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NANOTECHNOLOGY

HEARING

BEFORE THE

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

ONE HUNDRED SEVENTH CONGRESS

SECOND SESSION

SEPTEMBER 17, 2002

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ONE HUNDRED SEVENTH CONGRESS

SECOND SESSION

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NANOTECHNOLOGY

TUESDAY, SEPTEMBER 17, 2002

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

The Subcommittee met, pursuant to notice, at 2:35 p.m. in room SR–253, Russell Senate Office Building, Hon. Ron Wyden, Chairman of the Subcommittee, presiding.

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

Senator WYDEN. Today, the Subcommittee on Science, Technology, and Space convenes the first ever Senate hearing on nanotechnology. Certainly in coffee shops and senior centers this afternoon Americans are not exactly buzzing about this science of building electronic circuits and devices from single atoms and molecules, but there is no question that this field will dramatically change the way the American people live.

Today, I have introduced legislation on this issue with my distinguished colleague, the Senator from Virginia, and others. He and I have been pursuing all of these important technology issues on a bipartisan basis throughout the session, and I want to thank him for his support and also note that Senator Lieberman, Senator Landrieu and Senator Clinton are original sponsors of our bipartisan legislation as well.

My own judgment is that the nanotechnology revolution has the potential to change America on a scale that is equal to if not greater than, the computer revolution. As chair of this Subcommittee, I am determined the United States will not miss the opportunities in this exciting field. At present, efforts in the nanotechnology area are strewn across a half-dozen Federal agencies. I believe it is critical that the Government marshall its various nanotechnology efforts in one driving force to become the Nation's leader in this burgeoning field, and I am of the view that Federal support is essential to achieving the goal.

The legislation that we have introduced today will provide a smart, accelerated, and organized approach to nanotechnology research, development, and education. In my view, there are three major steps that need to be taken. First, a national nanotechnology research program should be established to superintend long-term, fundamental nanoscience and engineering research. The program's goals are to ensure America's leadership and economic competitiveness in nanotechnology, and to make sure that the ethical and social concerns are taken into account, alongside the development of the discipline.

Second, the Federal Government should support nanoscience through a program of research grants and also through the establishment of nanotechnology research centers. These centers would serve as key components of a national research infrastructure, bringing together experts from the various disciplines that must intersect for nanoscale projects to succeed. As these research efforts take shape, educational opportunities will be key to their success.

In this hearing room, I have already laid out a challenge to triple the number of people graduating with math, science, and technology degrees. Today, I commit to helping students who would enter the field of nanotechnology. This discipline requires multiple areas of expertise. Students with the drive and the talent to pursue physics, chemistry, and materials science, simultaneously, deserve all the support that we can offer.

Third, the Government should create connections across agencies to mesh the various ongoing nanotechnology efforts. These should include a national steering office, a Presidential Nanotechnology Advisory Committee modeled on the President's Information Technology Advisory Committee. I also believe that as these organizational support structures are put in place, rigorous evaluation must take place to ensure the maximum efficiency of our efforts. Personally, I would call for an annual review of America's nanotechnology efforts from the presidential advisory committee and a periodic review from the National Academy of Sciences.

In addition to monitoring our own progress, the Government should keep abreast of the world's nanotechnology efforts through benchmarking studies. If the Federal Government fails to get behind nanotechnology today with organized goal-centered support, the country runs the risk of falling behind other nations. Nanotechnology is already making pants more stain-resistant, more windows self-washing, and making car parts stronger with tiny particles of clay.

America risks missing the next generation of nanotechnology. In the next wave, nanoparticles and nanodevices will be the building blocks of health care, agriculture, manufacturing, environmental cleanup, and even national security. America does risk missing a revolution in electronics where a device the size of a sugar cube could hold all of the information in the Library of Congress. Today's silicon-based technologies can only shrink so small. Eventually, nanotechnology will grow devices from the molecular level up. Small though they may be, their capabilities and their impacts are going to be enormous. Spacecraft could be the size of mere molecules.

America risks missing a revolution in health care. In my home State, Oregon State University researchers are working at the microscale to create lapel pin-sized biosensors that use the color-changing cells of the Siamese fighting fish to provide instant visual warnings when a biotoxin is present. An antimicrobial dressing for battlefield wounds is already available today, containing silver and nanocrystals that prevent infection and reduce inflammation.

The health care possibilities are limitless. Eventually, nanoscale particles will travel through human bodies to detect internal disease. Chemotherapy could attack individual cancer cells and leave healthy cells intact. Tiny bulldozers could unclog blocked arteries. Human disease would be fought cell by cell, molecule by molecule, and nanotechnologies would provide victories over disease that cannot be imagined today.

So America does risk missing a host of beneficial breakthroughs. America's scientists could be the first to create nanomaterials for manufacturing and design that are stronger, lighter, harder, self-repairing, and safer. Nanoscale devices could scrub automobile pollution out of the air as it is produced. Nanoparticles could cover armor to make America's soldiers almost invisible to enemies, and incredibly enough, tend to their wounds. Nanotechnology could grow steel stronger than what is made today with little or no waste to pollute the environment.

And especially, there is an extraordinary opportunity to promote more jobs and an economic revolution. With much of nanotechnology now existing in a research surrounding, venture capitalists are already investing $1 billion in American nanotech interests this year alone. It is estimated that nanotechnology will become a trillion dollar industry over the next 10 years. As the field grows, the ranks of skilled workers needed to discover and apply its capabilities have to grow as well. In the nanotechnology revolution, areas of high unemployment could become magnets for domestic production, engineering, and research for nanotechnology applications, but only if the Government does not miss the boat.

The National Nanotechnology Initiative is clearly a step in the right direction. Significant funds have already been committed to nanotechnology research and development, and what we need to make clear is that funding is not enough. There has to be careful planning to make sure that the money is used for sound science over the long term. That is the reason for the bipartisan legislation that Senator Allen and I have teamed up on today.

I am going to put the rest of this statement that I have, and a lengthy one it is, into the record, and recognize my colleague. As I say, it has been a pleasure to team up with Senator Allen on a host of these technology questions. This is one that I think is going to be particularly exciting in States like Virginia and Oregon, where there are already pioneering efforts underway, and I want to again express my appreciation to my colleague.

[The prepared statement of Senator Wyden follows:]

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

Today the Subcommittee on Science, Technology and Space convenes the first-ever Senate hearing on nanotechnology. In coffee shops and senior centers this afternoon, Americans aren't exactly buzzing about this science of building electronic circuits and devices from single atoms and molecules. But there's no question that this field will dramatically change the way Americans live.

My own judgment is the nanotechnology revolution has the potential to change America on a scale equal to, if not greater than, the computer revolution. As Chair of this Subcomittee, I am determined that the United States will not miss, but will mine the opportunities of nanotechnology. At present, efforts in the nanotechnology field are strewn across a half-dozen Federal agencies. I want America to marshal its various nanotechnology efforts into one driving force to remain the world's leader in this burgeoning field. And I believe Federal support is essential to achieving that goal.

Legislation I am introducing today will provide a smart, accelerated, and organized approach to nanotechnology research, development, and education. In my view, there are three major steps America must take to ensure the highest success for its nanotechnology efforts.

First, a National Nanotechnology Research Program should be established to superintend long-term fundamental nanoscience and engineering research. The program's goals will be to ensure America's leadership and economic competitiveness in nanotechnology, and to make sure ethical and social concerns are taken into account alongside the development of this discipline.

Second, the Federal government should support nanoscience through a program of research grants, and also through the establishment of nanotechnology research centers. These centers would serve as key components of a national research infrastructure, bringing together experts from the various disciplines that must intersect for nanoscale projects to succeed. As these research efforts take shape, educational opportunities will be the key to their long-term success.

In this hearing room, I have already laid out a challenge to triple the number of people graduating with math, science and technology degrees. Today, I commit to helping students who would enter the field of nanotechnology. This discipline requires multiple areas of expertise. Students with the drive and the talent to tackle physics, chemistry, and the material sciences simultaneously deserve all the support we can offer.

Third, the government should create connections across its agencies to aid in the meshing of various nanotechnology efforts. These could include a national steering office, and a Presidential Nanotechnology Advisory Committee, modeled on the President's Information Technology Advisory Committee.

I also believe that as these organizational support structures are put into place, rigorous evaluation must take place to ensure the maximum efficiency of our efforts. Personally, I would call for an annual review of America's nanotechnology efforts from the Presidential Advisory Committee, and a periodic review from the National Academy of Sciences. In addition to monitoring our own progress, the U.S. should keep abreast of the world's nanotechnology efforts through a series of benchmarking studies.

If the Federal government fails to get behind nanotechnology now with organized, goal-oriented support, this nation runs the risk of falling behind others in the world who recognize the potential of this discipline. Nanotechnology is already making pants more stain-resistant, making windows self-washing and making car parts stronger with tiny particles of clay. What America risks missing is the next generation of nanotechnology. In the next wave, nanoparticles and nanodevices will become the building blocks of our health care, agriculture, manufacturing, environmental cleanup, and even national security.

America risks missing a revolution in electronics, where a device the size of a sugar cube could hold all of the information in the Library of Congress. Today's silicon-based technologies can only shrink so small. Eventually, nanotechnologies will grow devices from the molecular level up. Small though they may be, their capabilities and their impact will be enormous. Spacecraft could be the size of mere molecules.

America risks missing a revolution in health care. In my home state, Oregon State University researchers are working on the microscale to create lapel-pin-sized biosensors that use the color-changing cells of the Siamese fighting fish to provide instant visual warnings when a biotoxin is present. An antimicrobial dressing for battlefield wounds is already available today, containing silver nanocrystals that prevent infection and reduce inflammation. The health care possibilities for nanotechnology are limitless. Eventually, nanoscale particles will travel through human bodies to detect and cure disease. Chemotherapy could attack individual cancer cells and leave healthy cells intact. Tiny bulldozers could unclog blocked arteries. Human disease will be fought cell by cell, molecule by molecule—and nanotechnology will provide victories over disease that we can't even conceive today.

America risks missing a host of beneficial breakthroughs. American scientists could be the first to create nanomaterials for manufacturing and design that are stronger, lighter, harder, self-repairing, and safer. Nanoscale devices could scrub automobile pollution out of the air as it is produced. Nanoparticles could cover armor to makes American soldiers almost invisible to enemies and even tend their wounds. Nanotechnology could grow steel stronger than what's made today, with little or no waste to pollute the environment.

Moreover—and this is key—America risks missing an economic revolution based on nanotechnology. With much of nanotechnology existing in a research milieu, venture capitalists are already investing $1 billion in American nanotech interests this year alone. It's estimated that nanotechnology will become a trillion-dollar industry over the next ten years. As nanotechnology grows, the ranks of skilled workers needed to discover and apply its capabilities must grow too. In the nanotechnology revolution, areas of high unemployment could become magnets for domestic production, engineering and research for nanotechnology applications—but only if government doesn't miss the boat.

Our country's National Nanotechnology Initiative is a step in the right direction. This nation has already committed substantial funds to nanotechnology research and development in the coming years. But funding is not enough. There must be careful planning to make sure that money is used for sound science over the long-term. That is the reason for the legislation I am issuing today. The strategic planning it prescribes will ensure that scientists get the support they need to realize nanotechnology's greatest potential.

In 1944 the visionary President Franklin Delano Roosevelt requested a leading American scientist's opinion on advancing the United States' scientific efforts to benefit the world. Dr. Vannevar Bush offered his reply to President Harry S. Truman the next year, following FDR's death. In his report to the President, Dr. Bush wrote, "The Government should accept new responsibilities for promoting the flow of new scientific knowledge and the development of scientific talent in our youth. These responsibilities are the proper concern of the Government, for they vitally affect our health, our jobs, and our national security. It is in keeping also with basic United States policy that the Government should foster the opening of new frontiers and this is the modern way to do it."

Those principles, so true nearly sixty years ago, are truer still today. I propose that the government now accept new responsibilities in promoting and developing nanotechnology. Our witnesses today will make it clear that nanotechnology will vitally affect our health, our jobs, and our national security—as well as our economy. I look forward to hearing from them on how this Congress might take up what I believe is a proper concern—and an essential one—indeed.

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

Senator ALLEN. Thank you, Mr. Chairman, and I want to thank you for calling today's hearing. I want to share your enthusiasm about today's prospect as well as many other matters. We worked as leaders in a bipartisan manner to try to get our colleagues in the Senate and, indeed, the whole Federal Government to address many important needs of our country, especially in the areas of science and space and technology. I look forward to listening to our panel of experts. I know that one, Dr. Swami, is from Virginia, and there is a great deal of promise here. I think it is exciting, because it is not just a matter of jobs, which is great, but it is truly improving our lives, our communications, our material sciences, and many other areas.

We had a hearing in this Committee earlier about the importance of basic scientific research and whether or not Congress should consider doubling the budget for the National Science Foundation, and in the midst of that hearing, one of the more intriguing conversations was the discussion on nanotechnology, and those witnesses were saying, pay attention to that and, of course, you and I were, and in fact in preparing for this I looked back to a speech I gave in April of last year, and my view is, nanotechnology is quickly transforming every corner of our modern world and has already—as you gave some of the examples, already transforming and improving the quality of our life.

Whether it is electronic devices in computers to health care, pharmaceuticals, agriculture, energy, or national defense, nanoscience is really at the foundation and will be at the foundation of many of these revolutionary advances and discoveries in the decades to come. Some will be years to come, some decades to come, but it is certainly going to occupy a major portion of our technology economy. It is that promise, it is that potential that should impel us as Americans, in a land that has always historically valued and encouraged innovation and entrepreneurship, that we embrace and support this research and this work.

Our Nation has been at the forefront of virtually every important and transformative technology since the Industrial Revolution, and we must continue to lead the world in the new frontier of nanoscience, and that is why, Mr. Chairman, I am so proud and enthusiastically joining with you in supporting and introducing the 21st Century Nanotechnology Research and Development Act. I think it is vitally important for the future of our country, for our competitive edge.

Maybe some people will wonder what in the world is nanotechnology. We will get a definition of nanotechnology. It is typically defined by size, and the science of nanotechnology is really the ability to pick and place and manipulate atoms one one-hundred thousandth times smaller than the width of a human hair. So pull one of these out of your head.

Senator WYDEN. I do not have any left. I have given them to this cause.

[Laughter.]

Senator ALLEN. What a personal commitment.

[Laughter.]

Senator ALLEN. They are one one-hundredth times smaller than the width of a human hair. Of course, you would have to look at that under a microscope. You probably could not see it with the naked eye, but this is going to generate these materials and the fundamentally new and superior methods of science for us, and to improve our lives, so I agree with everything you said, Mr. Chairman, and I look forward to working with you and this Committee in making sure that the United States leads in this, as well as other areas. If we are going to lead, we have to be well-coordinated. We need a game plan.

We do not just—obviously there is more funding in our act, and it is consistent with President Bush's initiatives as well, but we do want to have measurement, also recognizing in this that many of these developments and improvements in the marketing of these advancements may be decades down the road, but this is what I think the taxpayers of the United States Government would like us to do. And we look forward to listening to this esteemed panel as to how we can make sure that the Federal Government, working with the private sector, working with colleges and universities and the scientists therein, to make sure we have the right fertile ground conditions present for the collaboration that is needed for us to move forward in this area.

Again, I thank you for this hearing, and thank these fine gentlemen for sharing their views with us.

Senator WYDEN. I thank my colleague for an excellent statement, we have got a big job ahead of us in terms of educating the Senate on these issues, and I look forward to tackling them with you.

So we will introduce our panelists. We will begin with Hon. Richard Russell, Associate Director for Technology, Office of Science and Technology Policy; and then we will have Mr. Mark Modzelewski, executive director of the NanoBusiness Alliance; and then Dr. Samuel Stupp, Board of Trustees Professor in materials science, chemistry, and engineering at Northwestern; Dr. Stan Williams, HP fellow and director of quantum science research at Hewlett-Packard; and Dr. Nathan Swami, Director of the Initiative for Nanotechnology, Commonwealth of Virginia, and the microelectronics program director at the University of Virginia.

Gentlemen, we welcome all of you. We are going to put your prepared statements into the record in their entirety, and I know that at these hearings there is almost a physical compulsion to just read, word for word, everything that is down in your statement, and I think in the interest of more having a free-flowing discussion, if I can talk you into summarizing some of your big concerns so that we can have a discussion about some of the issues, we will make your prepared statement a part of the hearing record in its entirety. Why don't you take, each of you, 5 minutes or so, and we will proceed with you.

Mr. Russell, welcome.

STATEMENT OF HON. RICHARD M. RUSSELL, ASSOCIATE DIRECTOR FOR TECHNOLOGY, OFFICE OF SCIENCE AND TECHNOLOGY POLICY

Mr. RUSSELL. Thank you, Mr. Chairman and Senator Allen, for this opportunity to testify about the National Nanotechnology Initiative and the importance of nanotechnology research. I agree with you wholeheartedly that this is a tremendously important area and a tremendously exciting area for us to be looking at. Properties that govern physics of materials and artifacts at the nanoscale can differ significantly from those at more conventional scales. As a result, nanotechnology represents more than simply another step in the progression of technology miniaturization.

Looking to the future, commercialization of nanotechnology is expected to lead to new products and in some cases the creation of new markets and applications as diverse as materials and manufacturing electronics, biotechnology, information technology, and national security. New discoveries in nanotechnology are being made on a regular basis.

Just last week, and I am sure we will hear from the other panelists, Hewlett-Packard announced a breakthrough in molecular electronics through a joint Federal/industry-funded project at UCLA. The team pioneered a method to fabricate closely spaced nanoscale wires. This novel device represents a major breakthrough in memory storage density.

Another example of great promise is federally funded BioCOM chip under development at UC Berkeley. This device allows for real-time blood screening for prostate cancer. Though still in the prototype stage, this device and others like it promise to improve significantly medical diagnostics.

Nanotechnology is still at a very early stage of development. The role of Federal R&D funding in this area is to provide the fundamental research underpinnings on which future commercial nanoscale technologies could be based. Numerous challenges must be addressed before the envisioned promise of these technologies can be reached. These challenges include fundamental research to improve our understanding in several fields of science and engineering as well as synthesis, analysis and manufacturing of nanoscale-based products.

Because of its significant potential impacts on the physical sciences, life sciences, and engineering and more broadly on the United States' economy and society, nanotechnology is viewed by the Bush administration as an important component of the Federal research and development portfolio. The President requested a 17-percent increase for nanotechnology research in fiscal year 2003.

The administration's ongoing support for nanotechnology was also articulated through a joint guidance memorandum issued to heads of Federal science and technology agencies from OSTP and OMB, which specifically identified nanotechnology as 1 of 6 interagency R&D priorities for 2004. Federal funding for nanotechnology is focused through NNI. NNI is an interagency program that encompasses relevant nanotechnology R&D-participating Federal agencies.

The research agenda for the 9 agencies currently participating in NNI is coordinated by the Nanoscale Science and Engineering Technology Subcommittee, or NSET, which is part of the National Science and Technology Council. The National Nanotechnology Coordinating Office assists NSET-participating agencies in coordinating their nanotechnology funding. It also serves as the secretariat for NNI. The coordinating office carries out the objectives established by NSET members, coordinates and publishes information for workshops sponsored by NNI, and prepares annual reports on the activities of NNI. The coordinating office also contracts for program reviews to provide feedback on NNI.

NNI funding provides support for a range of activities which include basic research, grant challenges, research infrastructure and centers, and networks of excellence, which are centralized facilities intended to provide sites for cooperative research amongst groups of researchers from multiple institutions. NNI funding is also used to address nontechnical research problems in the broader context, including societal implications and workforce and training issues that will likely emerge in relation to nanotechnology.

The National Research Council recently completed a report on NNI. The report highlighted the strong leadership of NNI, praising the degree of interagency collaboration and the early successes of the research programs. The report also provided a number of recommendations to further strengthen NNI.

OSTP is working through the coordinating office and the NSTC to improve the structure of NNI, and to create a strong framework for implementing NNI's technical objectives. NNI's early program success and positive independent review by the NRC provides a sound justification for continued support in this important research field. With a history of only 2 years, the ultimate impact of NNI lies in the future, and will only be realized through continued Federal R&D funding.

