of Luna Innovations, a research and development company located in Blacksburg, Virginia. I also serve on Governor Warner's Virginia Research and Technology Advisory Commission.

Luna Innovations is an industrial leader in the area of nanotechnology, and technology transfer. I would like to recognize the support of the Virginia congressional delegation, especially Senator Allen, the Commonwealth of Virginia, the Advanced Technology Program at NIST, and Small Business Innovative Research (SBIR) programs from multiple agencies for helping Luna to achieve the level of success we have in our rural location in southwestern Virginia. It is these agencies that will benefit greatly from this legislation, giving them the ability to propel our country's leading researchers in nanomaterial-related science and applications to great discoveries.

There are two major points I hope to make clear today, 1) the importance of our investments in university and government labs and moving their ideas into the commercial sector, and 2) the importance nanotechnology will play in our future.

Future economic growth around the globe will be led by collaborative research, development and commercialization efforts across university, government labs and industry both large and small. Investment in university and government research labs has placed the United States in a global leadership position in science and technology. We must recognize the importance of these strategic alliances and maximize the enormous investments made in our university and government labs by bringing their intellectual properties to the marketplace in the most efficient way possible. The Bayh-Dole Act has been a great start, and the work to facilitate technology transfer must continue to improve to utilize one of the greatest assets of our country.

Every facet of human life will be touched by advances in nanomaterial development. These areas include medical, homeland security, power generation and distribution, telecommunications, transportation and applications never before conceived. To realize this potential, this country must improve the transfer of technology from our universities and federal laboratories to the commercial world. Our internal threat is not transferring great discoveries made in the U.S. from the laboratory to commercial products. These discoveries are far too important to leave on the shelf. And, we must do it now to protect our competitive advantage from external threats, as other countries continue to make even larger investments in nanotechnology.

Luna strongly believes this proposed legislation will help secure the country's position as a leader in the nanotechnology field. By funding basic research, and technology transfer programs we will move the results of our nation's greatest researchers in nanotechnology to the market place creating higher quality jobs here in the U.S.

While there may be revolutionary discoveries in the nanomaterial world, it is most likely to be evolutionary progress that requires extensive collaborative efforts working over extended periods of time to truly utilize the capabilities of nanotechnology to address the problems of the world.

Nanotechnology is not any specific technology or discipline; instead it is a broad term used to define work conducted on the nanometer scale. True breakthroughs are often accidental discoveries while the majority of progress towards problem solving is incremental work done in a collaborative effort across many different fields of expertise. Try to imagine the different areas of scientific and business expertise that will be required to bring the following products from laboratory to consumer in a timely fashion:

Health

- Radio-pharmaceuticals which allow never before seen cell targeting giving "magic bullets" for cancer therapy,
- Less toxic photo-therapy agents for advanced cancer treatment,

- Contrast media for greatly enhanced diagnostic imaging,
- Super sensitive detection systems for drug discovery tools, reducing time to market and costs of drugs,

Homeland Defense

- Nanotube-based sensing devices allowing single molecule/cell detection of chemical/biological warfare agents,
- Lightweight, durable protective materials for soldiers, and military vehicles,

Power Generation and Distribution

- Next-generation fuel cells with improved efficiencies for household, and handheld devices use,
- Solar cell improvements with increased efficiency,

Communication and Computing

- Quantum computing for future generation systems that calculate on a neverrealized- scale for defense systems,
- Molecular electronics for next-generation computing; single molecule transistors and storage devices,
- Optical devices using nano-structured materials for higher rate communications,

Transportation

- Superconducting compounds for higher strength magnets for transportation and medical imaging,
- Fuel cell improvements and safe hydrogen storage for automobiles,
- Catalysts for higher- efficiency, cleaner-burning, fossil-fueled engines, and

Other Applications

- Exotic teflon-like nanomaterials which provide a new class of lubricants for today's applications and tomorrow's nano and micro machinery.

Luna Innovations has recognized the enormous value of discoveries made at our research institutions and is continually improving the technology transfer process to move these innovative ideas from the laboratory setting to the marketplace. Through this business model, Luna has licensed valuable patents from universities, government labs and large industries and has created competitive products in telecommunication, power generation and distribution, transportation, manufacturing, and pharmaceutical industries. Luna currently has a significant focus on several nanomaterial-related technologies and applications. For example, Luna has licensed patents and transferred intellectual property from a major discovery made by Dr.'s Dorn and Stevenson both at Virginia Tech, and are beginning to produce revenues from sales of these novel nanomaterials.

Virginia is a leader in this country in collaborative nanotechnology research and development. Virginia is one of the first states to establish a state-wide technology organization, the Center for Innovative Technology (CIT), focusing on the support of collaborative efforts and the creation of high-tech jobs. Also, Virginia was the first state to create the position of Secretary of Technology directly reporting to the Governor in order to enhance the climate for technology within the Commonwealth. Other Virginia organizations, such as INanoVA and VRTAC, complement this infrastructure allowing nanotechnology-specific communication to the upper levels of the state government.

The Federal Government must take the leadership role in funding nanotechnology research and the coordination of technology transfer for our nation. The creation of a National Nanotechnology Coordinating office and National Nanotechnology Advisory Panel, under the proposed legislation, will facilitate collaboration between federal and state government agencies, research universities and industry.

The 21st Century Nanotechnology Research and Development Act, with new vision and leadership, will ensure the U.S. a leading position for growth in the nanotechnology sector, thus creating high quality jobs, increasing the tax base, while solving significant problems in our society. It will allow us to not loose ground to foreign competition seeking to overtake our current advantage. The economic success of our nation is at stake. We must remain in the leadership position. This legislation is necessary for the United States, to ensure our future health, well being and safety in this rapidly advancing global economy.

Again, I would like to thank Senator Allen and the Committee for this opportunity to address you today.

Senator ALLEN. Thank you, Dr. Murphy, for your very positive and cogent information and testimony.

Now we'd like to hear from Mr. Von Ehr.

STATEMENT OF JAMES R. VON EHR II, CEO, ZYVEX CORPORATION

Mr. VON EHR. Well, thank you, Chairman Allen and Senator Wyden.

I'm the Chief Executive Officer of Zyvex Corporation. I started Zyvex in 1997 to develop molecular and nanotechnology and revolutionize the quality and economics of how we make physical goods. We currently offer products in the area of tools and materials, and we're working on nanomanufacturing systems.

I commend you for your leadership on this important legislation. It's leaders like Senator Allen and Wyden who make a difference by meeting with and listening to leading nanotechnology small businesses.

Thanks to my previous business success, I've been able to generously fund Zyvex myself. Today, we employ over 50 people, and we're one of the few nanotechnology companies generating revenue. I've also given nearly $4 million of my own money to a number of universities to help them enter this field. With that experience, I'd like to comment on technology transfer and commercialization, the two most important aspects of this legislation.

Senators Allen and Wyden know this is an important time for nanotechnology. Actions taken today will decide who, 30 years from now, will be the leader in science, manufacturing, and technology. Will it be the United States or another country?

The current bill calls for an advisory panel of scientists from academia and government. The voice of business is missing, and I'm really concerned about that. We need a business focus to ensure that the research we develop is commercialized in the United States. Therefore, I strongly recommend that representatives from both large and small businesses be included on the advisory panel. Without a commercialization focus, other nations may surpass us, become a dominant force in the global economy. Specific technology, such as the nanomanufacturing system, could be disastrous from the standpoint of national defense and economic competitiveness if it was in the hands of another nation.

I used to oppose any government funding for any industry; however, our private sector has now gone global, and it can invest anywhere. It's reasonable for the government to encourage economic competitiveness for national security reasons. And while I worry about the industrial policy implications of that, I worry even more about losing nanotechnology to nations able to invest for periods longer than 2 or 3 years.

Today, it's very difficult for small technology businesses to secure acceptable funding; however, small businesses employ 39 percent of high-tech workers and are responsible for 45 percent of the jobs in our nation. Small businesses also produce 13 to 14 times more patents per employee than large firms. High-tech private-sector jobs benefit the economy with a return of over $3 for every dollar invested in research.