Mr. Chairman, Senator Allen, the administration supports nanotechnology research, the NNI program, and I look forward to working with the Committee on this important research.

[The prepared statement of Mr. Russell follows:]

PREPARED STATEMENT OF HON. RICHARD M. RUSSELL, ASSOCIATE DIRECTOR FOR TECHNOLOGY, OFFICE OF SCIENCE AND TECHNOLOGY POLICY

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to appear before you today to speak about the National Nanotechnology Initiative (NNI).

Nanotechnology is research and development at the nanoscale—a scale on the order of 10^{-9} meters, or a thousandth of a millionth of a meter. To provide some perspective, this is approximately 1/100,000 the diameter of the average human hair. Research in nanotechnology is contributing to a fundamentally new understanding of the unique properties that occur on the nanoscale. The properties and governing physics of materials and artifacts at the nanoscale can differ significantly from those at more conventional scales. As a result, nanotechnology represents more than simply another step in the progression of technology miniaturization.

Looking to the future, commercialization of nanotechnology is expected to lead to new products, and in some cases the creation of new markets, in applications as diverse as materials and manufacturing, electronics, medicine and healthcare, environment, energy, chemicals, biotechnology, agriculture, information technology, transportation, national security, and others. Nanotechnology will likely have a broad and fundamental impact on many sectors of the economy. Some have even suggested that this impact will surpass the combined impact of both biotech and information technology.

New discoveries are being made on a regular basis. Just last week (9/10/02), researchers at Hewlett Packard announced a nanotechnology breakthrough in molecular electronics. Through a joint federal/industry funded project at the University of California at Los Angeles, the team pioneered a method to fabricate nanoscale wires separated by a thousand molecules. This novel device represents a major breakthrough in memory storage density that heralds a new era in microelectronic miniaturization. It serves as a prime example of the promise—and the challenge—posed by nanotechnology. This includes the promise of new materials, new devices, and new processes that will enable continued growth in our high tech industries. But it also highlights the challenge of understanding nanoscale phenomena, reliably producing nanoscale structures and systems, and converting this new knowledge into new technologies that contribute to our economic prosperity.

Another example of great promise is the federally funded BioCOM chip under development at the University of California at Berkeley. This device combines elements of both the nano- and the micro-scale into a lab-on-a-chip package that provides a new tool for real-time sampling of blood for Prostate Specific Antigen (PSA) screening. Though still in the prototype stage, this device, and others like it, promise to revolutionize medicine. These developments are leading to new sensors that will be utilized in medicine as well as homeland security, broadly contributing to healthcare, economic strength, and national security.

Nanotechnology is still at a very early stage of development. The role of federal R&D funding in this area is to provide the fundamental research underpinnings upon which future commercial nanoscale technologies will be based. Numerous challenges must be addressed before the envisioned promise of these technologies can be reached. These challenges include fundamental research to improve our basic understanding in several fields of science and engineering, as well as novel approaches toward synthesis, analysis and manufacturing of nanotechnology-based products. Because of the complexity, cost, and high risk associated with these issues, the private sector is often unable to assure itself of short-to-medium term returns on R&D investments. Consequently, industry is not likely to undertake the basic research investments necessary to overcome the technical barriers that currently face the nanotechnology field. The NNI program is structured to overcome these barriers so that America's industries will prosper from our investment in nanotechnology.

The President's FY 2003 budget represents a record request for federally funded R&D ($112 billion), an increase of eight percent over the previous investment. Because of its significant potential impact on the physical sciences, life sciences, and engineering—and more broadly on the U.S. economy and society—nanotechnology is viewed by the Bush Administration as an important component of the federal research and development (R&D) portfolio. Funding for nanotechnology was increased seventeen percent in the FY 2003 request ($679 million). In the previous fiscal year, President Bush signed into law a thirty seven percent increase in the NNI budget (from $464 million to $579 million).

The Administration's ongoing support for nanotechnology was articulated through a joint guidance memorandum issued to heads of Federal science and technology agencies from John H. Marburger III, Director of OSTP, and Mitchell Daniels, Director of the Office of Management and Budget, which specifically identified nanotechnology as one of six interagency R&D priorities for FY 2004.

Federal funding for nanotechnology is focused through the National Nanotechnology Initiative (NNI). The NNI is an interagency program that encompasses relevant nanotechnology R&D among the participating Federal agencies. The research agenda for the nine agencies currently participating in the NNI is coordinated by the Nanoscale Science and Engineering Technology (NSET) Subcommittee of the National Science and Technology Council (NSTC). The NSET is staffed by representatives of the participating agencies, OSTP, OMB, as well as other Federal agencies that lack relevant R&D programs but which have an interest in these technologies. NSET members meet on a monthly basis to measure progress, set priorities, organize workshops, and plan for the coming year. The National Nanotechnology Coordination Office (NNCO) assists NSET-participating agencies in coordinating their nanotechnology funding. It also serves as the secretariat for the NNI. The NNCO carries out the objectives established by the NSET members, coordinates and publishes information from workshops sponsored by the NNI, and prepares annual reports on the activities of the NNI. The NNCO also contracts for program reviews to provide feedback on the NNI.

The federal agencies currently performing nanotechnology research coordinated through the NNI are:

- Department of Defense;
- Department of Energy;
- Department of Justice;
- Department of Transportation;
- Environmental Protection Agency;
- National Aeronautics and Space Administration;
- National Institutes of Health;
- National Institute of Standards and Technology; and
- National Science Foundation.

This funding provides support for a range of activities, which include: basic research, focused efforts directed at answering specific sets of questions of high significance—so-called "grand challenges," research infrastructure (instrumentation, equipment, facilities), and centers and networks of excellence, which are 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 is being used to support mission-oriented research within agencies, research at national laboratories, or to support research at academic institutions. A small 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 that will likely emerge in relation to nanotechnology.

The National Research Council (NRC) conducted an evaluation study of the NNI from mid-2001 to mid-2002. Earlier this summer, the NRC released the results of this study in a report entitled *Small Wonders, Endless Frontiers: A Review of the National Nanotechnology Initiative*. The report highlighted the strong leadership of the NNI, praised the degree of interagency collaboration, and lauded the early successes of the research programs. The report also provided a number of recommendations to further strengthen the NNI. OSTP is working closely with the NNCO, as well as through its representation on the NSTC's Nanoscale Science and Engineering Technology Subcommittee, to improve the structure of the NNI, and to create a stronger framework for implementing the NNI's technical objectives. One recommendation of the NRC was to create an independent Nanoscience and Nanotechnology Advisory Board (NNAB) to provide input to the NSET members. OSTP believes that this function can be met through the President's Council of Advisors and Science and Technology (PCAST). As you know, PCAST members represent a distinguished cross section of industry and academia and have always functioned as an external advisory board on science and technology issues of relevance to the nation. They are clearly qualified to carry out such functions for nanotechnology.

The NNI was initiated in FY 2001. The early program successes and positive independent review by the NRC provide a sound justification for continued support in this important research field. With a history of only two years, the ultimate impact of the NNI lies in the future and will only be realized through continued federal R&D funding.

Mr. Chairman and Members of the Committee, I hope that this overview has conveyed this Administration's commitment to nanotechnology and the NNI program. OSTP is actively working with the NNCO to implement many of the NRC recommendations. We believe that our efforts will improve the program substantially and will enhance our investment in nanotechnology.

Senator WYDEN. Thank you. Mr. Modzelewski.

STATEMENT OF F. MARK MODZELEWSKI, EXECUTIVE DIRECTOR, NANOBUSINESS ALLIANCE

Mr. MODZELEWSKI. Mr. Chairman, Senator Allen, I thank you for allowing me, on behalf of the NanoBusiness Alliance, the member organizations, the opportunity to testify before you on the topic of nanotechnology as a transition from a science into a business.

Nanotechnology is rapidly becoming an industrial revolution for the 21st Century. However, today's nanotech industry might best be compared to the computer industry of the 1960s before the integrated circuit, or the biotech industry of the 1970s. While many nanotechnology sectors are in the nascent stages, others are already delivering products to market. A variety of nanomaterials, for instance, including enhanced polymers, coatings, and fillers, are already available, producing revenues and profits, and advanced nanotechnology medical and electronics applications will be imminently impacting our lives.

As production of nanoproducts becomes easier, faster, and cheaper, every market sector will begin to feel the impact. We at the NanoBusiness Alliance estimate that the global market for nanotechnology-related products and services could reach more than $225 billion by 2005. The NSF conservatively predicts a $1 trillion global market for nanotechnology in a little over a decade.

Since its inception, the National Nanotechnology Initiative has proven to be an incredible instance of Government outpacing the imagination of the private sector. Mike Roco, Jim Murday, and the other individuals who created and continue to advance the NNI should be highly commended. That is why the NanoBusiness Alliance and its members would like to enthusiastically endorse the 21st Century Nanotechnology Research & Development Act that is being introduced today by the Chairman and Senator Allen. This will be a timely and vital bill that builds on the fine work of the NNI and will assist America's long-term scientific and economic competitiveness in this field.

Currently, nanotechnology is becoming nanobusiness faster than anyone could have ever imagined. Just 5 years ago, only a few corporate visionaries, IBM, HP, Texas Instruments among them, were undertaking any research and development in the nanosciences. Today, you would be hard pressed to find a member of the Fortune 500 that does manufacturing without some nanotechnology effort underway. GM, GE, Siemens, Intel, Hitachi, Dow have all launched significant nanotechnology initiatives.

Unlike the dot com era, nanotech startups are built on science, and they are out there. They have real technology and real assets, and more often than not they are founded by researchers from universities, Government and corporate laboratories. More than half of the world's nanotech startups are in the U.S., and while it is difficult to pin an exact number on how many there are, it is safe to say at least 1,000 are currently in operation, up from approximately 100 just 3 years ago.

Venture capitalists, institutional investors, and wealthy angels have also begun to see the potential of nanotechnology. Chastened by the lessons of the dot com disaster, they are nevertheless aggressively seeking investment opportunities. As you mentioned, Mr. Chairman, over $1 billion will be invested this year in nanotechnology, when you look at corporate venturing efforts, venture capital firms, and other wealthy angels.

Ultimately, regional development efforts, the creation of technology clusters, Nanotech Valleys, if you will, will fuel the explosive growth of the nanotechnology industry. Localized development efforts are already underway from Virginia, to Texas, to California. The alliance ourselves launched a nanotechnology hubs initiative a few months ago to jump start regional technology cluster development, and frankly, we have been overwhelmed.

We launched efforts in 6 regions as well as affiliates in the EU and Canada, and have been inundated with calls from over 35 States and 11 countries to help develop this capacity. These States and regions are already looking to nanotechnology to ignite economic development.

As far as foreign competition goes, nanotechnology is truly emerging as a global technology, and unlike many past waves of technology development the United States is not dominating; in several areas of nanotech the U.S. is being outpaced by foreign competition. Japan, EU, Russia, Korea, and China are all significant players in the field of nanotechnology. A recent report from the Journal of Japanese Trade and Industry notes the Japanese Government views the successful development of nanotechnology as the, quote, "key to restoration of the Japanese economy," and they are not alone. Funding is growing at unprecedented rates across the globe over the past 3 years.

Not everything is rosy for the future of nanobusiness. While the NNI and overall Government nanotech efforts have been a great source of coordination and basic research funding, these nanotech grants remain among the most competitive in the Government. In addition, many nanotechnology companies have emerged from the basic research cycle and are addressing issues such as scaling and integration. Few Government programs address this time frame. Add to that a venture capital sector that is unwilling, too, and you have companies falling into what investors term, the Valley of Death.

Another great fear is uneasiness over lack of research in the nanotech health and safety issues, and more than one CEO has raised this as a concern. Others range from the U.S. Patent Office and its inability to understand the multidisciplinary nature of nanotechnology. In addition, the current state of technology transfer is lacking, by any measure. The technology transfer process from Government, academic labs, and the marketplace is impossible at times and arduous at best. And lastly the education as well as workforce training and development are beginning to become real issues among the nanotechnology community.

In summation, we certainly, as the alliance, greatly support this effort to continue to drill down on nanotechnology and to develop Government programs for it. While maintaining the development of basic research as a priority, we must expand our search to cultivate nanotechnology as an industry, and truly usher in a new Industrial Revolution.

I thank you.

[The prepared statement of Mr. Modzelewski follows:]

PREPARED STATEMENT OF F. MARK MODZELEWSKI, EXECUTIVE DIRECTOR, NANOBUSINESS ALLIANCE

Introduction

Mr. Chairman, Senator Allen, Members of the Subcommittee, I thank you for allowing me—on behalf of the NanoBusiness Alliance and our member organizations—the opportunity to testify before you on the topic on nanotechnology and its transition from a science into a business.

Nanotechnology has really been here since the dawn of creation. The difference now is that man is beginning to tap into it. Nanotechnology is the ability to do things—measure, see, predict and manufacture—on the scale of atoms and molecules. Traditionally, the nanotechnology realm is defined as being between 0.1 and 100 nanometers, a nanometer being one thousandth of a micron (micrometer), which is, in turn, one thousandth of a millimeter. Working at the scale of atoms and molecules is not merely about miniaturizing items. Working at this scale allows for the actual opening of nature's toolbox. Working at this scale allows man to act as nature does in creating things.

Currently, nanotechnology is transitioning from a science into a business. It is rapidly becoming the Industrial Revolution of the 21st century. The importance of nanotechnology cannot be overstated. It will affect almost every aspect of our lives, from the way we do computing, to the medicines we use, the energy supplies we require, the foods we eat, the cars we drive, and the clothes we wear. More importantly, for every area where we can fathom an impact from nanotechnology, there will be others no one has thought of—new capabilities, new products, and new markets.

We are at the earliest stage of this "nano-revolution." The nanotech industry might be compared to the computer industry of the 1960s, before the development of the integrated circuit, or the biotech industry of the 1970s. But while many nanotechnology sectors are in their nascent stages, others are already delivering products to the market. Forward-thinking corporations and entrepreneurs are reaping revenues and profits from a variety of nanomaterials, including enhanced polymers, coatings, and fillers. And advanced nanotech medical applications, such as disease detection and drug delivery, are in human trials and will be greatly impacting lives within a few years.

As production of nano-products becomes easier, faster and cheaper, every market sector will begin to feel their impact. We at the NanoBusiness Alliance estimate that the global market for nanotechnology-related products and services could reach more than $225 billion in 2005. The U.S. National Science Foundation conservatively predicts a $1 trillion global market for nanotechnology in little over a decade.

(It should be noted that the Microtechnology Innovation Team at Deutsche Bank AG. announced last week the results of a comprehensive market analysis on nanotechnology (full study available Q3/Q4 2002). They estimate that the current market size of nanotechnology products is greater than $116 billion, excluding electronics, and $300 billion total. According to the report, the nanomaterials market size is expected to reach $29.4B per year by 2006. While these significant numbers are appreciated, they do not align with other research in the field and will need to be explored upon the full release of the report.)

Nanotechnology Development

Nanotechnology is an enabling technology. It allows us to do new things. Like other enabling technologies, such as the internal combustion engine, the transistor or the Internet, its impact on society will be broad and often unanticipated. And nanotech is indeed changing many fields of business in truly revolutionary ways.

Life Sciences and Medicine

In life sciences and medicine, nanotechnology means we are beginning to be able to measure and make things on the level at which organisms in the living world, from bacteria to plants to ourselves, do most of their work. Being able to work at this scale doesn't just empower us in our control of the biological world, but also allows us to start borrowing from that world, leveraging the extraordinary inventions that nature has produced through billions of years of evolution.

Nanotechnology will ultimately help to extend the life span, improve its quality, and enhance human physical capabilities. In the near future, about half of all production of pharmaceuticals will be dependent on nanotechnology—affecting over $180 billion in revenues per year in 10 to15 years.

Disciplines in LifeSciences and Medicine that are seeing nanotechnology's impact are:

- **Nanoparticle Tagging:** Nanoparticles small enough to behave as quantum dots can be made to emit light at varying frequencies. If you can get particles that emit at different frequencies to attach to different molecules you can literally put a sign of identification on them. This development will allow for the tagging of disease, infection and bacteria, allowing for detection at the earliest moment of a disorder's onset.
- **Nanostructured Materials:** Nanostructured materials, coupled with liquid crystals and chemical receptors, offer the possibility of cheap, portable biodetectors that might, for instance, be worn as a badge. Such a badge could change color in the presence of a variety of chemicals and would have applications in hazardous environments. The U.S. armed forces are already in advanced research stage for this discovery to be part of the military uniform of the future.
- **Drug Delivery:** Drug delivery is one of the areas that is anticipated to have applications hitting the market very soon; clinical trials have already begun. Almost all current medications are delivered to the body as a whole, which is fine as long as they only become active in the areas you want them to. But this is not usually the case. When the treatment is designed to kill cells, as in the case of cancer, the side effects are enormous. Nanotech also promises to allow for substance "extraction" potentially removing poisons or toxins from the body or allowing for organic coatings of these substances so they pass harmlessly through the body.
- **Cellular Manipulation:** Cells are extraordinarily complex systems about which we are still quite ignorant. For this reason, it will be a long time before we see nanorobots doing complex work in our bodies. However, as we learn more we are likely to find ways to manipulate and coerce cellular systems and will achieve a lot that way—persuading lost nerve tissue to regrow.

Agriculture

Nanotechnology will ultimately provide the ultimate solutions for many hurdles presented by biotechnology and agri-sciences. The most likely area in which nanotechnology will initially enter the agricultural industry is the world of analysis and detection, such as bio-sensors to detect the quality of and the health of agricultural products and livestock. Also, innovative waste treatment options and composite materials, as part of the manufacturing and processing of agricultural products, are already entering the market.

- **Food Safety:** Advanced nano-sensors that can detect surface and airborne pathogens are already leaving the lab, yet work to develop these products for the agriculture sector remain limited. Should pricing continue to fall and enhanced development be undertaken, the extent of nano-sensor usage can go right to the consumer level with the packaging of agriculture products such as meat actually examining and denoting quality and safety.
- **Animal Health:** Work on unique drug delivery, protease inhibitors, cell tagging and treatment are already hitting the trail phases. Targeted drug delivery for instance is one of the areas that are anticipated to have applications hitting the market very soon. With protease inhibitors, viruses, prions and diseases such as BSE (Mad Cow Disease) and Brucellosis.
- **GMO Enhancements:** Nanoparticles small enough to behave as quantum dots can be made to emit light at varying frequencies. If you can get particles that emit at different frequencies to attach to different molecules you can literally put a sign of identification on them. This development will allow for the tagging of molecules in the GMO development process. This development can also be used to tag disease, infection and bacteria, allowing for detection at the earliest moment of a disorder's onset. Also the tagging can be a part of the treatment as cells that are tagged can be engineered or attacked separately from non-tagged cells—allowing for pinpoint eradication.
- **Nano-filtration:** NF uses partially permeable membranes to preferentially separate different fluids or ions, and will remove particles from approximately 0.0005 to 0.005 microns in size. NF membranes are usually used to reject high percentages of multivalent ions and divalent cations. while allowing monovalent

ions to pass. Removal includes sugars, dyes, surfactants, minerals, divalent salts, bacteria, proteins, particles, dyes, and other constituents that have a molecular weight greater than 1000 daltons. Waste treatment efforts are already in development.

- **BioCompositles:** Nano-bio composites are in development that can serve as composite material for manufacturing that is lighter, stronger, yet completely bio-degradable. Uses include body panels, parts, organic fibers and many other areas.

Materials Science

In materials, things start to behave differently at the nanoscale. The bulk materials that we have traditionally dealt with are uncontrolled and disordered at small scales. The strongest alloys are still made of crystals the size and shape of which we control only crudely. By comparison, a tiny, hollow tube of carbon atoms, called a carbon nanotube, can be perfectly formed, is remarkably strong, and has some interesting and useful electrical and thermal properties.

When particles get small enough (and qualify as nanoparticles), their mechanical properties change, and the way light and other electromagnetic radiation is affected by them changes (visible light wavelengths are on the order of a few hundred nanometers). Using nanoparticles in composite materials can enhance their strength and/or reduce weight, increase chemical and heat resistance and change the interaction with light and other radiation. While some such composites have been made for decades, the ability to make nanoparticles out of a wider variety of materials is opening up a world of new composites. For example, in 10–15 years, projections indicate that such nanotechnology-based lighting advances (utilizing nano-phosphorus among other materials) have the potential to reduce worldwide consumption of energy by more than 10 percent, reflecting a savings of $100 billion dollars per year and a corresponding reduction of 200 million tons of carbon emissions.

It has been estimated that nanostructured materials and processes can be expected to have a market impact of over $340 billion within a decade (Hitachi Research Institute, 2001). Like so many aspects of nanotechnology, this is a difficult thing to estimate because of potential new applications—if you can make a material ten times as strong and durable as steel for a lesser mass, what new products will people dream up?

The nanometer scale is expected to become a highly efficient length scale for manufacturing. Materials with high performance, unique properties and functions will be produced that traditional chemistry could not create.

Disciplines in Material Sciences that are seeing nanotechnology's impact are:

- **Nanoparticulate Fillers:** Alternatively, composite materials can use nanoparticulate fillers. Composite materials already enjoy an enormous market, but making the filling material nanophase (i.e. consisting of nanoscale particles) changes its properties. As particles get smaller, the material's properties change—metals get harder, ceramics get softer, and some mixtures, such as alloys, may get harder up to a point, then softer again.
- **Nanoparticles for Many Applications:** Recently, clay nanoparticles have made their way into composites in cars and packaging materials. (Widespread use of nanocomposites in cars could lead to an enormous decrease in fuel consumption: savings of over 1.5 billion liters of gasoline over the lifespan of one year's vehicle production, thereby reducing carbon dioxide emissions by more than 5 billion kilograms). You've probably heard of sunscreens using nanoparticulate zinc oxide. Nanoparticles are also being used as abrasives, and in paints, in new coatings for eyeglasses (making them scratchproof and unbreakable), for tiles, and in electrochromic coatings for windscreens, or windows. Anti-graffiti coatings for walls have been made, as have improved ski waxes and ceramic coatings for solar cells to add strength. Glues containing nanoparticles have optical properties that give rise to uses in optoelectronics. Casings for electronic devices, such as computers, containing nanoparticles, offer improved shielding against electromagnetic interference. That famous spin-off of the space age, Teflon, looks soon to be trumped for slipperiness thanks to nanoparticle composites.
- **Textiles:** Another huge industry that will be impacted by nanotechnology is the textiles industry. Companies are working on "smart" fabrics that can change their physical properties according to surrounding conditions, or even monitor vital signs. The incorporation of nanoparticles and capsules in clothing offers some promise and nanotubes would make extremely light and durable mate-

rials. Fabrics infused with nanoparticles are already being marketed that are highly resistant to water and stains and wrinkling.

Nanoparticle Catalysts

Many industrial processes will be affected by nanotechnology. One major early impact will come from our improved capabilities in making nanoparticles, the reason being that nanoparticles make better catalysts. A catalyst (a substance that initiates or enhances a reaction without being consumed itself) does its work at the point where it contacts the reactants, i.e. its surface. Since volume changes as the cube of the linear dimension, but surface area changes only as the square, when you make a particle smaller in diameter (the linear dimension), the volume, and thus mass, decreases faster than the surface area. Thus a given mass of catalyst presents more surface area if it consists of smaller particles.

Equally, a given catalytic surface area can be fitted into a smaller space. The use of catalysts in industry is widespread so there should be a large market here for nanoparticle manufacturers. It should be noted, though, that nanostructured catalysts have already been used in industry for decades—zeolites, catalytic minerals that occur naturally or are synthesized, have a porous structure that is often characterized on the nanoscale.

Catalysts are also of major importance in cleaning up the environment, allowing us to break down harmful substances into less harmful ones. Improved catalysts will make such processes more economical. Petroleum and chemical processing companies are using nanostructured catalysts to remove pollutants, creating a $30 billion industry in 1999 with the potential of $100 billion per year by 2015.

Improved catalysts offer a nice example of how taking an existing technology and making it better can open up whole new markets. Nanostructured catalysts look likely to be a critical component in finally making fuel cells a reality, which could transform our power generation and distribution industry (for example, our laptops and cell phones would run for days on a single charge).

Disciplines in Catalysts sector that are seeing nanotechnology's impact are:

- **Fuel Cells:** The development of fuel cells will probably be impacted by nanotechnology in other ways too, certainly by structuring components in them on a nanoscale but also in terms of storing the fuel, where the nanotube, yet again, shows promise for storing hydrogen for use in fuel cells. A relative of the nanotube, the nanohorn, has been touted as ready to hit the market in two to four years in a methane-based fuel cell.
- **Solar Cells:** Nanotechnology has been cited as a way to improve the efficiency of solar cells. However, typical commercial cells have efficiencies of about 15 percent, with over 30 percent having been achieved, which is already much better than photosynthesis, at about 1 percent. The cost of solar cells is currently the biggest barrier to commercialization.
- **Light Sources:** In the world of light transmission, organic LEDs are looking like a promising way of making cheaper and longer-lasting light sources, reducing power consumption in the process. By contrast, at least one group of researchers has created a bulb driven by nanotubes. Tiny electron emitters, called field emission devices, including ones based on nanotubes, hold promise for use in flat panel displays.
- **Pharmaceutical Processes:** The pharmaceuticals industry will probably experience a benefit not only from advances in catalysis, but also from the new, cheaper and smaller bioanalysis tools. One estimate claims that nearly half of all pharmaceutical production will be dependent on nanotechnology within 15 years—a market of some $180 billion per year (E. Cooper, Elan/Nanosystems, 2001).
- **Waste Treatment:** Photocatalysis will play in this field in the future. There are efforts underway to sensitize TiO_2 to visible light; this could open the door for this technology in large-scale waste treatment, because visible light is free and plentiful, especially as compared to UV-light.

Electronics and Information Technology

The impact of the Information Technology (IT) Revolution on our world has far from run its course and will surely outstrip the impact of the Industrial Revolution. Some might claim it has done so already. Key to this is decades of increasing computer power in a smaller space at a lower cost.

In electronics, the benefit of working on the nanoscale stems largely from being able to make things smaller. The value comes from the fact that the semiconductor industry, which we have come to expect to provide ever smaller circuits and ever more powerful computers, relies on a technology that is fundamentally limited by the wavelength of light (or other forms of electromagnetic radiation, such as X-rays). The semiconductor industry sees itself plunging towards a fundamental size barrier using existing technologies. The ability to work at levels below these wavelengths, with nanotubes or other molecular configurations, offers us a sledgehammer to break through this barrier. Ultimately, circuit elements could consist of single molecules. MEMS are generally constructed using the same photolithographic techniques as silicon chips and have been made with elements that perform the functions of most fundamental macroscale device elements—levers, sensors, pumps, rotors, etc. Nanoscale structures such as quantum dots also offer a path to making a revolutionary new type of computer, the quantum computer, with its promise of mind-boggling computing power, if it can be converted from theory to practice. Lasers constitute an area that is likely to be commercially affected by nanotechnology in the near future. Quantum dots and nanoporous silicon both offer the potential of producing tunable lasers—ones where we can choose the wavelength of the emitted light.

You may have heard of Moore's law, which dictates that the number of transistors in an integrated circuit doubles every 12 to 24 months. This has held true for about 40 years now, but the current lithographic technology has physical limits when it comes to making things smaller, and the semiconductor industry, which often refers to the collection of these as the "red brick wall", thinks that the wall will be hit in around fifteen years. At that point a new technology will have to take over, and nanotechnology offers a variety of potentially viable options.

Disciplines in Electronics and Information Technology that are seeing nanotechnology's impact are:

- **Carbon Nanotubes in Nanoelectronics:** Carbon nanotubes hold promise as basic components for nanoelectronics—they can be conductors, semiconductors and insulators. IBM recently made the most basic logic element, a NOT gate, out of a single nanotube, and researchers in Holland are boasting a variety of more complex structures out of collections of tubes, including memory elements. There are two big hurdles to overcome for nanotube-based electronics. One is connectibility—it's one thing making a nanotube transistor, it's another to connect millions of them together. The other is the ability to ramp up to mass production. Traditional lithographic techniques are based on very expensive masks that can then be used to print vast numbers of circuits, bringing the cost per transistor down to one five-hundredth of a U.S. cent. Current approaches to nanotube electronics are typically one-component-at-a-time, which cannot prove economical. Molecular electronics (which, strictly speaking, includes nanotubes) faces similar scaling hurdles. There are some possible solutions, however.
- **Organic Nanoelectronics:** Organic molecules have also been shown to have the necessary properties to be used in electronics. However, unlike nanotubes, the speed of reaction, for instance in switching a memory element, and hardiness in face of environmental conditions, will likely limit uses. Devices made of molecular components would be much smaller than those made by existing silicon technologies. But the issue of mass production remains.
- **Soft Lithography:** There is an approach to making nanoscale structures that potentially offers great promise for nanoelectronics in the near term, owing to its simplicity. This is soft lithography, which is a collection of techniques based around soft rubber nanostructured forms or molds. You can use these to stamp a pattern on a surface, in the form of indentations, or using some form of "ink". No special technology is required, and nor are the fantastically clean environments required for existing silicon chip production. Additionally, a wide variety of materials can be used.

  The approach is reminiscent of one of the most famous examples of mass-production—the printing press. Soft lithography is already used to make microfluidic systems, such as those in lab-on-a-chip systems, and it scales readily down to the nanoscale (depending on the variant of the technology used, resolution can get below 10 nanometers). The techniques also promise potential in the creation of optical devices, which may in turn ultimately be used in optical computing. As a replacement for traditional lithography for creating electronic devices, however, there is currently a major obstacle—the technique is not well suited to making the precisely-aligned, multi-layered structures currently used in microelectronics, although researchers are working to overcome this limitation.
- **Memory and Storage:** When it comes to the technology behind the vast IT market, there is much more than just shrinking microprocessors to consider.

Storing information is vitally important and can be done in many ways. Magnetic disks in computers have been increasing their capacity in line with Moore's law, and have a market at the moment of around $40 billion. The other type of information storage common to all computers is DRAM (dynamic random access memory). DRAM provides very quick access but is comparatively expensive per bit. Magnetic disks can hold much more information but it takes much longer to access the data. Also, DRAM is volatile—the information disappears when the power is switched off. The trade-offs between access speed, cost, and storage density dictate the architecture of computers with respect to information storage. New technologies may change this dynamic.

- **MRAM:** Some memory technologies that are currently being researched are single-electron tunneling devices, rapid single flux quantum devices, resonant tunneling diodes, and various types of magnetic RAM (MRAM). MRAM offers the promise of non-volatile RAM, enabling devices such as a PC or mobile phone to boot up in little or no time. This puts the technology somewhere between existing DRAM and magnetic disk technologies. Nanotubes also hold promise for non-volatile memory and recent news suggests nanotube-based RAM may hit the market very soon (commercial prototype in 1 to 2 years).
- **Quantum Computing:** In the much longer term, there's quantum computing, which offers staggering potential by virtue of the ability to perform simultaneous calculations on all the numbers that can be represented by an array of quantum bits (qubits). The atomic scale, the scale at which quantum effects come into play, argues for a requirement for nanoscale structures and quantum dots to come up regularly in discussions of quantum computing. Primary applications would be in cryptography, simulation and modeling. The realization of a quantum computer is generally believed to be a long way off, despite some very active research. Funding in the area is thus still largely that provided for pure research, though some defense department money has been made available.

The total potential for nanotechnology in semiconductors has been estimated to be about $300 billion per year within 10 years, and another $300 billion per year for global integrated circuit sales (R. Doering, "Societal Implications of Scaling to Nanoelectronics," 2001). But it's actually much harder to predict the commercially successful technologies in the world of electronics than in the world of materials. The assumption that continually increasing processing power will automatically slot into a computer hardware market that continues to grow at the rate it has done historically, is not necessarily sound. Most of the growth over the last decade has been driven by personal computers and some argue that this market is nearing saturation.

The National Nanotechnology Initiative

Since its inception, the National Nanotechnology Initiative (NNI) has proven to be an incredible instance of government outpacing the vision of the private sector. And already we are the better for it.

The NanoBusiness Alliance indeed fully endorses the work of the NNI and offers our deep appreciation to the fine work of Dr. Mike Roco, Dr. James Murday and the other individuals who created the NNI and continue to advance its efforts everyday.

The NNI has been an exceedingly successful program. From our industry vantage point the NNI has made an incredible impact in the following areas:

- **1. Funding:** The NNI has provided much needed funding for basic research at America's universities and government labs. By fueling innovation, this investment is—and will continue to—find its way to the public marketplace promoting industry development.
- **2. Awareness:** Before the NNI. the overwhelming majority of Americans thought that nanotechnology was science fiction—or they never even heard of it. A survey just a couple years back showed that less than 5 percent of CEOs knew what nanotechnology was, never mind what it meant to their businesses. This is changing rapidly. In fact, we now hear claims that people talk about nanotechnology too much.
- **3. Collaboration:** The NNI has been extraordinarily successful at fueling collaborations between corporations, universities, start-ups and government labs—in the U.S. and abroad. Also, the NNI has helped to break down internal research silos. Nanotechnology is an incredibly cross-disciplinary field. To succeed in developing applications you need chemists to work with engineers; and engineers to work with physics and so on. Due to the educational efforts of the NNI,

and the structure of their grants programs, this collaborative movement is beginning to ferment. Universities, such as University of Washington, are already giving out PhDs in NanoScience which trains students across many needed disciplines, and other schools are following at the undergrad and graduate level.

- **4. Competition:** For better and for worst, the announcement of NNI set forth a global contest for dominance in the nanoscience and nanotech industry. Ultimately this will make the consumer the winner. This global competition will push even more rapid developments.

That is why the NanoBusiness Alliance and its members would like to enthusiastically endorse the 21st Century Nanotechnology Research and Development Act that is being introduced by this Senator Wyden.

By all accounts it will be a vital and timely bill that will assist America's scientific and economic competitiveness as well as play a key role in developing nanotechnology efforts for Homeland Defense.

State of NanoBusiness

Few realize that the age of nanotechnology as a business—NanoBusiness—is already here. Though we are admittedly at the earliest stages, substantial change is already taking place. Some of the most recent predictions for the development of nanotechnology and time to market are being rapidly eradicated. For instance, in January 2000 at the NNI kick-off announcement at Cal Tech, President Clinton noted:

> "Just imagine, materials with 10 times the strength of steel and only a fraction of the weight; shrinking all the information at the Library of Congress into a device the size of a sugar cube; detecting cancerous tumors that are only a few cells in size. Some of these research goals will take 20 or more years to achieve."

When President Clinton said those words it seemed like a highly reasonable timeframe. Yet here we are a couple of years later and just last week Hewlett-Packard said they had created a 64 bit computer memory chip using new molecular technology that takes miniaturization further than ever before. Some thousands of these memory units could fit on the end of a single strand of hair.

In addition, incredibly strong nanocomposites are already available and being used by aircraft manufacturers and automakers among others. Researchers at Rice University are in early trials using quantum dots to detect cancer in the lab. Have we completely erased the 20 year prediction? No, but we are getting close. Very close.

Corporations

Just five years ago only a few corporate visionaries—IBM, HP, Texas Instruments among them—were undertaking any research and development in the nanosciences. Today you'd be hard pressed to find a single member of the Fortune 500 that is involved in manufacturing that does not have some nanotechnology effort underway—GM, GE, Ford, Siemens, Intel, Motorola, Lucent, Toyota, Hitachi, Corning, Dow Chemical, NEC, Dupont, 3M, etc. have launched significant nanotech initiatives. Some of the biggest spenders on R&D are allocating up to a third of their research budgets to nanotech.

As an example of current market applications in corporate America for one small area of nanotech—carbon nanotubes—already some 60 percent of the cars on our highways utilize nanotubes or other nanoparticulate fillers in their fuel lines, airbags, and body panels. And 50 percent of lithium batteries on the market utilize nanotubes to enhance their energy storage capabilities. These are compelling cases of American corporations already tapping into the potential of nanobusiness.

Some examples:

- **General Electric:** At a time when many corporations are scaling back research and development operations, General Electric, the world's largest company, reaffirmed its commitment to R&D this year with a $100 million+ pledge to modernize its global research center. The Center will focus its greatest emphasis on nanotechnology. GE views nanotechnology as a key component to its future.
- **IBM:** Few would question that IBM is the world's leading nanotechnology company with bleeding edge efforts in nano-electronics, life sciences and nano-materials. IBM has major nanotechnology operations underway in New York, Zurich and in Silicon Valley. They are patenting literally hundreds of new nanotechnology discoveries a year.
- **Mitsubishi Corp:** Mitsubishi Corp. created a joint venture with two Arizona-based start-ups, MER and Research Corporation Technologies, to form

Fullerene International Corp. (FIC). FIC has established a fullerene manufacturing facility in Osaka, Japan, with MER providing the reactor.

Start-Ups

Unlike the Dot-com era, nanotech start-ups are built on science. They have real technology. Real assets. And more often than not, they are founded by researchers from universities, government and corporate laboratories. These young companies are already pushing the growth of the field through their innovation. And these start-ups will most assuredly be part of the next NASDAQ boom.

More than half the world nanotech start-ups are in the U.S.. And while it is difficult to pin an exact number on how many there are, it is safe to say that around a 1,000 are currently in operation up from maybe 100 three years ago.

Some examples:

- **C Sixty Inc.,** A pioneering biotech company that is modifying fullerenes for medical applications,—drug delivery, protease inhibitors, and disease prevention. C-Sixty has begun clinical trials on an AIDS drug already. The Houston-based company also reported progress on another fullerene-based approach—this one for Lou Gehrig's disease, a degenerative disorder that affects nerve cells.
- **Luna Innovations:** A diverse research company based in Blacksburg, Va., recently received a $2 million federal grant to develop buckyballs that can be used in magnetic resonance imaging (MRI) systems and for possible diagnosis and treatment of cancer. They also have a cutting edge sensor in final development for the oil and gas industry.
- **NanoBio:** A start-up company spun off from the University of Michigan has created an emulsion that protects civilians and troops from biological terror attacks. It actually kills anthrax and was approved several years ago, far in advance of the horrible events of last fall. This antimicrobial substance called NanoProtect, can be applied either before or after an attack to all kinds of surfaces, including skin, clothing and vehicles. NanoProtect is the result of a five-year, $11.8 million grant by the U.S. Defense Advanced Projects Research Agency (DARPA) to researcher Dr. James Baker Jr.
- **Evident Technologies:** Evident is a nanotechnology manufacturing and application company that draws upon semiconductor nanocrystal expertise to develop sophisticated, cost effective, innovative devices and products. Their products have applicability in biotechnology, optical switching, and computing, telecommunications, energy and other fields. Evident's quantum dot technology can be used to "tag" cancerous cells, create new lighting source, or serve as part of developing electronics. This self funded company has been creating profits by supplying testing materials to the semiconductor and biotech industries.

Funding

Venture capitalists, institutional investors and wealthy angels have also begun to see the potential in nanotech, and, though chastened by the lessons of the "dot-com disaster," are nevertheless aggressively seeking investment opportunities. Over 60 U.S. venture capital firms invested in nanotech-related companies in 2000. Investment in nanotechnology start-ups will rise from $100 million in 1999 to nearly a $1billion by 2003. Recent investments include NanoPhontonic, a semiconductor company that received over $25mm this spring in venture investment. Surface Logic, a nanoelectronics firm obtained almost $22 mm in new funding as well.

All signs demonstrate that this growth curve will continue to increase rapidly over the next 3–5 years for nanotechnology regardless of the current economic slow down. So-called angel investors and corporate venturing operations are expected to outpace traditional venture capital firm's investments for the foreseeable future due to the business models and return times.

Regional Development

Ultimately, regional development efforts —the creation of technology clusters (Nanotech Valleys if you will)—will fuel the explosive growth of the nanotechnology industry. The bringing together of universities, government officials, corporations, investors, non- profits, start-ups and service firms to coordinate, plan, and develop an environment condusive for collaboration and attracting talent is the key to developing the industry. Region specific approaches. Region specific planning. National—even international—collaboration and impact.