The NIST Advanced Technology Program has been instrumental to Zyvex in overcoming this funding gap. It helps fund high-risk, high-reward projects and evaluates commercialization plans just like a venture capitalist would. An ATP award often requires cost sharing by the company, including ours. Thanks to our ATP, the impact of our nanomanufacturing effort will allow our nation to regain strength in manufacturing and bring jobs back to the U.S.

I think the NIST ATP should take on an even larger role, similar to the role of the NSF, by commercializing nanotechnology research. It could be elevated to an office within the Technology Administration in the Commerce Department. More nanotechnology dollars allocated to the NIST ATP and the SBIR program would accelerate the innovation and commercialization of nanotechnology.

As Senator Allen pointed out, 3 years ago I founded the Texas Nanotechnology Initiative to create a nanotechnology cluster. That has become a model for similar regional initiatives. It's important. Good jobs are at stake in this field. I really think it's our duty, as Americans, to assure these jobs stay in the United States.

The National Nanotechnology Initiative defines nine grand challenges. But what if we had one or two that the American public could embrace, where government, universities, and industry worked together? These could address serious problems for our Nation, such as how the United States can regain our position as the world leader in manufacturing or how we can reduce our dependence on imported energy. In fact, with a major nanoenergy program, we would reduce our dependence on fossil fuel by over 50 percent over the next 15 to 20 years. The economic benefit would be hundreds of billions of dollars per year. And nanomanufacturing could be part of the solution to both these problems.

Now, much vision and foresight are at the core of this legislation, yet long-term fundamental research alone will not guarantee leadership in nanotechnology. It requires a balance of fundamental and applied research, support for our regional initiatives, a constant voice from industry, and a competitive process for awarding federal dollars. So I, once again, applaud your vision and foresight to ensure that the United States is the nation that brings this powerful technology to the world. The legacy you leave now will be remembered by future generations. Mr. Chairman, Senator Wyden, I thank you for your kind attention, and I appreciate being here.

[The prepared statement of Mr. Von Ehr follows:]

PREPARED STATEMENT OF JAMES R. VON EHR II, CEO, ZYVEX CORPORATION

Introduction

Thank you, Mr. Chairman and Members of this distinguished Committee for allowing me to address you on S. 189. I am Jim Von Ehr, Chief Executive Officer of Zyvex Corporation. I started Zyvex to develop molecular nanotechnology and revolutionize how we make physical goods. Today, we offer the promises of nanotechnology to our nation through tools, materials, and nanomanufacturing. As the founder of one of the first nanotechnology businesses, I am honored to share my unique perspective.

First, I commend you for your leadership on this important legislation. It is leaders like United States Senator George Allen who make a difference by taking the time to really understand the issues and ensure the success of our nation by meeting with and listening to leading nanotechnology small businesses.

Senator Allen, and other Members of this Committee know that we are at a pivotal moment that will decide whether thirty years from now, it will be the United

States or another country that will be a world leader in science, manufacturing, and technology. S. 189 shows that our nation's leaders understand the benefits of nanotechnology and the need to educate more scientists and engineers. However, it is also vital that we more effectively commercialize university research. International competitors are aggressively developing their own nanotechnology industry, quite often based on discoveries first made in our own university labs here in the United States. We want a healthy manufacturing sector in the United States to assure good jobs for these newly educated technologists.

Thanks to my previous, significant business success, I've been able to generously fund Zyvex myself. Today, we employ over 50 people and are one of the few nanotechnology companies with revenue. I've also given nearly $4M of my own money to a number of universities to help them enter this field. With this experience, I feel entitled to comment on technology transfer and commercialization—the two most important aspects of this legislation.

As my friend, Nobel Laureate, Professor Rick Smalley says, "Nanotechnology is the art and science of building stuff that does stuff on the nanometer scale. The ultimate nanotechnology builds at the ultimate level of finesse—one atom at a time—and does it with molecular perfection." I started Zyvex seven years ago to commercialize that level of control and perfection.

The current Bill calls for an Advisory Panel staffed by academic and government scientists. The voice of business is missing, and I'm concerned about that. As you know, our nation's record of commercializing research from universities and government labs is good in the biosciences, but disappointing in most other areas.

The National Nanotechnology Initiative is inspiring competitive programs worldwide. The societal benefits of the NNI will come in the form of products. The role of business is to develop and sell products in a capital-efficient manner. We must have a business focus to ensure that the research we develop is commercialized in the United States. Therefore, I strongly recommend that representatives from both large and small businesses be included on the Advisory Panel.

Competition

Competition is a key reason U.S. business is the most competitive in the world. Competition is also important to science. Peer review is a powerful approach to filtering out junk science, but it also can filter out novel ideas from young researchers. We need ways to differentiate scientifically crazy ideas like building time machines from delightfully wild ideas like sequencing the human genome in three years. Of course, when Craig Venter decided that such a sequencing timetable was achievable, it probably would not have passed muster with a conservative peer review committee. He properly framed the issue as a business problem—not a scientific problem—and solved it.

Our most competitive industries are also our least regulated—semiconductors, personal computers, software, and the Internet, to name just a few. S. 189 has a light regulatory touch, and I urge you to follow the example of the Internet, and avoid premature regulation while the industry develops. There will be pressures from the usual anti-technology voices to ban or limit nanotechnology, but we should continue on the path of progress that has always been our nation's strength.

We also need to inject private sector competition into our nanotechnology program. The current Bill calls for significant funding for government labs to build new user facilities. Providing shared access to exotic equipment is a smart way to stretch funds and accelerate overall development. These facilities will not be available for at least five years. This is too long to wait in this dynamic field. Awarding competitive contracts or grants to the private sector to upgrade and reopen surplus or shuttered facilities could achieve faster deployment at a lower cost.

Barriers to Industry

Applied Research

While fundamental long-term research is a vital component of this legislation, nowhere is there a mention of the importance of funding applied research. I urge this Committee to consider this issue very carefully. Without a commercialization focus, other nations may surpass us and become a dominant force in the global economy. Specific technology, such as a molecularly precise nanomanufacturing system, in the hands of another nation would be disastrous from the standpoint of national defense and economic competitiveness.

Technology Transfer

The technology transfer programs at our nation's leading universities have produced dismal results. The barriers for small and large industry to commercialize this "long-term" research performed under federal dollars have brought very little economic benefit to the American Public. Stan Williams of Hewlett Packard has addressed this issue in previous testimony, so I won't belabor the point.

Funding

I used to oppose any government funding for any industry. The private sector is the most efficient way to make investment decisions. However, our private sector has gone global and can invest anywhere. The short-term economic decisions that make sense for a particular company might not be the best long-term decisions for our country. Perhaps it is reasonable for the government to encourage economic competitiveness for national security reasons. While I worry about the "industrial policy" implications, I worry even more about losing nanotechnology to nations able to invest for periods longer than two to three years. Nothing makes this point clearer to me than a recent trip to Taiwan where I witnessed, ITRI, a government/industry partnership staffed with 6,000 researchers developing an advanced technology base and focused on industrial competitiveness.

Funding is vital for any enterprise. Private equity funding today is short-term oriented. Taking research from the lab into the marketplace is a long-term endeavor. The gap between lab and market leads to the "valley of death" funding crisis—it is rare to find investors willing to take the risk of an investment lasting five years or more.

Today, it is more difficult for small technology businesses to secure acceptable funding. Small businesses employ 39-percent of high tech workers and are responsible for 45-percent of the jobs in our nation. Small business produce 13–14 times more patents per employee than large firms. These patents are also twice as likely to be among the 1-percent most cited.[1]

The Commerce Department has the NIST Advanced Technology Program, which has been instrumental to Zyvex in overcoming this funding gap. It helps fund high-risk, high-reward projects, evaluating commercialization plans as a venture capitalist would. The NIST-ATP program requires, in many cases, including ours, cost sharing by the company. The ATP helps put small companies on a more even research and development footing with large companies. The program wisely recognizes that small businesses are unable to afford the kind of R&D of an IBM or Lucent, yet are responsible for a majority of our nation's innovations and technical advancements.

Thanks to our ATP, we will have hired fifteen new employees in 2003; we also support researchers at two universities in Texas and one university in New York. We are developing a new manufacturing technology that will drive innovation in the silicon micromachine domain. The impact of parallel microassembly on the broader economy will be in the billions of dollars and will ultimately create thousands of jobs here in America.

We should consider a nanotechnology initiative with a greater balance between university long-term fundamental research and applied research and industrial development. The Advanced Technology Program should take on a larger role, similar to the role of the NSF. It could be elevated to an office within the Technology Administration in the Commerce Department. Outside venture capitalists with a longer-term viewpoint would help review competitive business plans. The program would focus on commercializing nanotechnology research. More nanotechnology dollars should be allocated to flow through the SBIR program, which will also help accelerate the innovation and commercialization of nanotechnology.

Components to Our Success as a Nation

Society

Studying the impact nanotechnology may have on the world is vital, and S. 189 addresses this issue head-on. Those of us in the field believe that we will be able to manufacture products in a clean, environmentally sound manner, and welcome qualified people to review our technology.

Three years ago, I founded the Texas Nanotechnology Initiative, a non-profit organization whose goal is to establish Texas as a world leader in the discoveries, development, and commercialization of nanotechnology. TNI has become a model for the NanoBusiness Alliance and other regional initiatives. We want to develop a nanotechnology cluster as an economic engine for the region. Good jobs are at stake here. While TNI is working to assure many of them are in Texas, it is our duty as Americans to do all we can to assure that they are in the United States. High tech private sector jobs benefit the economy, with a return of $3.32 for every dollar in-

[1] Small Business Administration's Office of Advocacy

vested in research.[2] Funding and support for these statewide initiatives needs to be addressed in the Bill.

Grand Challenge

You already know that we have a problem in the number of Americans pursuing study in science and engineering. To turn this around, we need to get government, universities, and industry to work in partnership to achieve the great promises of nanotechnology. This would be a grand challenge similar to the "man on the moon" challenge. The National Nanotechnology Initiative defines nine "grand challenges," but it is difficult to focus on nine things with undefined outcomes. What if we had one or two grand challenges? And what if these grand challenges were to solve serious problems for our nation? Such as how we reduce our dependence on imported energy. Or how the United States can regain our position as the world leader in manufacturing. Nanomanufacturing could be part of the solution to both of these problems.

Energy

With a major nanoenergy program—on the order of ten to twenty billion per year—we could reduce our dependence on fossil fuel by 50-percent over the next fifteen to twenty years. That would pay benefits of several hundred billion per year. It is hard to calculate the security benefits of being less dependent on energy imports. The nanotechnology that would come out of this program would provide multiples of that benefit in all the other areas identified as priorities.[3]

Nanomanufacturing

Nanotechnology isn't just about making small "stuff," but includes interfacing that "stuff" to the real world. We must be able to manufacture with molecular precision at all length scales—from molecular to the size of a jumbo jet. A nanomanufacturing program would be complementary to the energy program, and would also result in technologies that could be applied to materials, medicine, and computing.

Conclusion

Much vision and foresight is at the core of this legislation. To truly ensure the success of our great nation, we must now have the courage and perseverance to take such visionary steps. Long-term fundamental research alone will not guarantee commercialization of nanotechnology. *It requires a balance of applied and fundamental research, support for our regional initiatives, a constant voice from industry, and a competitive process for awarding federal dollars.*

I once again applaud your vision and foresight to ensure that the United States is the nation that brings this powerful technology to the world. The legacy you leave now will be remembered by all our future generations.

Mr. Chairman and Members of this Committee—thank you for your time and for this honor.

Senator ALLEN. Thank you very much for all your testimony. Senator Wyden and I will have a few questions here.

I'd like to focus on Dr. Murphy and Mr. Von Ehr, since you're in the private sector. You're the ones trying to adopt, utilize, and find a marketplace, whether it's the manufacturing or your ultimate nanoproducts, whatever they may be. And I was seeing yours, Mr. Von Ehr and Dr. Murphy. I've talked in many occasions about the precision of medical treatment. And with your technologies, you're killing the bad cells, so to speak, as opposed to just these shotgun blasts that weaken someone's whole body while trying to kill off the bad or non-cancerous—they're trying it kill off the cancerous cells. And I think there's just tremendous opportunities there for better application of pharmaceuticals and other aspects.

What could you all share—and, Dr. Murphy, I'll ask you first. Your business model is one that probably is similar to other professors or scientists that are in colleges and universities, where

[2] Office of the Texas Comptroller

[3] James R. Von Ehr II, "NanoEnergy Project—Vision 2020." 2003. Publication Pending. (For a copy, please email kgreen@zyvex.com.)

they're saying, "Well, for whatever reason, things aren't getting out, whatever is being developed." So you set up your own company and obviously have been successful. What is in your business model or what lessons can you share with all of us, including—and when I'm talking about "us," I'm talking about the government, but for other entrepreneurs, other scientists, whether in a university or a government, some other sort of government agency function—what could we learn from your success, both of you are successes here, as to how this can be approached? And I'm not talking about the specifics, "We did this, then we saw so-and-so, and then he had us go talk to this lady, and she then said, 'Here, I have another friend who'll invest,'" but what are the basic principles or lessons that you would see as applicable to others who would want to find the commercial applications of your research and your nanoscale products?

Dr. MURPHY. In general, one of the things that we've found at university settings is there's a lot of tendency towards being enamored with the technology rather than the application. Finding the end goal, finding a problem that you're going to solve, and then coming back and looking at the technologies that are being developed—certainly, basic research needs to be funded. Those technologies need to be moving forward. But someone's got to be in the go-between making sure that significant problems are being solved with those basic findings.

And then, just within the university itself, some things that I encountered personally there was, in general, a split between the university community as to—was this activity beneficial or negative for the university trying to commercialize technology out of a university and looking into how we could possibly change the university culture?

And I know this is not something that can be legislated, but something that can be discussed is the tenure and promotion process looks at teaching research and public service. Having the universities look towards technology transfer as something that they actually measure and pursue would be very, very beneficial. A lot of the folks that I ran into at the university saw what I was doing as something that tainted the university atmosphere, when I believe it actually brings real-life applications into the classroom.

Senator ALLEN. I would think that that would interest students, that the research is interesting, all of that is, but then the actual application towards a beneficial utilization of that would, I think, make it more exciting, more tangible, more practical.

Dr. MURPHY. Absolutely.

Senator ALLEN. Mr. Von Ehr, you mentioned—both of you all mentioned the NIST and ATP grants. What would you say would be the keys to it? And you mentioned, insofar as awards are concerned, the competitive awards—would you have any suggestions as to what the standards of assessment would be? Because there's so many people who have so many great ideas, and, you know, there's just millions of them, and then you have to determine which of these have the greatest potential.

Mr. VON EHR. Well, that is the crux of the issue.

Senator ALLEN. Well, maybe you could give us some standards. Mr. Teague was telling us standards. I do want to ask you about standards, but——

Mr. VON EHR. Well, if venture capitalists, who are the best people at that job——

Senator ALLEN. Don't want to invest.

Mr. VON EHR.—if they could figure it out, they would all be rich and retired now.

Senator ALLEN. Right.

Mr. VON EHR. The fact that the venture capitalists lost a ton of money in the dot-coms and the telecoms——

Senator ALLEN. They're a bit skittish these days.

Mr. VON EHR. The best people we have are not perfect. But I think the benefits of the ATP are vast, in terms of bridging the gap, the Valley-of-Death funding between a good idea at a university and a product that a customer can buy. And there are few VCs that want to step up and invest in something that may be a multiple-year payback. Their time horizon got very compressed during the Internet days. It's lengthening out slowly now; but still, they have been burned so badly, a lot of them are risk-averse. And we see that the ATP can help that.

And in terms of the judgment, I think it's just a matter of judgment again. They look at the business plan. They evaluate whether there's some credibility the company can pull that off. It's very similar to how peer review works for science. You know, you look at the scientists, you look at their track record, you look at what they've done, and you say, "Do I think they can do it again?"