Localized development efforts are already underway from Virginia to Texas to California. The NanoBusiness Alliance launched a "Nanotech Hubs Initiative" a few months back with the hope of jump starting regional technology cluster development. We have been overwhelmed. Though we have launched efforts in Colorado, New York, San Francisco, San Diego, Michigan and Washington DC metro—as well as affiliate organizations in the EU and Canada—we have been inundated with calls from 35 states and 11 countries to help develop this capacity. They are looking for best practices, partners and funding. They are looking for roadmaps and shared databases.

These states and regions are already looking to nanotechnology to develop local economies and fuel overall state economic development.

Some examples:

- **New York State:** Albany NanoTech is a fully-integrated research, development, prototyping, pilot manufacturing and education resource managing a strategic portfolio of state-of-the-art laboratories, supercomputer and shared-user facilities and an array of research centers located at the University at Albany—SUNY. Its first research center, the NYS Center for Advanced Thin Film Technology, was established to provide its company partners with a unique environment to pioneer, develop, and test new ideas within a technically aggressive, yet economically competitive, research environment. Governor Pataki has been instrumental in expanding this center, as has IBM. It has served to be a magnet for corporate development and start ups. It was recently announced that the SEMATECH—the largest semiconductor industry developers—would locate its next generation R&D facility at the Center. When the last SEMATECH located in Austin it turned the city from a quiet college town into one of Americas 5 great technology centers.
- **Chicago:** Chicago is looking to seize leadership in the emerging field of nanotechnology by providing tax subsidies to foster a high-tech corridor. The area has also created a Chicagoland nanotech initiative of sorts, with large corporate players like Boeing and Motorola; nanotech companies like NanoPhase and NanoInk; investors; consultants like McKinsey: Northwestern's Nanotechnology Center; U Chicago; and Argonne National Laboratory all collaborating.

Foreign Competition

Nanotechnology is emerging as a truly global technology. Unlike the many waves of technological development over the past seventy-five years, nanotechnology is not dominated by the United States. The U.S. is being outpaced by foreign competition in several areas of nanotechnology. Japan, Italy, Israel, Ireland, Switzerland, the Netherlands, UK, Germany, Russia, South Korea, China, France, Canada, and Australia are all significant players in the field of nanotechnology.

A recent report from the Journal of Japanese Trade & Industry notes that the Japanese government views the successful development of nanotechnology as the key to "restoration of the Japanese economy." They are not alone. Funding has grown at unprecedented rates in the last three years fueled by the awareness of the U.S. National Nanotechnology efforts.

Problems in the NanoBusiness World

Not everything is rosy for the future of nanobusiness. Though much development has occurred, many obstacles remain. While the NNI and overall government nanotech efforts have been a great source of .coordination and basic research funding for many, these nanotech grants remain among the most competitive in the government.

In addition, many nanotech companies have emerged from the basic research cycle and are addressing issues such as scaling and integration. Few government programs address this timeframe. Add to that a venture capital sector that is battered, not knowledgeable on nanotech and now working in a shortened cycle of investment return and you have many nanotech companies falling into what investors term "Death Valley."

Another area of concern for nanotech start ups is the current state of U.S. intellectual property and the USPTO. The Patent Office is in desperate need of training programs to ensure its examiners understand nanotechnology. At USPTO, nanotech patent applications—understandably due to the wide breadth of application areas the technology covers—go down many different review silos at USPTO. Also, several early nanotech patents are given such broad coverage, the industry is potentially in real danger of experiencing unnecessary legal slowdowns.

Another grave fear that is often expressed by CEOs, particularly at large corporations that are undertaking nanotech R&D, is uneasiness over the lack of research on nanotech health and safety issues. More than one CEO has raised the specter of "are we sitting on the next asbestos working with all these tiny things."

In addition, the current state of technology transfer is lacking by any measure. The technology transfer process from government and academic labs to the marketplace is impossible at worst—arduous at best.

And lastly, education, as well workforce training and development are beginning to become issues among the nanotech community.

Close

In closing, nanotechnology the science is indeed now rapidly becoming nanotechnology the business. As a nation we have been very fortunate to have the visionary support—from both sides of the aisle—in developing and maintaining the National Nanotechnology Initiative. However, we are now at a cross roads where we must expand the reach of this national initiative from the laboratory to the board room. While maintaining the development of basic research as a priority, we must expand our sights to cultivate the nanotechnology industry and usher in a new Industrial Revolution. Again, that is why the 21st Century Nanotechnology Research and Development Act is so important.

1. We see the Act's ability to strengthen the structure of the National Nanotechnology Initiative as being of vital importance—increasing the long term stability and growth of our Nation's nanotechnology efforts.
2. The Act makes the development of the nanotechnology sector a major government focus. Increasing understanding and awareness of nanotechnology throughout the government's political and civil service ranks by providing mechanisms for program management and coordination across government agencies and White House. We especially support Act's call for the development of a government advisory board made up of nanotechnology leaders to regularly discuss the state of the industry and recommend solutions to the President and Congress.
3. Due to real challenges to our Nation's efforts to obtain a secure leadership position in nanotechnology and nanobusiness, we also strongly support the Act's call for further examination and tracking of international funding, development and competition in nanoscience and nanobusiness.
4. And, we strongly support the Act's efforts to encourage nanoscience through additional grants, and the establishment of interdisciplinary nanotechnology research centers, as this will lead to more innovation and further development of the nanotech economy.

Long term, the Alliance would like to see Congress continue its focus on nanotechnology as it becomes nanobusiness and develop programs—and expand existing programs—for commercializing nanotechnology development.

a. Create programs that offer opportunities to entrepreneurial start-ups and innovative corporations alike. Programs that offer incentives, loans, and funding to take nanotechnology innovations into the marketplace.

b. Ensure that the USPTO is properly educated and equipped to evaluate and approve nanotechnology patents

c. Organize an extensive global effort with industry, academia and government to study the health and environmental effects—good and bad—on nanotechnology now before potential problems or even negative intimations arise. The effort should include social and scientific studies building on much of the fine work of the National Nanotechnology Initiative staff. Ensure that publicly accessible materials, events and websites are developed to disseminate such information to a broad audience.

d. Develop programs, possibly though the Office of Technology Policy in the Department of Commerce, economic development organizations, universities and industry groups to promote and nurture regional nanotechnology cluster development. Create best practices reports, guides, and extensive national nanobusiness database.

e. Develop programs to improve the state of tech transfer at government labs and academic institutions which will improve the commoditization of emerging technologies

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

Senator WYDEN. Mr. Modzelewski, we also understand you could provide a couple of demonstrations today, and since you are under your 5 minutes, please have at it.

Mr. MODZELEWSKI. One that we can start off with, if we could dim the lights, I am going to demonstrate a technology by a company called Evident Technology, which is based in New York, and this is a testing kit which basically uses quantum dot technology. This technology could be used for everything from potentially detecting individual cancer cells in the human body to being used actually for lighting sources, everything from light bulbs that use less energy to flat screens. It is even being used in the electronics industry in semiconductor work.

The thing that you will find most interesting about them is your ability to give off a large and intense color spectrum. I am going to use a black light to demonstrate that for you. As you can see, they are very hard to see initially, but when given the color spectrum they can give off an incredible glow, and these glows can literally be assigned to pick up individual pathogens, even can be used as biosensors for the military and be used for individual forms of cancer.

The thought is, is that this could be advanced in, say, cancer research to where you are not only identifying them, but are able to link up the light spectrum to things like lasers or other ultraviolet sources that could eradicate just the individual cells, as opposed to treating the whole area of the body.

Another thing we have is here from a company called Infomat, which is a Connecticut-based company, and what they are able to do is actually use a flexible ceramic coating, and you have instead an incredibly heat-resistant product here, and we have the flexible ceramic. We can start looking at things like ceramic engines and other things that have long been difficult for us to even imagine being able to successfully do this. This actual little piece of metal is actually a band that the U.S. Navy is beginning to use on some of the development of their ships and things along those lines.

I am not sure if we also want to demonstrate the nanochinos. Is anyone interested in that?

Senator WYDEN. We have a huge demand for nanochinos.

Mr. MODZELEWSKI. You have to understand, this is already in the marketplace. There is the availability of nanofibers, and these coated fibers create such a level of surface area that anything that is spilled on them does not just bead up like Scotchgard, but literally is repelled away, and we can actually be looking, potentially, within the next decade, for clothing that does not need to be cleaned, and you are seeing how grape juice, I believe, beads up and works off of the nanochinos.

Voice: I wipe it and it is all completely dry.

Senator WYDEN. That is unbelievable.

Voice: If it is submersed, it will release and allow washing.

Mr. MODZELEWSKI. That product is already available. He is not wearing something experimental. Big name brands n the American fabric industry, Levi's, Lee, Eddie Bauer sell nanochinos, nanojeans, and also shirts with such a capacity, and in fact Dockers is running a commercial right now where a gentleman is in a bar and his buddy keeps pouring a drink on him, and he is begging him to stop pouring the drink on him to watch how cool the nanotechnology works. And so I think we are starting to enter an age right now where, true, we do need the basic research, and we should continue to advance that, but we are already really seeing this technology start to enter our lives in very simple ways, and soon to be more advanced ways.

I thank you.

Senator WYDEN. Dr. Stupp.

STATEMENT OF SAMUEL I. STUPP, PH.D., CHAIRMAN OF THE COMMITTEE FOR THE REVIEW OF THE NATIONAL NANOTECHNOLOGY INITIATIVE, NATIONAL RESEARCH COUNCIL/THE NATIONAL ACADEMIES, AND BOARD OF TRUSTEES PROFESSOR OF MATERIALS SCIENCE, CHEMISTRY AND MEDICINE, NORTHWESTERN UNIVERSITY

Dr. STUPP. Mr. Wyden, Mr. Allen, thank you for the opportunity to present this statement. I chaired the review committee for the NNI of the National Research Council. I am here representing a committee which was composed of a mix of individuals from academe and industry, and drawn from a variety of scientific and engineering disciplines relevant to the topic of nanoscience and nanotechnology. The committee spent 9 months reviewing the NNI and writing the report that is the basis of my testimony to you today. During those 9 months, we heard from all of the agencies currently being funded under the NNI, and most of the agencies that are planning on joining the NNI in the near future.

In addition to the information gathered from these agencies, we also relied on the knowledge committee members have about activities ongoing in our universities, in the private sector, in State and local regions, and internationally. The committee was asked to review the NNI with particular attention to (1) whether the balance of the overall research portfolio is appropriate, (2) whether the correct seed investments were being made now to assure U.S. leadership in nanoscale work in the future, (3) whether partnerships were being used effectively to leverage the Federal investment in this area, and (4) whether the coordination and management of the program is effective, such that the whole is greater than the sum of its parts.

Our committee detailed many of the important outcomes that could come from nanotechnology, including applications in medical diagnostics, new therapies for disease and injury, the very exciting frontier of regenerative medicine, which is not discussed all that frequently, and homeland security as well.

The committee found that the agencies participating in the NNI have made a good start in organizing and managing such a large interagency program. The committee was impressed with the leadership and level of multiagency involvement in the NNI, particularly the leadership role played by the National Science Foundation. Programs funded to date that were presented to the committee were all of an appropriately high technical merit, and the participating agencies have sponsored a number of influential symposia in nanotechnology.

The committee formulated 10 major recommendations to help the NNI agencies build on their efforts to date to further strengthen the implementation of the initiative. So concerning the research portfolio, the committee recommended that (1) more emphasis be given to long-term funding of new concepts in nanoscale science and technology. Truly revolutionary ideas will need sustained funding to achieve results and produce important breakthroughs. There are not currently enough funding mechanisms to give longer term support to higher risk but potentially groundbreaking ideas. There are more of those in Europe than here in the U.S.

(2) The committee recommends increasing the multiagency investments in research at the intersection of nanoscale technology and biology. We can already see applications of nanoscale science and technology that will have significant impacts in biotechnology and medicine. Bionano is not currently as well-represented in the NNI portfolio as it should be. Since many of the advances foreseen in this area involve the marriage of physical sciences and engineering with biology, these investments should focus on collaborations between the NIH and the other NNI agencies.

(3) The committee recommends investment also in the development of new instruments for measurement and characterization of nanoscale systems. Historically, many important advances in science happened only after the appropriate instruments became available.

(4) The committee recommends that NSET develop a new funding strategy to ensure that the societal implications become an integral and vital component of the NNI.

On whether the "correct" seed investments are being made now for the future of U.S. leadership in nanotechnology, the committee recommends, (1) that NNI agencies provide strong support for the development of an interdisciplinary culture for nanotechnology. Nanoscale research is leading us into areas involving the convergence of many disciplines, biology, chemistry, physics, material science, all areas of engineering. However, the overall value system used by the scientific community to judge its members continues to discourage interdisciplinary research.

Looking at the question of whether partnerships are being used effectively in the NNI, the committee found that industrial partnerships need further stimulation and nurturing to accelerate the commercialization of NNI development. The U.S. is most likely to realize economic benefits from nanotechnology when its underlying intellectual property comes from U.S.-based laboratories, institutions, and corporations.

(2) Interagency partnerships also require further attention. While the NNI implementation plan lists major interagency collaborations, the committee has no sense that there is any common strategic planning occurring in those areas, any significant interagency communication between researchers in those areas, or any significant sharing of results before publication in the open literature.

To stimulate meaningful interagency collaborations, we proposed a special fund within NNI, perhaps under the oversight of OSTP, for grants to exclusively support interagency research programs.

On the topic of program management and evaluation, the committee recommends that NSET develop a crisp, compelling, overarching strategic plan for the NNI which includes both short, medium, and long-term goals.

The committee recommends that NSET develop performance metrics to assess the effectiveness of the NNI in meeting its objectives and goals. Currently, the programs have only been evaluated as a part of the procedures of individual agencies.

(3) The committee recommends that OSTP establish an independent standing nanoscience and nanotechnology advisory board now. The existence of such a board would help the NSET agencies vision beyond their own individual missions. It could identify and champion research opportunities that do not fit conveniently into any one agency's mission. To ensure that nanoscale research continues its progress towards its ultimate potential, such a board should be composed of leaders from industry and academia with scientific, technical, social science or research management credentials.

I think this is the end of my statement.

[The prepared statement of Dr. Stupp follows:]

PREPARED STATEMENT OF SAMUEL I. STUPP, PH.D., CHAIRMAN OF THE COMMITTEE FOR THE REVIEW OF THE NATIONAL NANOTECHNOLOGY INITIATIVE, NATIONAL RESEARCH COUNCIL/THE NATIONAL ACADEMIES, AND BOARD OF TRUSTEES PROFESSOR OF MATERIALS SCIENCE, CHEMISTRY AND MEDICINE, NORTHWESTERN UNIVERSITY

Good morning, Mr. Chairman and Members of the Committee. My name is Samuel Stupp. I am Board of Trustees Professor of Materials Science, Chemistry and Medicine at Northwestern University, and chaired the Committee for the Review of the National Nanotechnology Initiative of the National Research Council. The Research Council is the operating arm of the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine, chartered by Congress in 1863 to advise the government on matters of science and technology.

I am here representing a committee that was composed of a mix of individuals from academe and industry, and drawn from a variety of scientific and engineering disciplines relevant to the topic of nanoscience and nanotechnology. The committee spent nine months reviewing the National Nanotechnology Initiative or NNI, and writing the report that is the basis of my testimony to you today. During those nine months, we heard from all of the agencies currently being funded under the NNI, and most of the agencies that are planning on joining in the NNI in the near future. In addition to the information gathered from these agencies, we also relied on the knowledge committee members have about activities on-going in our universities, in the private sector, in state and local regions, and internationally.

The committee was asked to review the NNI with particular attention to:

- Whether the balance of the overall research portfolio is appropriate,
- Whether the correct "seed" investments were being made now to assure U.S. leadership in nanoscale work in the future,

Whether partnerships were being used effectively to leverage the federal investment in this area, and

- Whether the coordination and management of the program is effective, such that "the whole is greater than the sum of its parts."

In writing its report, the committee was very concerned with communicating to the reader the importance of nanotechnology and its future potential. There have been a lot of promises made for the wonders which nanotechnology will provide for society, and while there has been hype, the committee can say definitively that nanoscience and nanotechnology are not dreams but are here today in products and technologies we currently use. You already use nanotechnology everyday in applications as mundane as the sunscreen and lipstick you may be wearing, to those as sophisticated as the high-density hard disk that runs your pc or laptop. Current research results point to even more applications in the near future, such as improved medical diagnostics and new therapies for disease and injury.

The committee found that the agencies participating in the NNI have made a good start in organizing and managing such a large interagency program. The committee was impressed with the leadership and level of multi-agency involvement in the NNI, particularly the leadership role played by the National Science Foundation. Programs funded to date that were presented to the committee were all of an appropriately high technical merit, and the participating agencies have sponsored a number of influential symposia in nanoscale science and technology, including one on the potential ethical, legal, and social issues involved in these technical advances.

The committee formulated ten major recommendations to help the NNI-participating agencies build on the foundation of their efforts to date to further strengthen the implementation of the initiative.

Concerning the balance of the research portfolio, the committee recommended that:

- More emphasis be given to long-term funding of new concepts in nanoscale science and technology. Truly revolutionary ideas will need sustained funding to achieve results and produce important breakthroughs. There are not currently enough funding mechanism to give longer-term support to higher risk but potentially groundbreaking ideas.
- The committee recommends increasing the multiagency investments in research at the intersection of nanoscale technology and biology. We can already see applications of nanoscale science and technology that will have significant impacts in biotechnology and medicine. "Bio-nano" is not currently as well represented in the NNI portfolio as it should be. Since many of the advances foreseen in this area involve the marriage of physical sciences and engineering with biology, these investments should focus on collaborations between NIH and the other NNI agencies.
- The committee recommends investment in the development of new instruments for measurement and characterization of nanoscale systems. Historically, many important advances in science happened only after the appropriate investigative instruments became available. Since one must be able to measure and quantify a phenomenon in order to understand and use it, it is critical that we develop tools that allow for more quantitative investigations of nanoscale phenomena.
- The committee recommends that NSET develop a new funding strategy to ensure that the societal implications become an integral and vital component of the NNI. The current level and diversity of efforts concerning societal implications of nanotechnology is disappointing. Federal agencies have not given sufficient consideration to societal implications of nanoscale science and technology. To ensure that work in this area is funded, the participating agencies should develop a funding strategy that treats societal implications as a supplement or set-aside to agency core budget requests, which is then awarded to agencies willing and capable to engage in this type of work.

On whether the correct "seed" investments are being made now for the future of U.S. leadership in nanoscale science and technology, the committee recommends:

- That NNI agencies provide strong support for the development of an interdisciplinary culture for nanoscale science and technology. Nanoscale research is leading us into areas involving the convergence of many disciplines—biology, chemistry, physics, materials science, mechanical engineering, and others. However, the overall value system used by the scientific community to judge its members continues to discourage interdisciplinary research. Although the number of interdisciplinary research groups will grow as it becomes evident that this approach is necessary to make the most exciting advances in nanoscale research, federal agencies should accelerate this process by developing creative programs that encourage interdisciplinary research groups in academia.

Looking at the question of whether partnerships are being used effectively in the NNI, the committee found that:

- Industrial partnerships need further stimulation and nurturing to accelerate the commercialization of NNI developments. The U.S. is most likely to realize economic benefits from nanoscale science and technology when this technology and its underlying intellectual property come from U.S.-based laboratories, institutions, and corporations.
- Interagency partnerships also require further attention. While the NNI Implementation Plan lists major interagency collaborations, the committee had no sense that there is any common strategic planning occurring in those areas, any significant interagency communication between researchers working in those areas, or any significant sharing of results before publication in the open literature. All NNI funds are currently directed by each agency to the projects and programs of that agency's choice. To stimulate meaningful interagency collaborations, the committee recommends the creation of a special fund within NNI, perhaps under the oversight of the Office of Science and Technology Policy (OSTP), for grants to exclusively support interagency research programs.