Senator ALLEN. What would you—back to my original question; I got you off on that tangent—and all of you all may, but particularly Dr. Murphy and Mr. Von Ehr. Dr. Teague mentioned the need for control of processes. And I forgot which one of you all brought up polymers and so forth. And, you know, there's standardization of processes for that reliability, credibility, certification, so to speak. And having listened to you, Dr. Murphy, and learned about what Luna is doing and seeing what Zyvex is doing, as well, with the nanotubes, and actually seeing it on some of the amazing microscopes—they're more than microscopes, but, at any rate, on the nanotubes and the different ways those are processed—and there are, there's all those variables to it—would you agree with what Dr. Teague was saying, that there needs to be a standard or a control of processes—and I hate limits or controls; those are words that's very hard for me to say in a positive way—I'm just saying, you know, standards, standards of quality, so to speak, of your processes, do you all share that concern? Because I think that does matter in the commercialization, the reliability, and people worrying about liability, if certain nanoproducts might not uniformly meet a standard of performance.

Mr. VON EHR. Certainly, we are dying to start working on the process and make sure it's a good process. But, frankly, a lot of nanotechnology now is still in the early stages, and it's hard to put process control into something that has been demonstrated in the lab in milligram quantities or maybe with one experiment. So I'd say the technology has a little further to come, in our case, we're working with nanotubes and polymer mixtures, and the nanotube process development is not nearly as far along as Luna Innovations' process is.

We certainly are going to have to put process controls in place when we get a process to control.

Senator ALLEN. Understood. It's still very early.

Dr. Murphy?

Dr. MURPHY. We're very fortunate at Luna to have a product that is an extremely unique molecule and lends itself towards better process control. So, again, we're able to make things that are 99.99 percent pure materials and in kilogram quantities at this time. So, yes, it is going to be a very important factor.

In fact, recent things that I've read about nanotubes is that when you purchase a quantity of nanotubes, it's 40–45 percent of what you want and 50–55 percent of something else. So it is a very important point.

Senator ALLEN. Thank you both.

Senator Wyden?

Senator WYDEN. Thank you, Mr. Chairman.

Dr. Jiao, we're thrilled you're here and representing Portland State, and you've really sparked tremendous interest. And I'm curious, when you mentioned that your students were excited that you were coming and you, sort of, gave them the day off, what was particularly exciting to them about what you're going to do and what's ahead in nanotechnology? And what else can we do to get students even more involved, particularly in an earlier age in high school?

And I thought that would be a good question for you, since you've obviously spent a lot of time with interns and a variety of ways to get the students involved. So why don't you start us off?

Dr. JIAO. Okay. If I'm allowed, I'll tell you a little systematic story how this works.

First of all, my master's thesis in physics is about florins, which is buckyballs. I worked for a Professor Don Hoffman, who is the co-discoverer for the solid-state carbon 60 while the Professor Richard Smalley won the Nobel Prize for his discovery if it is a molecule in the—but the solid state is Professor Hoffman and his co-workers in the Max Planck Institute. They found a way how to extract those molecules to be solid state so that we can see them, touch them, and study them.

So then my Ph.D. thesis is a systematic study of the carbon nanotubes made by different method. So I carried this enthusiasm then to Portland State, and then we went to the laboratory, which we synthesized those molecules and in the solid state. So then in order to see them, you have to have the high-power electron microscope, because you have to magnify them a million times to see what they look like.

So by—why the students—seeing, how the seeing is believing. So under these high-power microscope, when they see the molecules and they see the atoms, they were just thrilled, they were excited. They said, "This is the science I want to go too." So this is why it's not, "I love it. Come to work for me." They just—I have too many students to handle, because they see it and they really want—they understand, "Oh, this is how atoms viewed themselves in this way." But then in working in a laboratory, when we change the parameters, which means we lower the temperature, then we mix something else, and then we change the fluoride to the gas, and they made the tube shorter or even longer, so by changing this process, then they look at it, then they said, “Okay, I can make a difference.” Okay?

So this kind of process made us feel to educate those young people you have to have—let them to have the chance to have hands-on, also to let them understand. So the best way is to not only teach them in theory in the class, but also to show them what you can do and what it will look like. So this is why students think, you know, “If you understand this principle started from atomic level, definitely I can build these things one by one. I can be good architect,” and then just to build these atoms to be the different way, then test their electronic properties.

So I think this process is a wonderful educational process so we can make them excited, and we feel like the future should be this way because you work it down to the level of atoms. And I think maybe the next level is to see the nucleus. But they feel like this is the way to go. This is why they are so excited.

Senator WYDEN. Well, we should put you in charge of the whole Federal Government.

[Laughter.]

Dr. JIAO. Thank you very much.

Senator WYDEN. Thank you for an excellent answer.

A couple of issues for you, Mr. Von Ehr. You’re the second industry leader who’s basically talked about how Bayh-Dole is dysfunctional, and that’s something that I essentially hear everywhere. And, of course, when you bring this up, you know, most of the world has no idea what Bayh-Dole is, number one; and, even those who know what Bayh-Dole is, just sort of say, well, we’re glad that it’s there. But what I find is that it really doesn’t work very well for any of the stakeholders that it’s designed to serve. It supposed to, of course, be a great tool for private sector innovation that, in this technology treasure trove that the government runs with taxpayer dollars, it’s supposed to get technological development out to the private sector, and it doesn’t seem to. And somehow the universities seem snarled in red tape and frustration, and the private companies can’t get access to it. And, of course, you’re supposed to explain it to taxpayers. I have often though that if taxpayers knew what really goes on with these research dollars, they would show up in Virginia and Oregon and say, “Um, excuse me, you’re spending billions and billions of dollars for research that’s supposed to be transferred to the private sector, and, you know, why isn’t it taking place?” And I’d be curious if you could give us some specific examples of some of what has made you frustrated about Bayh-Dole, Mr. Von Ehr.

Mr. VON EHR. Well, I mentioned that I have given close to $4 million—a lot of that has gone to the University of Texas at Dallas; and, while we love the people there, we love working with them, we have not succeeded in transferring any technology or having a blanket agreement to do so. The people at the university have to work through the people at the system level, and those people don’t have the same sort of drive that we do to productize what has been developed.

I was in Houston last week talking with a professor who's a friend of mine and he's written a book on his experience starting up a company. And he has the wry observation that professors seem to value their stuff a lot higher than industry does; that the professor thinks it has an infinite value. And he's a professor in this role, and he said, "They have no idea how much work it takes to actually turn it into a product and convince someone to sell it, to pay you money for it."

Senator WYDEN. Well, anything you'd like to furnish us for the record with respect to your frustrations on Bayh-Dole, I would be especially interested in. We've had Hewlett-Packard and others, where you are, and really it's a story that needs to be told. Because this statute governs billions and billions of dollars of research funds, and I'm convinced it doesn't work for the stakeholders, companies, universities, taxpayers, and society at large. So we'd welcome your examples.

The only thing that I would differ on. You can probably tell I feel strongly about it, so I don't take a back seat to anybody involving industry in these projects. The Advisory Committee, on page 17—I'm looking at it—says, "The panel shall contain a reasonable cross-section of views and expertise." And we wrote that specifically so as to involve industry. It comes from the High-Performance Computing Statute, which set up the Information Technology Council, which is just filled with industry people. And then on page 18, we talk about getting recommendations from industry, as well, with respect to this position. And I'd like to note, just for the record, that industry has a listing that comes before academia, with respect to the advisory council. So I know of your good work and do not want to jump you too much here this afternoon, but——

Mr. VON EHR. Okay, well, I thank you.

Senator WYDEN. I feel very strongly that we do what it is you seek to have done, which is to make sure that industry has a very, very important place at the table. And as we thrash through this final effort, I want to assure you that we're going to keep in mind what it is you desire, because you're right, and we'll make sure it gets done.

Mr. VON EHR. Well, that's excellent. Thank you.

Senator WYDEN. Thank you.

The only other question I had, Mr. Chairman, was for Mr. Baird. On the ethics question, what Chairman Allen and I have done in an effort to try to get out this ethics debate is to establish a center to begin the discussion, and we think that makes some sense, and we heard about that from a host of experts. But my sense is—I note Chairman Allen shares this view, as well—people are talking about this without waiting for the divine wisdom of the United States Senate. In other words, people are talking about ethics and social questions even before some characters in the United States Senate come along to tell them, "Well, you're supposed to have a big debate."

Tell us a little bit about the discussion that is going on today, absent any federal legislation, with respect to ethics and nanotechnology and some of which you and your colleagues are doing already to start looking at these issues.

Dr. BAIRD. Well, there's a lot of discussion about ethics, in general. But, in fact, I would say there is very little discussion by either trained ethicists or a fairly broad definition of "trained ethicists" about nanotechnology. I think, outside of the scientific and technical fields, people haven't heard of this, by and large. There are a few places where that's not true. South Carolina's one. Virginia's one. Illinois Institute of Technology is one. These are places I know of. They're doing some of this at Rice, although that's recent, I think.

And so, I mean, nanotechnology is recent, so I would say the debate is early and raw at this point. We're trying to begin to sort out what are serious issues for the near-term, what are serious issues for the longer-term.

I guess, in my view, in the near-term, you have clear issues about toxicity and regulation that need to be thought through carefully. I also think in the near-term, and this bears on the longer-term, it's really important to think about what are the—how are people constructing the goals and aims of nanotechnology as we build a National Nanotechnology Initiative? How, when we think about those goals, you know—what's the adage, you've got to be careful what you hope for—if we actually achieve them, what will really be the impact of achieving them? So we want to think about what are, as it were—the goals, if we actually achieve them, what will be the impact of them? That can be done now.

And then there's a fairly extensive, but, I think, at this point, difficult-to-assess debate about issues about the very important, but, as of yet, unrealized potential for nanotechnology in the form of assembler/assembly, as it were, nanotechnology assembler/assembly. I think it's probably early to really engage that, because we don't know really what's going to come of that.

That's a case where I think it's crucial that the people who are doing this debate are talking to the scientists. I think, to leave you with one thought, the most important thing that we need to have happen in this debate is to have engagement between the scientists and the ethicists. They have to talk to each other, they have to learn each other's language, they have to start, as it were, exchanging each other's views. And only in that way are we going to have some kind of positive move ahead.

Senator WYDEN. I agree with everything you said. I just want to add a lot more people to the debate, beyond the scientists and the ethicists.

Dr. BAIRD. Oh, I——

Senator WYDEN. Because if we don't, Michael Crichton will drive the debate. That's what people will remember, in a sense.

You all have been a terrific panel, between the two panels. Under Chairman Allen's leadership we've had a good cross-section of views. I also regret that we have now made it impossible for Dr. Jiao to get the one non-stop flight to Portland——

[Laughter.]

Senator WYDEN.—which all of us just pray for in terms of Oregon logistics.

But we welcome your counsel as we try to move forward on this legislation. Nanotechnology is so exciting, and, at the same time, all of you, as witnesses, and Senator Allen and myself, as legislators, have known about things that have come along in the past that sounded exciting, and a variety of things happened along the way, and it never really reached its potential.

I think nanotechnology's going to be different. I think that this is a field where we have not overstated the potential. And by listening to people like yourselves and the cross-section of people that we've sought to have involved in the legislation, we can do this job right. So our doors are open to you for input.

Mr. Chairman, excellent hearing, always good to be working with you, and I look forward to moving ahead.

Senator ALLEN. Thank you, Senator Wyden.

And I thank all our witnesses in both panels. This last panel, thank you for coming long distances. We'll get you a room in Northern Virginia if you——

[Laughter.]

Senator ALLEN. Our sales taxes aren't as good as those in Oregon, which are zero in Oregon.

[Laughter.]

Senator ALLEN. But, nevertheless, we'll welcome you there.

And, again, thank you all for your insight, for taking valuable time here to be a part of this nascent effort here in the Senate. The government is looking at this area. You all are our experts in your variety of fields. We thank you very much, look forward to working with you. And if you all ever do have any comments, insights, ideas, tweaking, maybe some parts of this measure have not been properly explained, please let us know. You don't have to go through the formalities of a hearing.

With that, this hearing is concluded. Thank you all.

[Whereupon, at 4:40 p.m., the hearing was adjourned.]

A P P E N D I X

PREPARED STATEMENT OF HON. MARIA CANTWELL, U.S. SENATOR FROM WASHINGTON

The United States of America has led the world in scientific research and in technological innovations in the 20th Century, and the 21st century will undoubtedly provide new challenges and opportunities. The true engine of the American economy has been to turn our scientific discoveries into practical applications and advancements in technology have allowed us to improve our economy, our national security, and to live richer lives. Today's science and technology innovations are uniquely characterized by the speed and information processing capabilities of our new machines. Traditional biology, traditional chemistry, and traditional physics have been literally transformed by technology. We are presently on the verge of new sciences, which will undoubtedly produce exciting new technologies.

The new fields of nanotechnology, genomics, bioinformatics, and microengineering, among others, grow out of a synergy of physics, biology, chemistry, engineering, and advanced computational modeling. Recent advances in proteomics and genomics promise to allow us to understand the complex interactions of proteins within living cells and provide important clues to the mystery of living organisms. This basic research in biotechnology will certainly have unique applications and the integrative and predictive understanding of biological systems will improve our ability to respond to the energy and environmental challenges of the 21st century. Nanotechnology is the other half of this complementary pair of new sciences. Like genomics, nanotechnology combines traditional sciences into a new 21st century science. Nanotechnology offers immense possibilities for scientific advancements, achievements, and applications, with immense potential to transform our lives. It has equally wide applications—from energy, to medicine, to electronics. Like genomics, nanotechnology is what scientists and technologists label as an "enabling" technology—a tool that opens the door to new possibilities constrained only by basic science principles and our imaginations.

I have introduced legislation in the Energy Committee to spur development and research in the field of genomics and bioinformatics, and look forward to considering the complimentary roles nanotechnology legislation can play. Along with Senator Wyden, I convened a Commerce Committee field hearing earlier this April on the Northwest economy that focused on the innovative science and industries that will drive that region's economy in the future. The hearing highlighted the exciting and unique opportunities that advanced manufacturing, including nano-scale fabrication, can have in spurring technological and economic development. At that hearing we heard about challenges facing these developing industries, and the role federal research and investment could play in growing those industries. In response to these findings, I have proposed legislation in partnership with the University of Washington to establish a Federal Aviation Administration Center for Excellence in Materials Science. Such a center would produce research that would develop techniques in maintaining and ensuring the durability of advanced material structures in transport aircraft, including at the molecular level.

Another part of that same productive hearing on the Northwest economy revealed that biotechnology, including the nano-scale research into biological systems, can play a role in diversifying and driving economic development. I learned about many exciting advances fueled by biotechnology, and spoke with many bright innovators about challenges their research and their industries have faced. I am excited to say that many of these roadblocks will be removed, and a good deal of basic research provided, through the Genomes to Life bill, S. 682, I have introduced in this session. That bill capitalizes on the enormous success of the Human Genome Project, and promises to take this important research to the next level. While the mapping of the human genome was an unparalleled accomplishment on its own, this new initiative would allow researchers to go beyond the science of description, and begin to explore the complex interactions of the elements within cells—truly exciting and micro, if not nano-scale, research that promises great rewards in response to grand challenges.

Other nations have already recognized the need to be at the forefront in these fields, and many have already provided support for genomic and nanotechnology research. In the U.S., both genomics and nanotechnology have been recognized by the Department of Energy, The National Research Council, and the National Science Foundation as high priorities for new research. American research institutions, companies, and universities have recently joined in these investigations. The State of Washington is already a national center for genomic research and the University of Washington is the first in the United States to offer Ph.D.'s in nanotechnology. Washington is home to many world-class research facilities. We have over 190 biotechnology companies employing more than 11,000 people. In 2001, the annual revenue of these companies exceeded $1.2 billion. Nearly one half of these companies were based on technologies developed at research and development institutions and over 40 percent of the companies have been established in the past six years. I believe that federally funded research in genomics and technology will provide more economic benefits, not only for Washington, but also for the nation.