On the topic of program management and evaluation, the committee recommends:

- That NSET, the Nanoscale Science, Engineering and Technology subcommittee of the National Science and Technology Council, develop a crisp, compelling, overarching strategic plan for the NNI. This plan should articulate short, medium, and long-term goals, and emphasize those long-range goals that move results out of the laboratory and into society. In particular, the strategic plan should include a consistent set of anticipated outcomes for each funding theme and each Grand Challenge in the NNI implementation plan.
- The committee recommends that NSET develop performance metrics to assess the effectiveness of the NNI in meeting its objectives and goals. Currently the programs have only been evaluated as part of the GPRA procedures of individual agencies.
- Finally, the committee recommends that OSTP establish an independent standing Nanoscience and Nanotechnology Advisory Board (NNAB). The existence of such a board would help give the NSET agencies vision beyond their own individual missions. It could identify and champion research opportunities that don't fit conveniently into any one agency's mission to ensure that nanoscale science and engineering continue to progress toward their ultimate potential. Such a board should be composed of leaders from industry and academia with scientific, technical, social science, or research management credentials.

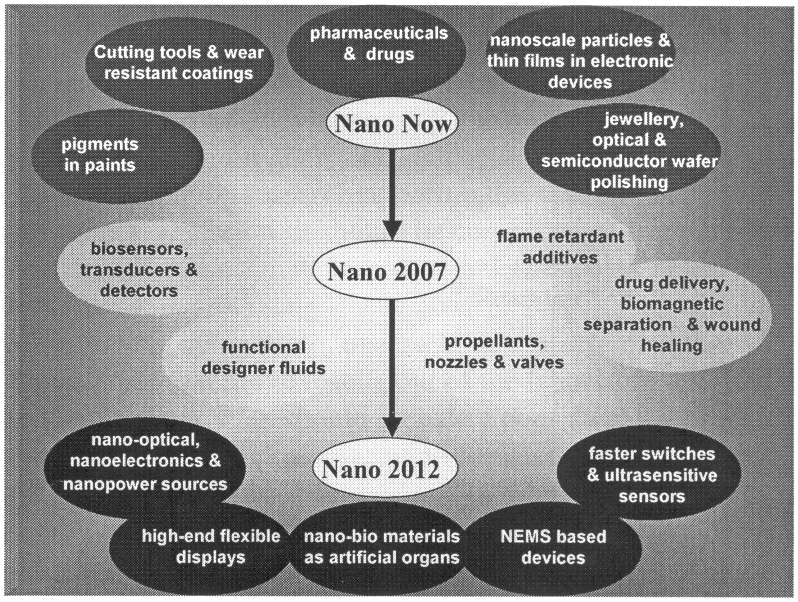
With this, I will be happy to take your questions on the report and its findings.

THE NATIONAL ACADEMIES, DIVISION OF ENGINEERING AND PHYSICAL SCIENCES

Small Wonders, Endless Frontiers: A Review of the National Nanotechnology Initiative—Summary

Background. Nanoscale science and technology, often referred to as "nanoscience" or "nanotechnology," is science and engineering at the scale of 10^{-9} meters, or 1/100,000 the width of a human hair. In the last two decades, researchers have begun developing the capability to manipulate matter at the level of single atoms and small groups of atoms, and to characterize the properties of materials and systems at that scale. This capability has led to the astonishing discovery that clusters of small numbers of atoms or molecules—nanoscale clusters—often have properties (such as strength, electrical resistivity and conductivity, and optical absorption) that are significantly different from the properties of the same matter in either the single molecule or bulk scales.

Using these discoveries, scientists and engineers have begun controlling the structure and properties of materials and systems. Current applications of nanoscale materials includes titanium dioxide and zinc oxide powders which are used by cosmetics manufacturers for facial base creams and sunscreen lotions. Nano-structured materials have been integrated into complex products such as the hard disk drives that store information and the silicon integrated circuit chips that process information in every Internet server and personal computer. In the future, these researchers anticipate that nanoscale work will enable the development of materials and systems with dramatic new properties relevant to virtually every sector of the economy, such as medicine, telecommunications, and computers, and to areas of national interest such as homeland security. With potential applications in virtually every existing industry, and new applications yet to be discovered, there is no doubt that nanoscale science and technology will emerge as one of the major drivers of economic growth in the decades to come.



Recognizing the tremendous scientific and economic potential of nanoscale science and technology, in 1996 a federal inter-agency working group formed to consider the creation of a National Nanotechnology Initiative (NNI). As a result of this effort, around one billion dollars have been directed towards NNI research since 2001. At the request of officials in the White House Economic Council and NNI-participating agencies, the National Research Council (NRC) agreed to review the NNI. A review committee was formed by the NRC and asked to consider topics such as the current research portfolio of the NNI, the suitability of federal investments and inter-agency coordination efforts in this area.

Findings and Recommendations. The committee was impressed with the leadership and level of multi-agency involvement in the NNI. Specifically, the committee commends the leadership of the National Science Foundation in the establishment of the multi-agency Nanoscale Science, Engineering and Technology (NSET) committee as the primary coordinating mechanism for the NNI. NSET has played a key role in establishing research priorities, identifying Grand Challenges, and involving the U.S. scientific community in the NNI.

Nevertheless, the committee has formulated a limited number of recommendations to further strengthen the implementation of NNI. Using information provided by all federal agencies involved in the NNI, the review panel considered the structure of this initiative over the past several months and makes the following ten recommendations:

- The committee recommends that the Office of Science and Technology Policy (OSTP) establish an independent standing Nanoscience and Nanotechnology Advisory Board (NNAB) to provide advice to NSET member agencies on research investment policy, strategy, program goals, and management processes. This board could identify and champion research opportunities that do not conveniently fit within any single agency's mission. It should be composed of leaders from industry, and academia with scientific, technical, social science, or research management credentials.
- NSET should develop a crisp, compelling, overarching strategic plan that emphasizes long-range goals that move results out of the laboratory and into the service of society. The Strategic Plan should include a consistent set of anticipated outcomes for each theme and grand challenge and estimated time frames and metrics for achieving those outcomes.
- The committee recommends that the NNI support more long-term funding and investment in nanoscale science and technology. Establishing a proper balance

between the short-term and long-term funding of nanoscale science and technology will be critical to realizing its potential.

The committee recommends increased multi-agency investments in research at the intersection between nanoscale technology and biology. The relevance of the NNI to biology, biotechnology, and the life sciences cannot be overstated. Cellular processes are inherently nanoscale phenomena. Barriers to inter-agency and interdisciplinary work must be over come to enable such developments.

- Historically, many important advances in science have come only after appropriate investigative instruments have become available. The committee recommends the NSET create programs to facilitate the invention and development of instruments for nanoscale science and technology. This should include analytical instruments capable of modeling, manipulating, tailoring, characterizing, and probing at the nanoscale.
- To help foster interagency collaboration the committee recommends the creation of a special fund for Presidential Grants, under OSTP management, to support interagency research programs relevant to nanoscale science and technology. These grants should be used exclusively to fund meaningful interagency collaborations that cross mission boundaries, particularly among the National Institutes of Health, the Department of Energy, and the National Science Foundation.
- Noting the need for greater interdisciplinary research, the Committee recommends that NNI provide strong support for the development of an interdisciplinary culture within science. To date, NSET agencies have encouraged multidisciplinary collaborations, but creative programs are needed that encourage the development of self-contained interdisciplinary groups as well.
- To enhance the transition from basic to applied research, the committee recommends that industrial partnerships be stimulated and nurtured, both domestically and internationally, to help accelerate the commercialization of NNI developments. NSET should create support mechanisms for coordinating and leveraging state initiatives, which focus on fostering local industry, to organize regional competitive clusters for nanoscale science and technology development.
- The committee recommends that the NSET develop a new funding strategy to ensure that consideration and assessment of societal implications becomes an integral and vital part of the NNI. This effort will help ensure that the "next industrial revolution" produces social and economic as well as technical benefits.
- NSET should develop metrics to assess the effectiveness of the NNI in meeting its objectives and goals. The committee sees a need to measure the progress of the NNI as a whole, with measurable factors including quality, relevance, productivity, resources, and movement of research concepts toward applications.

Senator WYDEN. Thank you. Dr. Williams.

STATEMENT OF R. STANLEY WILLIAMS, HP FELLOW AND DIRECTOR, QUANTUM SCIENCE RESEARCH, HEWLETT–PACKARD

Dr. WILLIAMS. Chairman Wyden, Senator Allen, and Members of the Subcommittee, I thank you for the opportunity to testify before you on the topic of nanotechnology. My name is Stanley Williams, and I work for Hewlett-Packard Company in Palo Alto, California.

To appreciate the smallness of a nanometer, first consider shrinking yourself down in three-dimensional factors of 1,000. You are now the size of an ant. Now shrink the ant down by another factor of 1,000. You would be the size of a red blood cell, the smallest cell in your body. Now take that cell and shrink it down by another factor of 1,000. That is the size of a nanometer, the size of a few atoms.

Nanoscience is the study of structures that are just a few atoms in size, and it is the scientific field where hundreds of years of advances in physics, chemistry, and biology have just recently converged. The unifying theme is that the intrinsic properties of matter such as color, chemical reactivity, and electrical resistivity depend upon the size and shape of matter only at the nanoscale.

Nanoengineered systems have the broadest possible arrangement of properties that human beings can design, which in turn means that building anything with control at the nanometer scale will enable us to produce them in the most efficient possible manner. Thus, nanotechnology is a collection of tools available to a broad range of scientists and engineers. However, it is not a complete solution to any problem. We will increasingly find that the crucial or enabling component of a system is engineered at the nanometer scale.

Indeed, Deutsche Bank in Berlin has estimated that the total value of nanotechnology-enabled products and services will be $116 billion this year. Thus, as we consider creating a national nanotechnology program, we must not neglect other scientific and engineering areas that provide the other components to complete solutions. I am going to give three examples that illustrate the breadth and scope of what is possible in the present, in the near future, and the longer term of nanotechnology.

By mixing hard and tough materials at the nanoscale, new composites have been made with levels of both properties never seen before in a single material. In the past year, General Motors has introduced a polymer clay nanocomposite already mentioned by Chairman Wyden that is used for running boards on their pickup trucks, and they plan to utilize this new composite in an increasing number of components in their vehicles in the future. In this one example, we see that a nanotechnology can help the fuel economy, the safety, the repair costs, and the ecological impact of our transportation system.

I believe one of the most significant nanoscience discoveries of the past couple of years is that carbon nanotubes and semiconductor nanowires are extremely sensitive sensors of chemical compounds. They should actually be ideal in home defense applications for the detection of explosives, poisons, and biological agents. Given an appropriate level of support, it should be possible to begin deploying such sensors in susceptible areas within 2 to 3 years.

On the 5 to 10 year time frame, it should be possible to cheaply manufacture such sensors in the hundreds of millions to billions of units per year to provide continuous monitoring of our public buildings, post offices, transportation networks, and other institutions vulnerable to terrorist attack.

On a longer time frame, recent discoveries and announcements in the areas of nanoelectronic memory and logic circuits promise to extend the dramatic improvements in performance of computers that we have seen well into the future. These advances also promise to extend the economic benefits of the electronics industry that the U.S. has enjoyed for many more decades.

From these examples, we see that nanotechnology has the potential to greatly improve the properties of nearly everything that humans currently make, and will lead to the creation of new medicines, materials, and devices that will substantially improve the health, wealth, and security of American and global citizens.

However, current experience in the United States shows that the number of excellent research proposals submitted for nanotechnology-related research far outstrips the available funds. The ramp-up in funding must be steep. I estimate approximately 30 percent a year, and sustained for at least the next 5 years. A national nanotechnology program will allow for continuous monitoring and feedback to make sure the best ideas are funded.

Also, increases in nanotechnology support must be consistent with an overall increase in the total physical science and engineering base in agencies such as the National Science Foundation, the Department of Energy, and the Department of Defense.

My primary concern for U.S. nanotechnology is that we will not train or retain enough of the best researchers to be the leaders in this crucial area. Currently, the United States is supplying only 25 percent of the global funding for nanotechnology research by national Governments. Other countries are determined to keep pace and even surpass our efforts by investing heavily and by recruiting the best and the brightest researchers away from the United States.

We will need to leverage our academic, Government, and corporate research capabilities to compete globally. However, relations between large corporations and American universities have never been worse. Severe disagreements have arisen over conflicting interpretations of the Bayh-Dole act. Many large U.S.-based corporations now work with the leading institutions in France, Russia, and China, which are willing to offer extremely favorable intellectual property terms for their support.

The U.S. Government has several roles to play to ensure that America leads the world in nanotechnology. The first is to invest sufficiently in the basic research enterprise which produces the scientists and engineers who will invent the future. The second is to act as an early adopter of new technologies, especially in the areas where technological advances enhance our security.

Finally, the Government should consider a new role, that of mediator to bring together academic, corporate, and national labs so that they can work together, and the Nation can share in the benefits of their discoveries.

Thank you very much.

[The prepared statement of Dr. Williams follows:]

PREPARED STATEMENT OF R. STANLEY WILLIAMS, HP FELLOW AND DIRECTOR, QUANTUM SCIENCE RESEARCH, HEWLETT-PACKARD

Chairman Wyden, Senator Allen, Members of the Subcommittee, I thank you for allowing me—on behalf of Hewlett-Packard Company—the opportunity to testify before you on the topic of nanotechnology.

Few words have generated as much hype and controversy over the past few years as 'nanotechnology'. On the one hand, some enthusiasts have established a quasi-religion based on the belief that nanotechnology will generate infinite wealth and life-spans for all humans. On the other, alarmists fear that nanotechnology will somehow end life as we know it, either by poisoning the environment or releasing some type of self-replicating nanobot that conquers the earth. Neither scenario is realistic, and both have been propagated by people who are good communicators but actually have no relevant scientific experience in the nanosciences.

This knowledge gap exists primarily because most scientists actually working in the field are either unable to communicate what they are doing to lay audiences or think they are too busy to try. I am afraid that many scientists are guilty of believing that the public in general and policy makers in particular are incapable of understanding science, and that their work should be supported simply because it is important and beautiful. This patronizing attitude has not served the citizens of the

U.S. or American scientists. It is certainly true that policy makers do not have the time to understand the full details of the research in any field of scientific endeavor, just as most scientist have no clue about the intricacies of the legislative process. However, we owe it to each other and to the American public to engage in meaningful dialog. Our two communities may not understand the details of what the other does, but we should each appreciate what the other has to contribute to the overall benefit of society.

I will attempt to provide you with some of that appreciation today by providing a high-level description and a series of analogies, each of which is certainly flawed but taken together I hope they provide you with a picture that you can utilize in your deliberations. Nanotechnology is particularly frustrating to describe. It is not one thing, and it is certainly not all things. I have been told by public relations experts that I need to simplify the field and provide a single rallying point upon which policy makers can focus. However, this would do a grave injustice to the field and I think in the long run it is an insult to your intelligence. Therefore, let me attempt to describe what nanotechnology has to offer by delving into some of the complexity.

First, one needs to appreciate the smallness of a nanometer. Consider shrinking yourself down in all three dimensions by a factor of 1000—you would become the size of a fairly small ant. Now take that ant and shrink it down by a factor of 1000—it would be about the size of a single red blood cell, which are the smallest cells in your body. Finally, shrink that red blood cell by a factor of 1000—that is the size of a nanometer, essentially the width of a few atoms. When thinking explicitly about this as a fundamental building block, Richard Feynman was truly prescient when he said there is 'plenty of room at the bottom'.

Nanoscience, the study of structures that are a few nanometers in size, is the field where hundreds of years of advances in the fields of physics, chemistry and biology have come together in just the past decade. Each discipline naturally and separately evolved toward this common goal through a series of intellectual advances, instrument developments and experimental discoveries. A significant fraction of the Nobel prizes in physics, chemistry and medicine in the past 10 years have been awarded for research discoveries at the nanoscale. Now that all three disciplines have arrived at this same goal, each has realized that it can learn much from the others, so that the field of nanoscience has transcended traditional academic boundaries. Engineers have been very quick to adapt the insights gained at the nanoscale, and in many cases have actually been the leaders in recognizing the trans-disciplinary synergies available. Material science, bio-engineering and electrical engineering are all rapidly becoming components of a nano-engineering super-discipline. The unifying issue for engineering is that the intrinsic properties of matter, such as color, chemical reactivity, and electrical resistivity, depend on size and shape only at the nanoscale. Thus, nano-engineered systems have the broadest possible range of properties that can be designed, which in turn means that building anything with control down to the nanometer scale will enable them to be produced in the most efficient possible manner. Thus, nanotechnology can and will be applied to everything made by human beings—it will allow us to dramatically improve nearly everything that we currently make, and it will enable us to create an entire range of new materials, medicines and devices that we cannot even conceive of today. Human cleverness is at a premium—which means high value added products and high wages for companies and countries that dominate nanotechnology.

With that said, we must realize that nanotechnology is a collection of new tools available to a broad range of scientists and engineers—it is not a complete solution to any problem. For the next several decades, there will be very few cases in which an entire product is the result of nanotechnology, but more and more we will find that the crucial or enabling component of a system is engineered at the nanometer scale. A current example of this is the giant magneto-resistance, or GMR, read head currently found in hard disk drives for computers—the recent dramatic increase in storage capacity of disk drives is directly attributable to the fact that GMR heads have components that are nano-engineered. The value of the read heads alone is fairly small, but they enable a multi-billion dollar per year industry. Indeed, Matthias Werner of Deutsche Bank has estimated that the total value of nanotechnology-enabled products will be $116 billion in 2002, and will increase dramatically in the near future. Thus, as we think about increasing support for the U.S. Nanotechnology Initiative, we must not neglect other disciplines that will also be contributing necessary components to complete solutions. As in all things, a balanced approach is essential.

What are the recent advances in nano science and engineering?

There have been so many recent advances in the nano sciences and engineering in recent past I could take up all my time just listing them. Let me give just three examples that illustrate the breadth and scope of what is possible in the present, the near future, and the longer term.

During the past couple of years, a significant number of new nanocomposite materials have come into the market place. These materials are engineered to combine properties that natural materials have never displayed, such as hardness and toughness. Naturally hard materials such as diamond shatter easily, whereas naturally tough materials like wood are easy to scratch or dent. However, by mixing hard and tough materials at the nanoscale, new composite materials can be made with levels of the two properties never seen before. In the past year, General Motors has introduced a polymer-clay nanocomposite material that is used for a dealer installed optional running board on their SUVs and pickup trucks. This material is not only harder and tougher, but it is also lighter and more easily recycled than other reinforced plastics, and GM plans to utilize it in more and more components of their vehicles as economies of scale make it cheaper. In this one example, we see that a nanotechnology can help the fuel economy, the safety, the maintenance cost, and the ecological impact of our transportation system. In the future, nanocomposites will become increasingly sophisticated and truly smart, with the ability to adapt to new environments and even to self-repair.

One of the most significant nanoscience discoveries of the past couple of years that came out of Stanford, Harvard and UCLA is that nanowires, especially carbon nanotubes and semiconductor wires, can be used as extraordinarily sensitive detectors of light and of chemical and biological agents. In this case, the nanowires have such a small diameter that any change on the surface of the nanowire has a dramatic effect on its electrical conductivity. There is already a significant activity in the U.S. and abroad to build sensors based on this discovery. These sensors can be used for medical diagnostics to detect and report extremely small amounts of pathogens for the early detection of disease such as a known cancer or even a new bacterial or viral infection not previously known. Prof. James Heath of UCLA has proposed a vision in which a laboratory on a chip with nanosensors could help investigators go from a new 'bug to drug' in 24 hours. However, probably their most pressing near term application will be for security applications for the detection of explosives, chemical warfare agents and biological threats. Given an appropriate level of support, it should be possible to begin deploying such sensors in sensitive areas within two to three years. Given economies of scale, it should be possible on the five to ten year time frame to cheaply manufacture such sensors in the hundreds of millions to billions of units to provide continuous monitoring our public buildings, post offices, transportation networks and other institutions vulnerable to terrorist attack.

I will also mention that on a longer time frame, recent discoveries and announcements in the area of nanoelectronic memory and logic circuits promise to extend the dramatic improvements in performance for cost that we have seen over the past 40 years. These advances promise to extend the economic benefits of the electronics industry that the U.S. has enjoyed for several decades, and also continue the efficiency with which we conduct our business and government affairs. We will see a wide variety of new products emerging, but most important of all we will see our electronic tools become much easier and intuitive to use.