While our past leadership in science and technology may provide us a head start, it must not lull us into a false sense of accomplishment. We cannot afford to become complacent, but must take proactive steps to ensure our economic and scientific future is a real possibility, and that barriers to these new technologies are removed through targeted federal involvement. While these new fields involve experiments at the microscopic level, they often require sizable instrumentation and investments of federal support. This support is an example of the targeted role the government can play, not in competing with businesses, but in training America's workforce and providing fundamental theoretical research into new fields of knowledge.

We must provide the federal support for a coordinated national program of research and development in emerging sciences. Federal investment in these new sciences will produce important scientific breakthroughs and result in long term benefits to our health, our economy, and our national security. I look forward to hearing today how we can do just that.

Prepared Statement of Hon. Frank Lautenberg, U.S. Senator from New Jersey

Mr. Chairman, this is an important hearing. Clearly, there is a limitless future with regard to the applications of nanotechnology across a wide variety of disciplines, including engineering, physics, chemistry, material sciences, and life sciences—to name just a few.

The estimates of the economic impact of nanotechnology on existing and new manufacturing reach into the trillions of dollars.

In time, nanotechnology will have an enormous impact on virtually every aspect of our lives.

Not surprisingly, my home State of New Jersey is on the cutting edge of nanotechnology research and development. Lucent Technologies, the State of New Jersey, and the New Jersey Institute of Technology established the New Jersey Nanotechnology Consortium (NJNC) in early 2003.

The nucleus of the NJNC is the world-renowned Bell Labs nanofabrication laboratory in Murray Hill, along with the Bell Labs scientists and researchers who will become NJNC employees.

By combining the leading-edge fabrication capabilities of this laboratory with New Jersey's academic research institutions and universities, NJNC is able to carry out basic and applied nanotechnology research and it has a unique capability to bring nanotechnology ideas from concept to commercialization.

We must nurture the same type of capability at the federal level.

Nanotechnology is being touted as "the next industrial revolution" and we must maintain our lead in the field to build on and sustain our commercial advantage over competing nations. That means we need to invest in the academic community and support the work of the National Science Foundation (NSF), which leads the way in interdisciplinary efforts.

All nanotechnological advances, even the most beneficent, have what are called "externalities." The automobile, for instance, represented an enormous improvement over horse-drawn carriages. But each year, thousands of people are killed in auto accidents and hundreds of thousands more are hurt. Moreover, cars are a leading cause of greenhouse gas emissions.

I'm not suggesting that we would be better off without cars—far from it. My point is that there will be adverse consequences stemming from the development of nanotechnology.

It may not be possible to anticipate *all* of the unintended consequences of developing nanotechnology, but we should try. I applaud Senator Wyden for recognizing this and adding to S. 189 provisions for establishing a Center for Societal, Ethical, Educational, Legal and Workforce Issues Related to Nanotechnology. Clearly, the earlier we grapple with the ethical issues and harmful consequences related to nanotechnology, the better off we will be at mitigating them.

Thank you, Mr. Chairman.

PREPARED STATEMENT OF HON. JOSEPH I. LIEBERMAN, U.S. SENATOR FROM CONNECTICUT

Today, we are talking about the world's tiniest particles-and the huge, sweeping changes they could bring about for American science, technology, and business.

Nanotechnology, as you all know, is an emerging field that seeks to understand and control events at the molecular scale and develop new materials with unique properties currently beyond the realm of conventional technology. The applications-from medicine and defense to electronics, environmental protection, and energy-are endless and endlessly impressive. To give just one example, in the life sciences, building innovative tools to study biology at the nanometer scale will shed light on a vast number of now mysterious biological processes. Those fantastic voyages and others like it can lead to novel therapeutic treatments and a better fundamental understanding of diseases like cancer.

The economic impact will be equally profound. It has been estimated by the National Science Foundation that the impact of nanotechnology on existing and new manufacturing will be measured in the trillions of dollars. That could produce millions of new American jobs.

One would think the world's most innovative and ingenious economy would be the uncontested pioneer in nanotech-but unfortunately, one would be wrong. As we speak, the United States is in danger of falling behind its Asian and European counterparts in supporting the pace of nano-technological advancement. While we have the resources and talent we need, unless this talent is well organized-with big-picture vision and new collaborations between government, academia, and industry-we may find ourselves left in the wake of the next great wave of innovation.

To support ongoing nanotechnology efforts and to spur new ones, I was pleased last September to join Senators Ron Wyden and George Allen in cosponsoring the "21st Century Nanotechnology Research and Development Act," and its reintroduction in the 108th Congress this January (S. 189). This Act will build on the efforts of the National Nanotechnology Initiative (NNI), which was started under President Clinton and has received continued support under President Bush, to establish a comprehensive, national program for addressing the full spectrum of challenges confronting a successful national nanotechnology agenda.

Why is an executive initiative no longer enough? Funding for nanotechnology will soon reach $1 billion a year, with the NNI responsible for orchestrating programs across a wide range of federal agencies and departments. This level of funding and the coordination challenges that arise with so many diverse participants strongly recommend having a program based in statute, provided with greater support and coordination mechanisms, afforded a higher profile, and subjected to constructive Congressional oversight and support.

Our bill will require a carefully integrated national effort and create an independent advisory panel to help shape that effort. The National Research Council (NRC), which completed a thorough review of the NNI in 2002, specifically recommended establishing such a panel. As the field of nanotechnology covers a wide variety of disciplines including engineering, physics, chemistry and life sciences-and experts from both inside and outside academia-guidance should come from a broad and representative panel. Although members of the President's Council of Advisors on Science and Technology are highly accomplished and esteemed, they are not necessarily steeped in the fast-changing field of nanotechnology. The task of providing an advisory roll for the overall direction of the program should not be a top-down process, but rather should fall to a group of members from both academia and industry that represents the range of nanotechnology disciplines and who are well-versed in the difficult challenges facing this emerging field.

To ensure that the United States takes the lead in this new and promising field of science and technology, we must provide for the organization and guidance necessary to foster interaction between government, academia and industry. This legislation provides a strong framework to elicit contributions from all three sectors and thereby move nanotechnology research and development to the next level. I look forward to working with Senators Wyden and Allen to get this important bill through the Congress, and hope that we may all work together in a bipartisan fashion to set the stage for U.S. economic growth over the next century.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. FRANK LAUTENBERG TO JAMES R. VON EHR II

Question 1. How can new technologies best be turned into useful products? What role should the Federal Government play in this process?

Answer. Market competition is the best, most cost-competitive way of turning technology into products. The private sector excels at this, but has a short-term time horizon, and will not invest in long-term programs with a return on investment that might be captured by a competitor. Hence, there is some justification for federal involvement in long-term technology development. In order for the American people to truly benefit from nanotechnology products and applications in the next decade, the Federal Government needs to ask the question: "How can we foster real competition?" when deciding to fund programs. Are the programs we are deciding to fund focused on both fundamental and applied research?

Government funding of universities and government labs mostly funds basic fundamental scientific research, not technology development. The difference is important. Science is about understanding why something works, and doing it once to test the theory. Technology is about doing it reliably and repeatably, at an affordable cost, meeting environmental and safety standards, for a customer willing to pay for it.

Universities embrace Bayh-Dole (regarding technology ownership by universities under federal grants). This allows universities to receive federal dollars to fund research programs in which they own the IP and can license and sell this science to companies. In order to take this science and turn it into meaningful technology, companies must, in addition to paying the steep university IP license and legal fees, also invest significant funds for engineering, manufacturing, and testing.

Many companies are very frustrated and more importantly, the high-risk, high-benefit technology that could benefit the American people the most is many times not transferred because the financial risk is too great. The American taxpayers are losing out on jobs and technology benefits because of the current technology-transfer process.

We should strive to more effectively transfer university and government science to private sector technology firms. If I choose to fund a program at a university as an outsider, I am also expected to pay again to license any technology developed (the university lays claim to all intellectual property). That means I've paid once as a taxpayer, once as a funder, and once as a licensor. Three times seems excessive. If we just hire a consultant, with the same or greater expertise as a professor, our company contractually lays claim to the IP developed before hiring the consultant, and only has to pay once. We should strive to more effectively transfer university and government science to private sector technology firms.

The role of the Federal Government should be to foster our national competitiveness in the following ways:

(1) Ensure an educated populace, with a basic understanding of science and technology

(2) Continue funding basic science, but start giving "extra credit" in future funding for successful tech transfer of past research.

(3) We should NOT fund a new governmental agency or program to hire scientists and engineers and tell them to commercialize things—that won't work, because there's no competition and no personal gain for winning or personal pain for losing. Many of our foreign competitors in Europe and Asia fund governmental or quasi-governmental agencies tasked with developing technology and transferring it from labs (ironically, often labs in American universities) to local industry. Entrepreneurial business people, like we frequently see in Taiwan or China, will be first in line to catch this technology as it spins out of these entities, exploiting their advantage of cheap, educated labor and governmental assistance, instead of hindrance. We should be sure the mission of our government laboratories is clearly focused on "big science" projects that the private sector shouldn't do (like nuclear fusion), and not on things that could be done more cheaply in universities or the private sector.

(4) Our government should not "pick winners," nor engage in "corporate welfare," but we should consider helping industry in that development gap between a scientific result and a saleable product. U.S. private-sector investment time horizons are short, and investors are risk-averse. Today, we have two governmental pro-

grams, the SBIR, and the NIST–ATP, that award money competitively. Both could be improved with some minor changes:

(a) SBIR Phase 1 awards are less than $100K, which is quite small in 2003 dollars, and Phase 2 awards, while larger, are still not large enough to support collaborations required for complex projects. A well-managed company can easily decide the SBIR economics aren't worth applying for this money, and focus on more near-term, less risky opportunities with less potential reward. Significantly, the NIH funds larger SBIR Phase 1 and 2 awards to life science companies than other agencies. It would be advantageous to increase competitive SBIR awards in other agencies.

(b) On the other hand, many companies become SBIR mills, living from grant to grant without ever productizing anything. The government has started penalizing such companies in their future competitions, and should start evaluating the business case as well as the technical merits in proposals (like the NIST–ATP currently does).

(c) The NIST–ATP is nearly a model program, but has been savaged as "corporate welfare" by some detractors. However, using expert peer review for the technology component and business plan review for the business component, is how the venture capitalists invest and succeed. This program should be elevated in the Commerce Department, and professional venture capitalists recruited to help with the business plan evaluation. The role of the ATP should be as a competitive "seed fund" to incubate technologies with too long a development time to be privately funded. Again, for future applications, points could be awarded for successful commercialization of past awards, or deducted for failure to make a commercial product. The program should be funded in a more stable fashion, and funding increased in an even more competitive manner.

(d) We should, through the Homeland Security Agency, increase competitive funding through both the NIST–ATP and SBIR programs to solve our most pressing Homeland Security scientific and technical needs. The country that is dominant in Nanotechnology holds a competitive edge in this war against terrorism.

What if we do nothing?

We'll still have short-term nanotechnology technology development in the U.S., funded by private equity and private sector corporations. And the government will save money in the short run. But long-term research will migrate offshore, following the educated workforce, adequate long-term government funding, and friendly government regulation, and in 10–15 years, we'll be buying our highest technology from Asia. We won't be exporting just manual labor jobs—we will have exported our top-tier technology jobs as well. In today's dynamic world, this technology migration MIGHT happen even with such a program, but it certainly WILL happen without it.

Question 2. What role do you see for the federal government in encouraging and developing of public private partnerships and business-to-business partnerships?

Answer. It is hard to formulate a model public-private partnership, due to the immense power difference between the two parties. Even a partnership between a large company and a small one is very difficult to make work, where both parties are signed up for the same goals. The small company, as is the case with Zyvex, has to spend 10-percent of its total resources on proposals, compliances, and reporting. Our foreign competitors in Asia are able to spend more of their time competing and figuring out how to sell to more customers.

It is distressingly rare to find government and industry signed up for the same goals, so it is not surprising that we have few examples of success. Sematech is the only one that comes to mind. And Sematech participants were, if I recall, given limited exemption from antitrust laws, allowing them to work together in a way that would send non-exempted companies to antitrust court.

However, the voice of industry can be helpful to helping government spend its money more wisely, and get more return. A simple way is to assure that panels, such as the review panels for the nanotechnology program in S. 189, include representatives from large and small businesses, and not just academia and government. The voice of business would consider issues like deployment of technology, return on investment, competition, strategic partnering, and reporting burdens in a way the other representatives would not. The President's PCAST group has an incredibly strong representation by well-known big business executives and academics, but there is not much small business representation on that panel, and few members in emerging fields like biotech or nanotech.

Business-to-business partnerships are going to be increasingly important to our national competitiveness. Problems today are too big, and technology is becoming too specialized, for any but the biggest companies to stand alone. Japanese companies frequently get together independently, and with governmental ministries, to solve problems, and even plan their competitive strategy. American companies must do this very carefully, or run the risk of violating antitrust laws.

Our NIST–ATP award, with Zyvex as lead and Honeywell as our manufacturing joint venture (JV) partner, is an example of how the government can help a business-to-business relationship. Honeywell replaced our first JV partner, a small firm that fell victim to bad management and the technology recession. Before winning the ATP award, Zyvex was too small to get Honeywell's attention, but when we approached them about replacing our first JV partner, they were very receptive, even though the program required a 50-percent cost-share by both JV partners. Zyvex got a world-class MEMS (MicroElectroMechanical System—or silicon micromachines) foundry and MEMS processing engineers, and Honeywell got to work with a world-class MEMS design team at Zyvex to develop a new MEMS process enabling whole new applications. This new process may become an additional publicly-available technology to augment a particular MEMS technology (MUMPs) developed at great government expense by an American university, spun into an American company, sold to a Canadian company, and recently sold to and now controlled by a French company. This French MEMS company now runs most of the standard MEMS components American small companies and universities use to train our next generation of MEMS engineers. The Zyvex-Honeywell process could bring some of that business back to the U.S., providing superior design flexibility to MEMS designers in the process.

This development would not have happened without our NIST–ATP award. Zyvex would be working in less risky areas, and Honeywell would be developing processes only for their own internal needs. The three university subcontractors (RPI, University of North Texas, and University of Texas at Dallas) would not be working on this leading-edge technology commercialization. Other American small companies and universities would have no choice but to build their own MEMS foundry, if they were big enough, or buy the French components if they couldn't afford the required $20–50M investment.

Our NIST–ATP is one of the rare examples of government, small and big business, and universities working together toward a shared vision of developing parallel micro and nano assembly of heterogeneous systems. Although our NIST–ATP is still in the early stages, we expect significant economic benefits to come later in the program, as we demonstrate new manufacturing techniques that will lay a foundation for the U.S. to regain the lead in manufacturing.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. FRANK LAUTENBERG TO DR. E. CLAYTON TEAGUE

Question. Do you think the National Science Foundation's (NSF) current balance between funding long term research and more short-term commercial enterprises is appropriate? How would you suggest the distribution be altered?

Answer. The Federal Government has a clear role to play in funding the type of long-term, basic research that industry simply cannot support given its bottom line-directed emphasis on research and development (R&D) with nearer term benefits. While many agencies support fundamental research as part of a portfolio that includes applied research and development and is focused on the agency's mission, the National Science Foundation (NSF) is charged with supporting research across the entire range of scientific and engineering disciplines—a unique role. NSF Director Rita Colwell has described the agency's mission as "to keep science and engineering visionaries focused on the furthest frontier, to recognize and nurture emerging fields, to prepare the next generation of scientific talent, and to ensure that all Americans gain an understanding of what science and technology have to offer." The agency's focus on fundamental research has resulted not only in breakthroughs of importance to researchers, but has also contributed to discoveries with tremendous societal and commercial significance—such as the Internet and Magnetic Resonance Imaging (MRI).