What is the significance of and potential for the development and deployment of nanotechnology?

From these examples, we can see that nanotechnology has the potential to greatly improve the properties of nearly everything that humans currently make, and will lead to the creation of new medicines, materials and devices that will substantially improve the health, wealth and security of American and global citizens.

Is the Federal Government adequately investing in nanotechnology (i.e. perspective on the National Nanotechnology Initiative)?

Given the starting point of the NNI in the year 2000 and budgetary realities, I think the current funding for nanotechnology is appropriate. It would be a mistake to put too much money earmarked for nanotechnology too quickly into the research community, since it could not adjust and efficiently absorb that funding . However, current experiences show that the number of excellent proposals for research funding in nanoscience and engineering far outstrips the available funds, and thus the ramp-up must be steep, approximately 30 percent per year, and sustained for at least the next five years. A National Nanotechnology Program will allow for continuous monitoring and feedback to make sure that the best ideas are funded. Also, increases in nanotechnology support must be consistent with an overall increase in the total physical science and engineering base in agencies such as the National Science Foundation, the Department of Energy, and the Department of Defense.

As a nation, we have neglected our investments in physical sciences and engineering over the past decade. We have forgotten that these have been the drivers for our current level of material well being. The analogy is that physical science and engineering have been orchards, and we have been busily harvesting the fruits of those orchards for the past 20 years. However, we as a nation have forgotten that if we want to continue to harvest from such orchards, we must continually be planting new trees. As a fraction of GNP, our investments in basic research in the physical sciences and engineering have declined nearly 30 percent over the past decdade. This state of affairs has convinced American young people that there is no future for them in these disciplines, even though the potential in these areas is great.

As an expert and a leader in this field what are your concerns in the nanotechnology area?

My primary concern is that we in the United States will not have enough of the best researchers to be the leaders in this crucial area. Currently, the U.S. is supplying approximately 25 percent of the global federal funding for nanotechnology. Other countries are determined to keep pace and even surpass our efforts. Even though Japan has experienced significant economic problems, they make certain that their NNI meets or exceeds the funding levels approved in the U.S.. The European community is doing the same. Korea, Singapore, Taiwan and China are pouring a much higher percentage of their economy into research in this area, and when considering the local purchasing power of currencies, the PRC has the largest NNI in the world in terms of the number of researchers they intend to support. Another significant part of the NNIs of all other nations is that they have set aside significant funds to recruit senior and talented researchers from other countries, and for the most part they are targeting the U.S. The primary requirement for federal support of basic research, from a large corporation point of view, is the training of the people needed in our corporate research and development labs to invent the new products that secure our futures. We are going to have to be smarter and more efficient going forward—we need cooperation among government at all levels, national labs, and corporate R&D facilities.

I also have some secondary concerns for the future health of the U.S. R&D enterprise.

Largely as a result of the lack of federal funding for research, American Universities have become extremely aggressive in their attempts to raise funding from large corporations.

Severe disagreements have arisen because of conflicting interpretations of the Bayh-Dole act. Large U.S. based corporations have become so disheartened and disgusted with the situation they are now working with foreign universities, especially the elite institutions in France, Russia and China, which are more than willing to offer extremely favorable intellectual property terms.

The situation with respect to corporate partnering with U.S. National Labs is not much better. In this case, inconsistent policies, the long time lines to negotiate relationships, and constantly shifting government priorities often make it too difficult for companies to partner with National Labs. Again, there is an international market place. National Labs in other countries are aggressively courting American companies. Perhaps the major example of this is Center for Innovation in Micro and Nano Technologies, or Minatec, in Grenoble, France, which provides access to facilities and a source of students for companies that locate research labs on their campus.

The most important problem of all is that we have lost sight of the fact that government and corporate funds spent on research are not expenditures or luxuries that can be cut at a whim, they are essential investments to the long term viability of an enterprise. We have neglected those investments for a long time now. The prosperity of the 1990's was prepared by the investements of the 1960's, when the U.S. Federal Goverment was investing 2 percent of GNP on R&D. That investment has paid off many fold over the decades, but because we became wealthy, we forgot that we needed to keep investing to stay wealthy. The impatience of corporate boards and institutional investors have placed too strong a focus on short term results with too little long-term investment. A significant factor in the current economic situation, especially in the high tech sector, is that we do not have enough new and compelling products and services to generate customer demand. The internet bubble was a failed experiment to substitute clever business plans for new goods.

How should and could government-industry collaboration enhance research and development in the nanotechnology area?

The U.S. government has several roles to play to insure that America leads the world in nanotechnology. The first is to invest sufficiently in the basic research enterprise, which produces the scientists and engineers who will invent the future. The second is to act as an early adopter of new technologies, especially in the areas where technological advantage enhances our security. Finally, government should consider a new role, that of mediator to bring together academic, corporate and national research labs so they can work together and the nation can share in the benefits of their discoveries.

Senator WYDEN. Thank you, very helpful. Dr. Swami, welcome.

STATEMENT OF NATHAN SWAMI, DIRECTOR, INITIATIVE FOR NANOTECHNOLOGY, COMMONWEALTH OF VIRGINIA, AND MICROELECTRONICS PROGRAM DIRECTOR, UNIVERSITY OF VIRGINIA

Dr. SWAMI. Thank you, Mr. Chairman and Senator Allen. My name is Nathan Swami, and I am here representing the Initiative for Nanotechnology in Virginia, INanoVO for short. We are a coalition of State Government, leading research universities, and a growing family of nanobusinesses all across the Commonwealth. A list of our members and stakeholders is attached in the written version of this testimony.

Our organization has the goal to position Virginia among the national leaders in nanotechnology research and business development, as we are keenly aware that leadership in this key technology is a key to our economic future. In our short history in this field, we have seen great enthusiasm amongst different institutions in Virginia, different labs and different universities, including businesses, and we urge the passage of the 21st Century Nanotechnology Research and Development Act, as in the draft bill.

In my remarks this afternoon, I wish to sketch some general arguments in favor of this bill, and touch briefly on Virginia's perspective, which we believe will be shared by numerous regions across the Nation, and conclude with two recommendations that we believe will strengthen the impact of this legislation.

First, some comments. The rest of the panel have talked about scientific and business aspects of nanotechnology. I will extend it to its social implications and also its regional implications. First, we must recognize that our entire economy has become heavily dependent on technological innovation. Some economists estimate that nearly half of the American economy is now driven by new scientific discoveries in the technology-heavy sectors, ranging from agriculture and medicine, to man-made materials, electronics, information technology, and telecommunications.

We now know that further development in these and other industries will be driven in large part by a broad general movement that we have come to know as nanotechnology. So it is inevitable that we view nanotechnology, which in its simplest definition is a natural outgrowth of our ability to work with ever-greater precision in ever-smaller dimensions, as the foundation upon which we will enter this new age of innovation.

Some may ask, why do we need this bill? If nanotechnology is so promising, why cannot private enterprise foot the bill? The answer, quite simply, is this. We owe our leadership in high technology to the Government's timely investments in critical early stages, time and again, when emerging technologies were most in need of a boost in order to move toward eventual commercial success. From the dawn of modern agriculture, to aerospace, to the launching of the information age, Government support has been a powerful catalyst to drive basic research and accelerate technology transfer from the laboratory to the marketplace.

To those who ask, why pass this bill, we can respond to another question. What will happen if we do not? The answer is disconcerting. As we see other Governments of the European Union and East Asian nations investing heavily in long-term major nanotechnology research and development centers, the hard reality is the worldwide race for preeminence in nanotechnology is on, and America must push to stay ahead.

From Virginia's perspective, we see great promise for nanotechnology to boost business and industries that are crucial to our own overall economy, which include information technology, biotechnology, advanced materials, health care, et cetera. We have an impressive infrastructure in the State, with leading research universities, a lively venture capital community, and a business-friendly State government. For all our strengths, however, we are not yet at the point of critical mass. We have not yet created the synergies necessary to form leading nanotechnology research and development centers such as those currently under development in several other States.

I believe this will be the case with numerous regional areas where nanotechnology is carried out, and so we believe that this bill will be a catalyzing force to encourage nanotechnology research and education in Virginia, as in industrial regions of the Nation, to foster development of major public-private partnerships and to actively engage larger segments of our business communities and academic communities in nanotechnology movement.

Regarding the bill itself, we have two major recommendations that we believe will enhance its effectiveness. First, we judge that the pace of nanotechnology research will be accelerated considerably if the bill were to encourage the development of regional centers for excellence in research instrumentation which encompass both multidisciplinary facilities and state of the art infrastructure.

All scientific disciplines are engaged in nanoscale research, and much of this work requires sophisticated and expensive equipment. If this bill were to encourage the formation of regional networks of such research equipment, then access would be enhanced. We would anticipate more efficient utilization of equipment, a much broader participation of researchers from colleges and universities of all sizes, and a faster spread of the scientific, technological, and educational benefits of nanotechnology.

Second, we believe the bill should specifically require coordination between the National Nanotechnology Coordination Office and existing State nanotechnology initiatives, as well as university research offices. This decentralized approach is particularly necessary for nanoscale sciences, where much of the fundamental innovations will occur, or have been occurring in a bottom-up fashion.

One method to accomplish this is for the national office to directly fund State initiatives and charge them with the task of identifying and encouraging specific lines of research and business development based on identified strengths in their particular regions.

In conclusion, the Initiative for Nanotechnology in Virginia strongly supports the proposed bill and envisions it as a much-needed catalyst to help the Nation and regional centers realize their ultimate potential for scientific, technological, educational innovations through the enabling science of nanotechnology.

Finally, I would like to thank the committee Chairman and Senator Allen for inviting us to speak at this forum, and I gladly offer the services of our organization to help the swift passage of this bill.

Thank you.

[The prepared statement of Dr. Swami follows:]

PREPARED STATEMENT OF NATHAN SWAMI, DIRECTOR, INITIATIVE FOR NANOTECHNOLOGY, COMMONWEALTH OF VIRGINIA, AND MICROELECTRONICS PROGRAM DIRECTOR, UNIVERSITY OF VIRGINIA

Good afternoon. My name is Nathan Swami, and I am Executive Director of the Initiative for Nanotechnology in Virginia, or INanoVA for short. We are a coalition of state government, leading research universities, and a growing family of nanobusinesses that are emerging throughout the Commonwealth of VA. A list of our members and stakeholders is appended to the written version of my testimony. INanoVA's overall goal is to position Virginia among the national leaders in nanotechnology research and business development, as we are keenly aware that leadership in this exciting field is the key to Virginia's economic future. In our short history, we have found a rising tide of interest in nanotechnology, and it is with great enthusiasm that we urge passage of the "21st Century Nanotechnology Research and Development Act."

In my remarks this morning (afternoon), I wish to sketch out some general arguments in favor of this bill, touch briefly on Virginia's perspective, and conclude with two recommendations that we believe will strengthen the impact of this important legislation.

First, we must recognize that our entire economy has become heavily dependent on technological innovation. Some economists estimate that nearly half of the American economy is now driven by new discoveries in technology-heavy sectors ranging from agriculture and medicine to man-made materials, electronics, information technology, and telecommunications. We now know that further developments in these and other industries will be driven in large part by the broad general movement known as nanotechnology. So it is inevitable that we view nanotechnology, which in its simplest definition is the natural outgrowth of our ability to work with greater and greater precision in ever smaller dimensions, as the foundation upon which we will enter a new age of innovation. This new age, the Age of Nanotechnology, is one where we will imitate nature itself, thus endowing us with the capability to make materials, devices, machines and medicines with an efficiency and effectiveness that is undreamt of today. We are on the cusp of that new age now, and government support can assure that we will get there first.

Some may ask, "But why do we need this bill? If nanotechnology is so promising, why can't private enterprise foot the bill?" The answer quite simply is this: We owe our world leadership in high technology to the government's timely investments at critical early stages, time and again, when emerging technologies were most in need of a boost in order to move toward eventual commercial success. From the dawn of modern agriculture to aerospace to the launching of the Information Age, government support has been a powerful catalyst to drive basic research and accelerate technology transfer from the laboratory to the marketplace. In industry after industry, one sees the same pattern: federal dollars encourage early discoveries in a new technology, which then attracts private investment, which then grows into a successful industry, with large employers and many jobs for working Americans. Trace the history of agribusiness and the green revolution and you find federal dollars funneled through Agricultural Extension services in our land grant universities, an ongoing investment that has revolutionized American farming. Silicon Valley and Boston's Route 128 high tech corridor would not exist if the Federal Government had not invested in early stage research in computer science. The Internet itself is an outgrowth of federally supported research. We are now at another critical juncture in our technological evolution, and timely passage of this bill will go far to assure continuing American leadership in the global economy.

To those who ask, “Why pass this bill?,” we can respond with another question: “What will happen if we don’t?” The answer is discomforting, as we see other governments of the European Union and East Asian nations investing heavily in major nanotechnology research and development centers. The hard reality is that the worldwide race for preeminence in nanotechnology is on, and America must push to stay in the lead.

From Virginia’s perspective, we see great promise for nanotechnology to boost business development in industries that are crucial to our overall economy: information technology, biotechnology, advanced materials, health-care, aerospace, shipbuilding, and telecommunications, to name just a few. We have an impressive infrastructure in this state, with leading research universities, a lively venture capital community, and a business-friendly state government. Indeed, INanoVA owes its very existence to timely funding from Virginia’s Center for Innovative Technology, an economic development agency focused on innovative technologies with an impressive track record in facilitating the start up and growth of leading edge businesses. For all our strengths, however, we are not yet at the point of critical mass, and we have not created the synergies necessary to form leading nanotechnology R&D centers, such as those currently under development in several other states. This bill, we believe, will be a catalyzing force to encourage nanotechnology research and education in Virginia, to foster the development of major public/private partnerships, and to actively engage larger segments of our academic and business communities in the nanotechnology movement.

Regarding the bill itself, we have two recommendations that we believe will enhance its effectiveness.

First, we judge that the pace of nanotechnology research will be accelerated considerably if the bill were to encourage the development of regional centers for excellence in research instrumentation, encompassing both multi-disciplinary facilities and state-of-the-art infrastructure. All scientific disciplines are engaged in nanoscale research, and much of this work requires sophisticated and expensive equipment. If this bill were to encourage the formation of regional networks of such research equipment, then access would be enhanced. We would anticipate more efficient utilization of the equipment, a much broader participation of researchers from colleges and universities of all sizes, and a faster spread of scientific, technological, and educational benefits.

Second, we believe the bill should specifically require coordination between the National Nanotechnology Coordination Office and existing state nanotechnology initiatives, as well as university research offices. This decentralized approach is particularly necessary for nanoscale sciences where much of the fundamental innovations occur in a “bottom-up” fashion. One method to accomplish this is for the national office to directly fund state nanotechnology initiatives and charge them with identifying and encouraging specific lines of research and business development based on identified strengths in their particular regions.

In conclusion, the Initiative for Nanotechnology in Virginia strongly supports the proposed bill and envisions it as a much-needed catalyst to help the nation and regional centers realize their ultimate potential for scientific, technological, business and educational innovations, through the enabling science of nanotechnology.

Finally I would like to thank the Committee for inviting me to speak, and I gladly offer the services of our organization (INanoVA) to help in the swift passage of this bill. Thank you.

Senator WYDEN. Dr. Swami, thank you. that is very helpful. All of you have been very good. Just a few questions from me on this round, and Senator Allen and I always go back and forth, and as I said, what I would really like to do is just see if we could engage in a discussion.

I think it is fair to say, gentlemen, that the premise of this bill is that the National Nanotechnology Initiative is a sensible step for Government. I think it is a good step, a constructive step, and we are for it.

We think we can do better. We think we can build on it. I think what would be helpful is if you would highlight for us what you think the strengths and limitations of the NNI are. We'll start with you Dr. Stupp because of your work with the Academy. That way we can get your sense of where we are without getting you into endorsing every part of our bill as it is written.

Feel free, if you would choose to, to endorse every part of this legislation. But seriously, what I think we are more interested in is getting your sense of what the Government is doing well in this area, what areas the Government could do better in, and starting off our discussion in that kind of way.

Dr. STUPP. Certainly, what the Government did well was create NNI. That was a great concept. I think the only way to ensure that nanotechnology proceeds to its ultimate potential here in the U.S. is to have some kind of national program in nanotechnology. I think what is being done very well is certainly the great interest that all Federal agencies have shown in this initiative. I think across the board all agencies recognize the importance of nanotechnology, and that it has been very reassuring for members of the scientific community.

The limitations, of course, are along the lines of interagency partnerships, which we view as being key to the future of nanotechnology. A very important partnership, for example, is that of the NIH and the other agencies, because the only example of nanotechnology at work in its best expression is biology itself.

Senator WYDEN. What should be done in the biology area? I noted that in your testimony earlier. What would you like to see done in the biology area that isn't being done now?

Dr. STUPP. I think I would like to see programs that are specifically targeted to this interface of biology, medicine, and the physical sciences in the nanocontext, programs that are started by or initiated by agencies such as NSF, working alongside the NIH.

I think the NIH, for example, needs to invest a lot more money in nanotechnology than they are investing today, and the NSF on the other hand needs the funds to leverage those interactions with agencies such as the NIH.

I think my community, you know, the scientific community is really screaming for initiatives that are at this interface. The NIH has been an organization that has had a very strong mission, and you cannot criticize that. Their mission is to look over the health of our Nation, but at this point we all recognize in the scientific community that many of the most exciting opportunities lie at this interface with biology, and the NIH does not have the background, perhaps, to deal with it, and the NSF does not have the funds, so we have I think a problem of resources. We have, on the other hand——

Senator WYDEN. But that is a serious problem, we have a mix of insufficient talent and insufficient funds in an area that has extraordinary potential.

Dr. STUPP. We have great talent, and insufficient funds.

Senator WYDEN. Maybe I missed it. Did you not say at NIH there are people with the requisite expertise in the biology field, and at NSF there are the funds?

Dr. STUPP. But, of course, I am referring to the NIH as an agency that funds research. I am not speaking about the community of scientists, but there is, if you talk to any young person, our brightest young people in American universities today that are interested in science, you will find a large majority of them are interested in biology, but not necessarily traditional biology. They would like to innovate in medicine, and they see the technology as an enabling tool to get there.

Senator WYDEN. Let us see if we can get from Mr. Modzelewski and Dr. Williams and Dr. Swami the pluses and minuses of the NNI.

Mr. MODZELEWSKI. The biggest plus was the actual awareness. It told so many people in the corporate world and other Nations that nanotechnology was real and was serious. Unfortunately, the negative side of that awareness was sort of the nanotechnology race that might be best compared to a space race that was set off among Governments, who are increasingly funding and are increasingly aware of what this means to their economies in the future.

Other positive areas were the much-needed funds, the level of coordination, and a lot of groundbreaking research that I think was actually very visionary for a new program that looked into social aspects and implications, and economic aspects and implications of what was greatly a basic research program, so it was quite innovative.

We see some negative, not so much negative comments, but where there is a jumping off point to go a little further is probably look at research and development for commercialization. Again, things like scaling issues, it is one thing to make a very small amount of something on basically a small piece of glass in a laboratory, it is another thing to scale it up to production levels that industry could use. That is something in particular that many of the Asian competitive Nations such as Japan and Korea are very good at.

Another area to look at is the integration of private sector, all the more so into the NNI, and ensure that on things such an advisory panel, that industry is strongly represented, so that much of the research direction does go to the future of the economy, not that we would like to take out a lot of wild-haired ideas that are some of the foundations of great scientific discovery. But to know that there is a level of looking towards the commercialization of these technologies I think would be very important to any further direction.

And then I think there are a couple of issues that you could look at that are problematic across emerging technologies, and I think that would be things like the technology transfer system in the United States. It has certainly been improving at the Government level, but it still by most standards would be considered lacking at the universities, and still at a corporate level, when compared to other commercial operations, so to speak, and also the fear of a lot of patent issues, with the Patent Office being properly trained to understand this multidisciplinary structure, in granting patents that are too wide or too small, and also very timely and accurately approving patents.

Senator WYDEN. Dr. Williams.

Dr. WILLIAMS. I will have to second most of that. I think the primary issue that NNI did was give the field legitimacy. At that point in time it was viewed primarily as fiction, and it was often very difficult for people who were working in the area to be taken seriously, or to get grants funded when they submitted proposals.

Also, I think one thing that NNI did wonderfully was accept responsibility for ethical issues. Very early on, we were looking at the societal impacts and issues, trying to make sure that we did not have any nasty surprises that would come along and blindside the people working in this area. There was good communication about both the good, the benefits, and the potential downsides of nanotechnology and how they could be dealt with.

It is also true that the creation of the United States NNI has seeded tremendous competition worldwide. As soon as we had an NNI, the world had an NNI. In fact, Japan makes absolutely sure that whatever we do in this country, they do at least as much, because their fiscal year follows ours by about 5 months. Whatever the United States enacts, they do the same or more, and that can also be said of the European Union.

So as I mentioned in my remarks, I think the only way we can deal with global competition is to leverage all of the assets we have available in this country: the academic research community, our national labs and our corporate labs. I think the problem we have right now is that what few interactions existed are dramatically falling apart.

I see these communities essentially turning their backs on each other and just walking away. I myself have just given up hope of negotiating with universities anymore to get engaged in joint research ventures. It is just too painful. I think we really need to have, as a part of a national nanotechnology program, means for bringing these communities back together and conflict resolution among these communities. Perhaps even an explanation of what the heck Bayh-Dole actually means, and what it was intended to do, rather than the very, shall we say, aggressive types of actions that we see taking place whenever we try to negotiate with the university now.

Senator WYDEN. We'll talk a little bit more about Bayh-Dole in a minute or two. Dr. Swami.

Dr. SWAMI. Yes, briefly, I think a major strength, as has been stated in the past, has been increasing the visibility and the legitimacy of nanotechnology, no doubt about that.

Another strength, although it has been also pointed out as a drawback, by Dr. Stupp, is getting organizations to work together. Yes, there is no doubt that there is a limitation in that, but to me it is also a major strength that agencies as diverse as the EPA were brought into, with the NSF, all to work together on nanotechnology. Five years, seven years ago I would never have thought this would have happened.

Major limitations from the point of view of at least a regional center is, there are just too few large center opportunities, and since these are too few they end up being extremely competitive, fighting for a certain small amount of funds for a small amount of time, with a large number of competitors, and so I think the programs of the NSET and the interdisciplinary research programs that NSF has should be expanded to basically allow longer term research.

Second is research infrastructure has not been directly addressed. There is a lot of good infrastructure available to some centers which are near national labs, or which work with those national labs, but otherwise universities have to build this infrastructure, and then have the industry come and work with the universities at these, the infrastructure, and I think the infrastructure should be addressed in some form, for nanotechnology especially.

And finally, coordination of agencies, which many people have pointed out as a limitation, I would take that a step further. It is not just coordination of agencies for actual research done, but coordination of what happens with that research, who is doing what, coordination at the State and at the regional levels. That would be a limitation I think that could be acted upon.

Thank you.

Senator WYDEN. Okay. Senator Allen.

Senator ALLEN. Thank you, Mr. Chairman. Thank you all for your insightful testimony here, and answering questions. Let me ask Hon. Richard Russell a question. Listening to all of these concerns, I am going to follow up on some of them with him, but does the Administration have any target plans to aid in technology transfer and the commercialization of nanotechnologies?

It has been said through a variety of ways, and I do want to follow up on why it is so hard to work with universities for the private sector and so forth, but do you have any target areas to get through some of these problems? Much of which is saying, get it into commercialization like some of the examples we have, and that will obviously pay for some of the research in the future.

Mr. RUSSELL. Let me break that into two pieces. I think part of what NNI has been trying to do is push the envelope, and push technologies out, and if you look at the grand challenges under the NNI programs that currently exist, and look at things like nanoscale manufacturing, this is clearly an effort to push nanotechnology into, not just manufacturing, but into the economy. The second issue revolves around generically the concept of how we push tech transfer, and I think that with nanotechnology, as with all research we do with the Federal Government that we try to get commercialized, I think the very same issues that are revolving around nanotechnology are also relevant across the board, and so we wanted to promote things like CRADAs, we want to promote—

Senator ALLEN. Like what?

Mr. RUSSELL. CRADAs, corporate research and development agreements. We want to promote the use of the existing legal framework. Bayh-Dole was mentioned, and obviously there are issues between universities and industry, because really it is a win-win when you look at the universities and you look at industry. It is in both their interests to get this technology out. Industry obviously gains, the economy obviously gains, as does the university, and so where there are breakdowns in terms of nanotechnology I think there are probably the exact same issues we see across the board for all technology issues.

Senator ALLEN. Let me follow up, then, with the rest of the panel here. Thanks for your comments.

Some have alluded to the space race, and so forth, of the 1960s, and we have heard about how the Japanese and obviously Taiwan, Korea, and the European countries are all wanting to emulate or do more than we are. We hear the same things in aeronautics research. There are a lot of similarities in here.

The one thing that has been a thread through here, though, and especially from Dr. Williams and Hewlett-Packard's comments, as well as Mr. Modzelewski's comments, is the scientific research here, as far as the collaboration which is necessary with the private sector and universities and the Government, everyone collaborating, rather than having the Federal Government kind of as a mediator, and maybe it has to be.

Why are intellectual property laws—in some cases, I have heard you say that is harming us, and how is that different from the intellectual property laws in other countries, whether it is Japan or whether it is Europe? And if anyone of you all—and maybe, Dr. Williams, I would ask you to do this, since you say you do not want to bother working with universities and colleges, that Hewlett-Packard, it is just too much of a nightmare, it is too difficult.

These sorts of things, such as our patent laws, our intellectual property laws, and whatever other laws there may be at the Federal level that are harming cooperation with the private sector and universities, all are just fundamental problems that need to be addressed. And to the extent we can we ought to fix it so that people will have that collaboration, and make those investments, and obviously help the universities as far as their education, but ultimately, of course, benefit the competitive leadership role of our country.

So Dr. Williams, if you could start off, and any of you all who want to lend some commentary to that, I would appreciate hearing it.

Dr. WILLIAMS. I think the problem is not that the legislation is not good. I have now read the Bayh-Dole Act so many times I think I have actually memorized significant portions of it, and as I read it, it is a very fine act. However that is as I interpret it, and what we find is that people at universities interpret the same act, the same words in an entirely different fashion.

Senator ALLEN. For purposes of the record, would you share with us what your view is of the purpose of the Bayh-Dole Act? And how is it being misinterpreted?

Dr. WILLIAMS. My view of the Bayh-Dole Act is that it is a vehicle by which universities should be able to license intellectual property that they create in order to generate an economic benefit to the universities, and reward them for having created intellectual property. And in a sense to repay the investment that the public has made into performing research in generating an income stream for the universities. From that standpoint I believe that that is a very excellent idea. What it does is, it made universities more aware that intellectual property was important, and that it was an asset that they should take seriously.

I would say that from a large corporation point of view the problem comes down to the interpretation of just a few very simple sentences in the Bayh-Dole Act, which state that in the case of commercialization opportunities, small companies should be preferred over large companies. And there's also another sweet little sentence in there that says, if a company provides some funding to a research program, the university “may” give a license for that work to the company that provides the funding.

A large company reads that and says, okay, I give money to Professor X, whatever Professor X does, I own that. The university says, no, we actually have to prefer small companies, so you give money to Professor X, we, the university owns it. And by the way, when it comes time to license it, we are going to license it to a small company, and it is going to be very likely that that small company actually was created by Professor X.

So large companies have been burned many times by giving money for research to universities, only to find that they had absolutely no rights to the intellectual property that was created at all, and the intellectual property winds up being put in the hands of a small startup company which actually has the principals of the startup company being the professors who got the research funding. There’s a fairness issue there, and enough large companies have been burned enough times by this type of thing happening that most of the people I have talked with at large companies say, forget it, we are just not going to go there anymore. This is the end.

But in fact there is a reasonable decent and fair middle ground. The thing that the University interpretation of the Bayh-Dole Act does not really recognize is that there is a difference between an exclusive and a nonexclusive license, that if a company gives money to a professor to do research, of course it is totally unfair for the company to claim ownership to all of that research because they are not paying for the infrastructure that has been paid for by State and Federal funds and everything else that goes on. But on the other hand, it is possible to grant a nonexclusive license, in other words a license that recognizes a sharing of that intellectual property, the fact that the company provided money, and also often provides intellectual input to help to create those ideas as well.

So I think there is a meaningful middle ground. What has happened is that the discussion between most large companies and universities has become so strident that they become polarized and refuse to even acknowledge that there is a middle ground available to them, and what is happening is that they are growing further and further apart. And for my own part, I find it is far easier to me to start up a research collaboration with a university in Russia, or China, or France, than it is with a university, shall we say, just a few miles from where I am located.

Senator ALLEN. Thank you, Dr. Williams. Dr. Stupp.

Dr. STUPP. As Professor X, I guess I have to say something. right?

[Laughter.]

Senator ALLEN. This is a great concern, that it is easier for a company to deal with it especially in another country.

Dr. STUPP. I just wanted to say for the record that even though I agree with many of the things that my colleague Mr. Williams said, I think for the most part universities are careful, usually, to grant exclusive or nonexclusive licenses to those companies that funded the research. I think, I am sure there are exceptions. There may be different trends on the West Coast versus the East Coast or the Midwest, but I think if you look at the problem specifically, usually the universities are careful to do that.

The issue of a nonexclusive license, I agree with what Stan said, and yet the problem is that sometimes we receive, you know, $50,000 for 1 year of research from a company, often times a large company, and we are always very eager to please the company and show good results, so that you end up spending a lot more than $50,000 to achieve the goals. And so in that case, of course, a nonexclusive license is perfectly reasonable, and that is the way it should be done.

But just for the record, I think that if one wants to assess if this is a real problem, you really have to look at the statistics. There are too many universities in this country, and many of them are extremely careful, I would say, about matching one-to-one, and funds versus licensing.

Senator ALLEN. Well, Mr. Modzelewski, from your association, which obviously has a multitude of folks, you are looking for capital in your alliance, as far as your nanobusinesses, what do they say about this? We have two slightly different points here.

Mr. MODZELEWSKI. I think actually, picking off of something you just said, it is that careful nature. They are so careful that nothing gets transferred out. There tends to be, there are very few operations. I have heard less than a dozen among all the thousands of universities in America that are actually profitable on a tech transfer standpoint. Something like 6, I think, were last year, and one of the reasons for this is that nothing gets transferred out. The negotiations tend to be quite aggressive and quite onerous. The amount, the percentage that the university asks for tends to be very high.

This is—looking at the psychology, I mean, not being a psychologist myself, but looking into some of it, you tend to see from conversations with tech transfer people that they are all trying to hit a home run. They are all looking for the next Gatorade, or the next giant biotech revolutionary discovery that will bring in millions if not billions to the university, so in light of that they tend to negotiate so tough that nothing gets out.

They tend to look for such a big percentage just in case something hits, and that they are not held responsible for only getting 10 percent of a multibillion dollar drug discovery, that instead they just put the brakes on everything. And it does include, certainly, the corporations, but also the startups. There are many entrepreneurial professors at universities that try to take their discoveries off, and just cannot, or the fight is so long they say, I am really considering leaving my university.

I have had professors say, I would rather go to one of the ones that is working, or get out of here and give up my past portfolio, just cede it to the university, rather than sit here and just not be able to get anything done. They want to be entrepreneurs, they want to get things out, but the negotiation process generally just ties them up so badly.

Continuing along the same lines, there is also just issues with taking intellectual property and making it something that is global. The cost of registering patents in the U.S. is actually very cost-effective, and our processes really should be the envy of the world, but when you try to take a simple discovery that is here in the United States and get global protection, you are talking about more than a $100,000 process with legal fees and registration fees, and that is an incredible burden that most universities, unless award after award is being given to the research that was discovered, are willing to extend to the professor. And so that is another point that once you get to that global level, you start having some real difficulties and hit the wall.

Senator ALLEN. Well, some of those are similar to business decisions, regardless of whether it is a university and having to register it.

Mr. MODZELEWSKI. They cannot be blamed for that. If every professor who discovered something wanted a global patent, I think the university certainly does need to make that business decision. Nevertheless, you are entering an area of where might there be some easement of that sort of pain on a researcher, and where might there be programs, whether they be loan programs, or something along those lines, that might be able to help this bottleneck, the ability to get global protections.

Senator ALLEN. If I may, Mr. Chairman, can I follow up on this line of concern?

Senator WYDEN. Of course.

Senator ALLEN. In listening to the three of you all on this, there is maybe three different perspectives. Let us assume that some universities are more easy to deal with than others, some are very picky and very restrictive. Apparently, Hewlett-Packard has not found those that are better.

In listening to you, obviously the Nanobusiness Alliance, their view is that some are better than others. Could it be the case, or could it occur that those universities that are, let us say, more willing to strike a reasonable deal and a partnership with the private sector working with their professors, students and so forth, would those not then be one of the more attractive universities, or are they commonly known?

And I do not ask you to start listing names here, but if they were more commonly known, say the top 10 percent that have good business sense and are willing to take some of these risks and partner, would not more research go to those universities in the event that they have that reputation, so that it does not matter? Any company, Intel or Micron, would want to do that?

Mr. MODZELEWSKI. Yes. It almost becomes self-fulfilling. The ones who are very good at it are able to cut much easier terms, because they have so much flow that they know there will be something to receive on the other end. We have a lot of other universities, a few that they only have one shot. They swing for the fence on the ones they do get out. So you do see the schools that are well known in technology development, some of which are actually represented right here, being able to be much more fair in their negotiations than others, who are again just looking for that big hit that will change the university's dynamic.

Senator ALLEN. Dr. Swami, have you found this in Virginia, since you have worked with a dozen universities?

Dr. SWAMI. Yes. In Virginia we have the same paradigm with the big company and the small company, but clearly even small companies have had trouble getting these technologies on board because of negotiations with universities. Nevertheless, we still have had some success with at least about a handful of such technologies. Usually that has occurred when the professor, the entrepreneur, is entrepreneurial enough to take it to the next stage. If the professor has not been of that nature, then usually there is an even bigger stumbling block than anything else.

Senator ALLEN. Dr. Stupp, do you have any closing comments on behalf of the universities?

Dr. STUPP. I think one other thing one should add is that our experience with this process is still pretty young, and I would argue that maybe 5 years from now you will be able to make a better assessment, and this is a self-selecting process, I think. The universities who are really smart about dealing with technology transfer, eventually they will become attractive places, as you said, and people will gravitate to those, and those will be successful, I think.

We do not have many decades of experience in tech transfer at universities, and so I think you just need to let things sort out.

Senator ALLEN. Thank you, and thank you, Mr. Chairman, for letting me go a little longer.

Senator WYDEN. I thank my colleague, and I thank Dr. Williams. I have been trying to get everybody in this town to get interested in Bayh-Dole, because I think if people really understood what was at stake, we would do more than talk about this from time to time for a few minutes.

The fact of the matter is, and we have considerable statistics on this, Dr. Stupp, we spend billions and billions of taxpayer dollars every year on the National Institutes of Health, energy laboratories, and environmental laboratories. Under the Bayh-Dole law, which is more than 20 years old, we are supposed to have a process for commercially transferring these fruits of the taxpayers' research treasure trove to the private sector, yet virtually nothing gets out.

I have done a number of analyses of Bayh-Dole, and in my view, not only does the system not work for companies, it does not work for universities, and it does not work for taxpayers. We are at the point now where major agencies cannot even document where the tax dollars go with respect to key areas of investments with the universities and companies. Specifically at my instigation, the National Institutes of Health has sought to document Government investments in medicines, and they have not been able to do it. They literally do not know where all the investments are in promising medicines that the taxpayers have put up money for.

We do have a sense that perhaps half of the breakthrough drugs can get to market with taxpayer money, but we do not know where all of those investments go, and NIH is just now trying to assemble such a database.

And so I am going to leave this question of Bayh-Dole, other than asking Mr. Russell one question. We discussed this when you came to my office, when you were going to be confirmed. In light of the testimony today, our discussion, and other discussions I know you have had on Bayh-Dole, are you now convinced that it is time for an administration task force composed of university officials, of companies, and taxpayer advocates, to work together in a cooperative way to get more value out of taxpayer investments?

What Dr. Williams has done is blow the whistle here. Thank goodness somebody did from the real world, because when people talk to me about it, they say it does not work for universities, it does not work for companies, and it sure does not work for taxpayers. The statistics are pitiful, beyond the paltry return and the fact that we do not know where the money goes.

I have talked about this several times, and every time I do—Dr. Williams, I am going to be able to invoke your name—everybody heads for the ramparts. The universities worry that Ron Wyden is about to upset the apple cart. Western civilization is going to end, universities will not be able to do any more of the research, and all I have talked about is creating a winner for universities, companies and taxpayers.

I want to leave Bayh-Dole after we get Mr. Russell's comments, but what I would like to hear from Mr. Russell is that you get the message. You understand how serious this is. I would like to know within 30 days, whether the administration is willing to work with universities, companies and taxpayer groups to take a look at this 22 year old law. I believe it was enacted in 1980, and it does not seem to work for anyone now. I think we ought to examine this on a cooperative basis, because after all this is not a question of somebody being corrupt or evil.

[For example] a big part of Bayh-Dole did not even envisage the kind of health care applications that Senator Allen and I are so excited about. It did not even envisage what would happen with the tax law, where Bristol Myers Squibb made $1.6 billion last year and virtually nothing was given back to the taxpayers. So I would like to see you all within the administration review this on a cooperative basis.

Mr. RUSSELL. As you indicated, you have raised this with me previously. We took it seriously at that time, as we continue to take it seriously. We did ask PCAST, the President's Council of Advisors on Science and Technology, which is made up of both university presidents and industry CEO's, to look at this issue.

The initial reports that we have gotten back is that Bayh-Dole as a framework makes sense. I think some of the specific issues that have been raised here today, though, are interesting, and I think that we should look at those, I am more than happy to work with you and your staff on fleshing out some of these very specific issues, because clearly, we are talking about nanotechnology, the Federal Government is investing a lot of money in nanotechnology. It will be investing a lot of money in the future in nanotechnology.

The universities are going to get a lot of that research money, and we do want to see that research passed through to the U.S. economy, so I am more than happy to work with you and your staff on the issue. I hate to commit to a task force. I will tell you that right up front.

Senator WYDEN. If you all want to try and reinvent the Bayh-Dole law through the prism of nanotechnology, that is fine with me, but what Dr. Williams just told us is that he is having so much trouble with this that he and his colleagues will traipse to Russia and around the world, rather than work with universities here. That is not a trifling kind of concern. That goes right to the heart of what I have been interested in trying to change.

Mr. RUSSELL. And I would say, as I think I started my comments off to Senator Allen, that I use nanotechnology as an example. I do not think this is a nanotechnology-exclusive issue. I think we have to be careful that when we talk about tech transfer we look at it broadly, and not based on any single emerging technology, because I think whatever lessons we learn from nanotechnology are going to be the same for other technologies as well.

Senator WYDEN. I am willing to look at it broadly. I have looked at it broadly, and I have looked at it in depth; I have even looked at the exclusivity matter, Dr. Williams. A few years ago, there was an exclusive deal between Scripps and Sandoz, and I basically busted that up, because it was totally contrary to the interests of the public, to the business community, and to this country.

The Scripps-Sandoz deal would essentially have put an exclusive agreement together with respect to general scientific knowledge, and it would all have been lubricated with taxpayer money. We broke that up, and since then I have followed the issue. At a minimum, Mr. Russell, I would hope that the administration would use nanotechnology in a cooperative way with universities, companies, and with taxpayer groups to get some changes. I think we can do so much better, and I have tried to promote such a discussion for some time.

Dr. Williams, I did not know you were going to discuss Bayh-Dole today, but I think you performed a great service by blowing the whistle on this.

Dr. STUPP. Mr. Chairman, I wonder if you would allow me just one extra thing.

Senator WYDEN. Sure.