In keeping with its mission, NSF has directed the lion's share of its nanotechnology-focused resources toward the support of long term, fundamental research, much of which goes to academic institutions. NSF's nanotechnology research funding is distributed among seven research and education themes including nanobiosystems, novel processes and materials, novel device and systems architecture, modeling and simulation, manufacturing science, nanoscale processes in the environment, and societal implications, and is awarded based on a competitive, merit review-driven process.

Considering NSF's charge, the current ratio of long-term vs. short-term funding is appropriate. It is also consistent with a recommendation of the National Research Council (NRC) in their report *Small Wonders, Endless Frontiers: A Review of the National Nanotechnology Initiative*. Specifically, the NRC recommended that the National Nanotechnology Initiative should support long-term funding in nanoscale science and technology, saying "if an idea is truly revolutionary and promises higher impact successes, a longer period—and longer term funding—is needed to demonstrate results."

At the same time, NSF makes awards to small businesses as part of the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, in order to help support technology transfer and development. In FY 2002, NSF funded approximately $10 million worth of SBIR and STTR grants related to nanotechnology. NSF also funds, using a competitive, merit review-based process, centers and networks of excellence that bring together researchers from different organizations—including industry—to address nanotechnology research questions and to enhance the transition of basic research into applications and commercialization. These centers arid networks provide access to advanced instrumentation and computation capabilities, and are focused on topics such as nanobiology, environmental engineering, molecular electronics, and others. The President requested $46 million for these NSF centers in the FY 2004 Budget. Other agencies, notably the Department of Energy and the Department of Defense, sponsor additional multiuser facilities.

In addition, as part of the multi-agency Nanoscale Science, Engineering and Technology Subcommittee of the National Science and Technology Council, NSF arid the other member agencies sponsor workshops aimed at facilitating interactions amongst government and university researchers and representatives from industry in order to promote the commercialization of federally-funded research results.

Finally, it is worth noting that commercialization of federally-funded, long-term research at academic institutions and other enterprises occurs regularly. Universities and other non-profit organizations are increasingly engaged in efforts to commercialize the results of Federally-funded research, Many, if not most, research universities now have active technology licensing offices that seek to license and commercialize university-owned intellectual property.

Response to the following questions submitted by Hon. John McCain was not available at the time this hearing went to press.

WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO DR. JAMES MURDAY

Question 1. Based on your experience as the first director of the National Nanotechnology Coordination Office (NNCO), what kind of response does NNCO usually get from participating agencies?

Question 2. S. 189 would codify the NNCO. What functions should NNCO be directed in statute to specifically carry out?

Question 3. Your testimony states that the Department of Defense has nanoscience programs that are 20 years old. Do the National Nanotechnology Initiative (NNI) and NNCO run adequately designed programs that facilitate the transmission of lessons learned and "best practices" from more established government nanoscience research programs, such as the DOD one, to agencies that have not been studying the area for such a long time?

Question 4. Based on your experience in the Office of Naval Research and NNCO, what are best practices that agencies should pursue to successfully transfer nanoscience research to practical technology applications?

Question 5. When you were director of the NNCO, what were the greatest challenges to the transfer of nanotechnology to the commercial sector?

WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO DR. JAMES ROBERTO

Question 1. Given your position at the Oak Ridge National Laboratory, do you feel that the federal research infrastructure is adequate at this point to support the level of funding that is being proposed for nanotechnology research?

Question 2. You mentioned in your statement that the boundaries between disciplines are disappearing at the nanoscale.

a) Is this the beginning of a new discipline area for the colleges and universities?

b) If so, are you aware of any schools which have already started degree programs in this area?

Question 3. The Department of Energy has Nanoscale Research Centers that are designed to be "user facilities" for use by U.S. industry researchers. How has industry utilized these research centers?

Question 4. How does the Department of Energy's nanoscale research tie into the President's FreedomCAR Initiative?

Question 5. What are the greatest barriers today to the application of greater nanoscale research to the commercial sector?

Question 6. Based on the research that you have conducted, what are some of the short-term, mid-range, and long-term results that the average American consumer should see from energy-related nanotechnology research?

WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO DR. E. CLAYTON TEAGUE

Question 1. The Administration proposes reconstituting the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee with higher level agency management. What benefits do you believe will be achieved by this plan?

Question 2. One objective of the National Nanotechnology Coordination Office (NNCO) is to assure the broadest possible geographical distribution of the benefits of nanotechnology development, and work with state nanotechnology initiatives. Considering that many states are facing budgetary challenges this year, how much support has there been in the states for nanotechnology initiatives?

Question 3. Your testimony states that the National Science Foundation (NSF) has added a new research and education theme on "manufacturing at the nanoscale," and that the program element "Nanomanufacturing" has been established in the Directorate of Engineering. What are some of the topics that are being researched in the field on "nanomanufacturing"?

Question 4. You have outlined some of the challenges that still face basic nanoscale processes, such as the need to develop the understanding and tools for the full control of assembling reasonably large numbers of atoms into desired structures. What are some of the other basic research areas that require greater research in order to develop commercial applications of nanotechnology?

Question 5. S. 189 would establish a Center for Societal, Ethical, Educational, Legal, and Workforce Issues. Are there specific issues that you believe this center should be directed to study?

WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO DR. DAVIS BAIRD

Question 1. What changes to S. 189 would you recommend to ensure that social and ethical concerns are properly addressed?

Question 2. Your testimony brings up the sensational warnings of Michael Crichton and Bill Joy about the dangers of nanotechnology research. How should government officials, academic researchers, and private sector companies engaged in nanotechnology research constructively address these warnings?

Question 3. What new discoveries in the social and ethical areas of nanotechnology are you learning from your work at the University of South Carolina that may warrant a change in the future course of the nanoresearch programs?

WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO DR. JUN JIAO

Question 1. Can you discuss the extent of your partnerships with industry concerning your research? Are they for funding support or commercialization agreements?

Question 2. You spoke about the excitement of students in this area at both the college and the high school level. Here in the Senate, we often hear stories about how U.S. students are not interested in math and science. Your experience seems to contradict that. Can you comment on this?

Question 3. Your testimony emphasizes the importance of education for the future nanotechnology workforce. What type of educational background and skills will be required?

WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO DR. KENT A. MURPHY

Question 1. You have mentioned Bayh-Dole as a great start. What changes would you recommended to Bayh-Dole to facilitate even greater technology transfer? Does the transfer of nanotechnologies have unique requirements?

Question 2. Your statement indicates that Luna has generated $6 of private sector funding for $1 of government funding. Can you elaborate on the importance of this 6.1 ratio and how you have been able to accomplish that?

Question 3. Luna has been able to spin-off five companies since 1999 in various high tech areas. Luna was presented the prestigious Tibbets award by the U.S. Small Business Association for its work in research and development. It appears that Luna has positioned itself to commercialize new technologies as they become viable for commercial use. Can you comment on your business model and what lessons others, including the government, may be able to learn from your success?

Question 4. As a company that's engaged in the nanotechnology business, can you identify a federal source that you can contact for information on the latest concerning federally funded activities in this area?

Question 5. Can you discuss an application of nanomaterials in which your company has generated revenues?

Question 6. You mentioned that Virginia was the first state to establish the position of Secretary of Technology. What has that meant for the technology companies of the state?

WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO JAMES R. VON EHR II

Question 1. Questions have been raised about the industrialization of nanotechnolgy research, such as factory design, issues regarding the health of workers, and worker skill level. Could you please comment on these issues, and how Zyvex is addressing them?

Question 2. Many nanotechnology companies are still in the start-up phase. Based on your experience, what strategies should start-up companies use to attract investors and generate a profit?

Question 3. What impact did the failures of Internet companies have on other technology start-up companies?

Question 4. What changes would you recommend to Bayh-Dole and other statutes to facilitate greater technology transfer?

Question 5. You mentioned that Craig Venter framed the sequencing of the human genome as a business problem, and not a scientific problem. He then proceeded to solve it. Can you discuss what it means to approach the problem as a business problem and not a scientific one?

Question 6. Can you discuss why 5 years will be too long for the availablity of new government labs to support nanotechnology research?

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