Dr. STUPP. That when you speak about the enormous investment of taxpayers' money, and the billions of dollars, you should also recognize that this always needs to be a part of the equation if we are going to revisit the law and so forth, that we have, of course, we provide—I mean, the main function that we have is education, and we have invested—a lot of that taxpayer money actually goes into training a very technically competent workforce, perhaps the best in the world, possibly, and we use the investment from taxpayers' money to educate our people, and this is a very costly procedure.

At the same time, large companies in the last 20 years have downsized their basic research efforts, and so there is now suddenly a much greater—you know, there is a spotlight on universities to take the burden of basic research and development, which is very difficult to do inside universities, because it is not compatible with education.

Senator WYDEN. I think that is a very fair comment, and there is no question that there are many beneficial ramifications of the work between companies and universities. Bayh-Dole's central premise is that when taxpayers support research, we are supposed to get breakthroughs out of the laboratory and turn it into innovations in the marketplace. Clearly this is an area where we must do better. If companies like Hewlett-Packard tell us that not only are we not doing it, but they are so frustrated at this point that they are going to go to the former Soviet Union, we have got a challenge on our hands.

Dr. STUPP. Maybe you should come to the Midwest.

Senator WYDEN. Let us have those discussions. I thank my colleagues. I have additional questions. Would you like to ask any?

Senator ALLEN. No, but I do want to thank you all for your very insightful testimony.

Mr. Chairman, I am sorry, I have other meetings I have to get to.

Senator WYDEN. Thank you. Let us go specifically back to nanotechnology. Now that we have had this discussion on Bayh-Dole, I would like to hear about the health care applications of nanotechnology, and particularly what kind of nano-inspired health care applications look promising in the short term. What does the landscape look like further down the road? Would any of you like to start with that? Dr. Stupp.

Dr. STUPP. Well, there are two technologies, I think, that are likely to be nano-inspired, that will have broad impact. One of them is targeted drug delivery. If you think about cancer, for example, we basically kill our patients with toxic drugs, and in the end the battle is lost, and a lot of these problems have to do with our ability to target medicines to the right locations of the body.

I think the nanodesigns of drug couriers will definitely address this problem. Whether you see this as a short or a long term is not really clear, but nonetheless I think, I would prefer to think that it is not really long range, it is actually middle range.

The other one is regenerative medicine, because that is an alternative to medicines. Why not use nanotechnology to regenerate parts of the heart, or to regenerate cartilage, or bone, or regenerate spinal cords so you can reverse paralysis, reverse blindness?

What is needed there is, you have to design materials, which are typically referred to as scaffolds, that will give cells the right signals to regenerate normal tissue, and the only way we are going to be able to get that is to design materials at the nanoscale that can in some rational way interact with cells, so I would say regenerative medicine is one of those areas where nanotechnology has enormous potential, and it happens to be a wonderful example of something that biologists alone will not do, engineers alone will not do. This is going to have to be a team effort, and highly interdisciplinary effort, and a very important fruit of nanotechnology, basically repairing human beings, and this will eliminate the need for a lot of the medicines that we now take which are not very successful, probably shorten our life span.

Senator WYDEN. Others on the health care applications of nanoscience? Dr. Williams?

Dr. WILLIAMS. I think an area that actually has potential for happening relatively soon is an entirely new means for diagnosis. Right now, of course, when you go to the doctor you give a little blood sample and it goes off to a lab, and it takes several days to come back, and then, of course, it is fairly nonspecific set of information that the doctor gets.

With new technologies for being able to build entire laboratories on a chip, and within those laboratories, being able to build extremely sensitive nanoscale detectors which can be targeted at a wide range of vectors, if you will, for either external attack or some type of internal disease like cancer, a medical exam can essentially be performed immediately. You get results back in real time.

I think that with the marriage of advanced information technology we also have the possibilities of creating in real time with the diagnosis a directly specific treatment for the particular patient who is coming to see the doctor, so I think that this whole area of diagnosis is going to change the way people interact with their doctors, and the way you have your physical exams, and that I think is the type of thing that literally can happen within a relatively short number of years, 2, 3 years, some of these things can be up and ready to go if there is the will to actually do it.

Senator WYDEN. Dr. Swami, did you want to comment on health?

Dr. SWAMI. My comments would probably follow on what Dr. Williams said. Basically, I would just extend it. Diagnostics is probably one specific application in the general field of sensors, because nanotechnology has the ability to sense extremely sensitive signals. Due to that, and due to the fact that it can be embedded very easily into products, sensors would be a field where you can see an immediate application, a platform where they could immediately or very soon work directly on the product development in that field.

Mr. MODZELEWSKI. One other area that is already happening right now and is already in trials from a company called C–60 is actually using a Bucky ball as a protease inhibitor for the AIDS virus. As the AIDS virus tries to attach itself to a cell, you might almost consider it like an octopus trying to latch on, and what they basically are working on right now is actually using a Bucky ball to actually block it from attaching itself to the cell.

It is not treating the HIV, so the HIV is not developing any mutations towards it, or going about it different ways. It is just thwarting it from doing its job, which is to attach itself and to replicate.

Senator WYDEN. Gentlemen, some are raising concerns about the ethics of nanotechnology and saying in effect the scientific developments are outpacing the focus on ethical concerns. I am curious whether you share that view and, if so, whether you have any recommendations for how it ought to be dealt with.

Dr. WILLIAMS. Frankly, I think, and largely because of Mike Roco's leadership, the NNI has been almost unique in its focus on societal issues, and trying to elevate the awareness very early in the entire cycle, so yes, it is very, very true that right now our tools that we have are evolving much faster than we ourselves are.

For millennia we have all very slowly worked with our tools, but now the tools are changing by orders of magnitude, well within the life span of any individual, so that is very difficult for us to deal with and adjust to, but in my own opinion the NNI provides the model that exists so far for being able to take into account these ethical and social issues in watching a science evolve into a technology and beyond.

I think this is a first. I think it is the first time this has been done, so I am sure that the process can be improved. But I applaud Mike Roco and the others who have been involved in Examining ethical issues doing this, because it is imperative for people to be well educated in the tools that are going to be used in the society around them.

Senator WYDEN. Doctor.

Dr. STUPP. I just would add, briefly, that our committee, our report very specifically talks about this in recommendation 9, because we felt that even though there was the intention of the NNI to look into issues of societal implications, the reality is, it really has not happened to a great extent, and so we are recommending that the NNI implements a new strategy to make sure that those programs do take place.

Senator WYDEN. Gentlemen, in your view, what needs to be done to make sure that this country has a properly educated nanotechnology workforce? It is very clear that the educational aspects of this are going to be key, and we are going to have to look at this systematically, particularly at the universities. Why don't we take a minute or two to get your thoughts on what it is going to take for this country to have a properly educated workforce to really tap the potential in nanotechnology.

Dr. Stupp, do you want to start with that, with the academy's views?

Dr. STUPP. Definitely, the development of an interdisciplinary culture is key for nanotechnology development. I think that it would be fair to say that most universities have recognized that multidisciplinary research is important. However, it is not yet clear to a lot of investigators what interdisciplinary research really is.

I mean, there is a difference between multidisciplinary and interdisciplinary. What we need most is interdisciplinary culture, meaning that individuals themselves are interdisciplinary, and this is a very challenging educational task, but in fact the NNI, and hopefully with the advice of some external board that includes members of the scientific community, as well as individuals with expertise in research management, will be able to impact directly on this goal by creating the right programs that will encourage this kind of interdisciplinary development among individuals. So interdisciplinary culture is key.

I think we need to catalyze it through the NNI programs, and so somebody has to think hard about how to do that. The solutions are not there yet.

Senator WYDEN. Others? Mr. Modzelewski, particularly the private sector. I can think of an awful lot of public schools in Oregon where we are very excited about the prospects of nanotechnology, where we would like to see your companies make investments.

Mr. MODZELEWSKI. I think it starts there. I think it starts very early. I mean, I think we have to make a real effort not to just consider this as a college program, but to get kids interested in the physical sciences at a much younger age, and not just getting them interested. I think too much emphasis is put on, perhaps, an idealistic view that this excitement in science will just naturally be drawn within them.

I think there needs to be other buttons pushed, and I think certainly financial incentives, and that the entrepreneurs of tomorrow might be—are the researchers of today is certainly something that should be underlined far more, that the companies of tomorrow in nanotechnology are the startups that are being started by researchers at university and corporate labs, and that they are going out to start these, and I think that level of incentive also being worked in is something that we need to accept as probably being part of the incentive package for young people to think of this as a career move.

Right now, you are talking about a field that is greatly dominated at American universities by foreign students. You will find Chinese nationals in some cases being the entire program at a university, and at some of the startups the entire research team being Chinese nationals, who they know at one time or another are going to be recalled to their home country to do their work. So we really do need to think of this as an imperative how we incentivize, and I think mainly just getting the information out there as science is cool and exciting is one thing, and that is sort of a path we have taken, but I think also to point out that it is a great career move, and a very lucrative career, is something that will certainly attract young people.

Senator WYDEN. Any idea, of today's nanotechnology workforce in this country, how many are from other countries?

Mr. MODZELEWSKI. I would be giving a blind guess, but it is definitely more than half.

Dr. WILLIAMS. I can give an observation. 17 out of the last 18 people I have hired were born outside the United States, and half of those were educated outside the United States.

Senator WYDEN. Well, that sort of sums it up.

Dr. WILLIAMS. Actually, if I may just make a comment along this line, to be real crude about it, money talks. If you look at what has happened over the course of the past decade, and track as I have the enrollments of American undergraduate students in various disciplines as a function of time, what has happened is that the enrollment of American undergraduates tracks almost exactly the investments in basic research.

So over the past decade, NIH has actually been doing very well. Their budgets have been going up. The enrollments of American under graduate students in biology departments in the United States is skyrocketing. It is up over 55 percent in just the past few years.

On the other hand, in mathematics, in physical sciences, in engineering, overall funding is down, and down significantly. Enrollment of American undergraduates in those programs is down 20 to 30 percent over the past decade.

I have asked young people what they want to do, and they always tell me, oh, I am going to go into biology. I ask then why. Well, that is where the action is. You know, from the standpoint of a young person looking at a career, you go to a college and you see where all the money is being spent on a college campus, it is being spent primarily in the biology departments because of the strength of the NIH, so of course, that is what draws them into it.

I believe that by taking the steps that we have taken, by legitimizing nanotechnology and as long as we have the commitment to increase the funding and keep it going, we will see significant increases in students going into this area, because it is very exciting intellectually. There are tremendous careers associated with nanotechnology, but the interface, the only place where young people learn that is when they first show up on a college campus; especially disadvantaged young people, who are the ones who are most likely going into sciences, you might say they do not know any better, but it turns out to be a great opportunity for them. And so I think that the NNI, just in being what it is, and in focusing attention and putting money into it, is going to have a tremendous impact on them.

Senator WYDEN. Well, gentlemen, there are a couple of questions I am going to ask of you all in writing. One of them deals with some technical issues with respect to the employment picture. It is clear that this is a significant opportunity for new jobs. It is very important in my State. We have the highest unemployment rate in the country, and what I would like to do is get into some of the specific areas where you think the biggest sources of jobs are likely to be. We will submit that and a couple of other questions in writing.

Let me leave you with this. The irony is that we did get into a significant area that I did not expect to talk about at all today, which is the Bayh-Dole law, because it is clear that cutting edge science and nanotechnology is something we are all particularly excited about. It means we have got to get it right with respect to the role for Government, the role for private sector, and the role for universities. As I think Mr. Modzelewski said, with respect to education, we need to start even earlier than the universities, and I think we have got that opportunity with nanotechnology. I think we have got an opportunity to get it right.

The administration clearly is moving in the right direction. Mr. Russell is a good man, and we have worked with him in the past. The NNI is a very positive step, and that was clearly the consensus of all today. The purpose of the legislation Senator Allen and I have with Senator Lieberman, Senator Landrieu, and Senator Clinton introduced is to build on it.

We can do a bit better, and you can be very sure we are going to work closely with the administration and all in this country who care so much about it. We hope as we adjourn today's hearing and leave with a great deal of excitement about the possibility of regenerative medicine, never having to buy a pair of khakis again, and all kinds of other excitement that we have heard about today, that we leave with the idea that if we work together and get it right, nanotechnology can serve as a model that we will be able to duplicate again and again when there are other exciting fields. There is certainly enough goodwill and commitment over on that side of the dais to do it, and we will match it with bipartisan support over here, and we thank all of you for your patience. You have been here a long time, and with that, the Subcommittee is adjourned.

[Whereupon, at 4:25 p.m., the Subcommittee adjourned.]

A P P E N D I X

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

Our nation has long prided itself on being the world's premier innovator of new ideas. Over the last two and a half centuries, the uniquely American willingness to experiment with novel concepts and to chart bold directions has placed us at the forefront of scientific and technological progress. Our ability to engage in scientific exploration and to marry research findings with the development of practical applications has, in turn, enabled us to set the benchmark on virtually every indicator of human progress, from longer lifespans, to higher standards of living, to unparalleled economic productivity.

However, while past accomplishments may confer a present competitive advantage, it does not guarantee future success. We cannot afford to rest on our laurels in a world that is becoming increasingly characterized by the speed with which scientific paradigms shift and technological revolutions occur. In a global economy in which ideas and technology are the new currency, every new breakthrough represents an opportunity to claim—or, in our case, lose—global leadership.

The emerging field of nanotechnology constitutes such an opportunity. It is not just any opportunity, however, but one whose magnitude and significance locates it on the scale of harnessing electricity, creating antibiotics, building computers, or wiring up the Internet. It is, in short, a new frontier in science and technology that has the potential to transform every aspect of our lives. Nanotechnology, in fact, may have even greater potential to affect the way we live since it has such broad prospective applications in so many different areas, from medicine, to electronics, to energy. Nanotechnology is what scientists and technologists often call an "enabling" technology—a tool that opens the door to new possibilities constrained only by physics and the limits of our imaginations.

Yet, despite the enormous potential that nanotechnology offers, it is not an area in which we have assumed uncontested leadership. From an international perspective, the United States faces the danger of falling behind its Asian and European counterparts in supporting the pace of nanotechnological advancement. Other nations have grasped the fact that the first players to fully capitalize on the promise of nanotechnology have the potential to leapfrog in productivity and precipitate a reshuffling in the economic, and perhaps aspects of the military, pecking order. Accordingly, they have undertaken substantial efforts to invest in nanotechnology research, and to accelerate technology transfer and commercialization. While our nation certainly possesses the raw resources and talent to lead the world in developing this technology, it is also clear that a long-term focus and sustained commitment, as well as new collaborations between government, academia, and industry, will be needed to ensure our place at the head of the next wave of innovation.

In recognition of the need to support ongoing nanotechnology efforts and to spur new ones, I am pleased to join Senator Ron Wyden in cosponsoring today the "21st Century Nanotechnology Research and Development Act." 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, intelligently coordinated program for addressing the full spectrum of challenges confronting a successful national science and technology effort, including those related to funding, coordination, infrastructure development, technology transition, and social issues.

I feel it is appropriate at this point to give credit to President Clinton for having the prescience and initiative of creating the NNI, and to applaud President Bush for expanding support for nanotechnology R&D from $270 million in FY 2000 to the $710 million targeted in his budget request for FY 2003. The NNI has been a key driver of nanotechnology in this country by bringing coherence and organization to what had previously been a scattered set of research programs within the Federal Government. It has, in no small part through the efforts of its spokespersons, Dr. Mike Roco and Dr. Jim Murday, achieved a higher profile for nanotechnology both within and outside the government, and brought the importance of this field into the national consciousness.

The time is now ripe to elevate the U.S. nanotechnology effort beyond the level of an Executive initiative. Funding for nanotechnology will soon reach $1 billion a year, and the NNI currently attempts to coordinate 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 closely tracks the recommendations of the National Research Council (NRC), which completed a thorough review of the NNI this past June. The NRC report stated how impressed the reviewers were with the leadership and multi-agency involvement of the NNI. Specifically, it commended the Nanoscale Science, Engineering, and Technology (NSET) subcommittee, which is the primary coordinating mechanism of the NNI, as playing a key role in establishing research priorities, identifying Grand Challenges, and involving the U.S. scientific community in the NNI. To catalyze the NNI into becoming even more effective, the NRC made a number of recommendations. These recommendations have largely been incorporated into our bill, including establishing an independent advisory panel; emphasizing long-term goals; striking a balance between long-term and short-term research; supporting the development of research facilities, equipment, and instrumentation; creating special funding to support research that falls in the breach between agency missions and programs; promoting interdisciplinary research and research groups; facilitating technology transition and outreach to industry; conducting studies on the societal implications of nanotechnology, including those related to ethical, educational, legal, and workforce issues; and the development of metrics for measuring progress toward program goals. This legislation will also complement the provision that I authored in this year's Senate defense authorization bill, S. 2514, establishing a nanotechnology research and development program in the Department of Defense. If this provision is supported in conference, we will have matching pieces of legislation that will encompass and coordinate both civilian and defense nanotechnology programs, establishing a truly nationwide effort that leverages the expertise residing in every corner of our government.

If history teaches us anything, it is that once the wheels of innovation have stopped and stagnation has set in, mediocrity will soon follow. Nowhere in the world are those wheels of innovation spinning more rapidly than in the realm of nanotechnology. This legislation provides a strong foundation and comprehensive framework that elicits contributions from all three sectors of our society in pushing nanotechnology research and development to the next level. I look forward to supporting Senator Wyden in getting 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. RON WYDEN TO HON. RICHARD RUSSELL

Bayh-Dole Act

We heard from Dr. Stan Williams of HP and others at the September 17 hearing that the Bayh-Dole Act and the way that universities deal with intellectual property is a major barrier to university-industry collaboration. In fact, Dr. Williams noted that it is easier to work out a partnership with foreign universities than with U.S. academic institutions. While the promise of Bayh-Dole is to get research off the shelf and commercialized, the reality of Bayh-Dole is that industry and academia often view the process differently and we get few useful results.

Question 1. As you know, I am of the opinion that the Bayh-Dole law isn't working for any of its constituents—universities, industry, government, or taxpayers. How can we fix Bayh-Dole? Would OSTP or another appropriate agency be willing to lead an Administration task force made up of university people, companies, taxpayer advocates, and other interested parties that would work in a cooperative way to reform Bayh-Dole?

Answer. The President's Council of Advisors on Science and Technology (PCAST) has created a Panel on Federal Investment in Research and Development and its National Benefit. The panel has been charged with two goals:

1. To review the R&D portfolio to determine areas where programs should be expanded, curtailed and maintained; and

2. To give advice on technology transfer mechanisms that will encourage commercial development to ensure maximum benefit for research funding.

With respect to the second goal, one of the Panel's primary interests is the Bayh-Dole Act. The PCAST Panel is seeking perspectives on the Act from all parts of the science and technology community, including representatives from industry, academia, government labs, the venture capital community, and other interested parties.

The Panel is working with these representatives to understand their viewpoints regarding whether the Bayh-Dole Act has been effective in promoting or catalyzing the transfer of technology from federally funded research to the private sector through licensing of patented intellectual property. Likewise, these representatives may also suggest to the PCAST Panel whether improvements to Bayh-Dole would involve the Act itself, or the manner in which the Act is interpreted or implemented. The Panel is hoping to include these perspectives on the Bayh-Dole Act in their larger analysis of technology transfer mechanisms that should be developed at the end of 2002.

In addition, PCAST tentatively plans to hold an open forum on tech transfer in December to assist in soliciting a wide range of viewpoints on tech transfer programs including best practices under Bayh-Dole.

Sufficient Government Support of Nanotechnology Research

Question 2. Given that other countries are also investing significant amounts in this field, do you feel that we are doing enough to ensure our leadership in this field?

Answer. The administration proposed a $679 million investment in nanotechnology for FY 2003, a 17 percent increase over FY 2002 funding levels. Taken together with past increases (FY 2002 levels were 25 percent higher than FY 2001 levels, for example), nanotechnology represents one of the fastest-growing areas of federal research funding. The investment in nanotechnology also leverages the overall federal R&D investment, which reached unprecedented levels in the President's FY 2003 budget request. This overall investment helps support the research facilities and the higher education system that make the U.S. science and technology enterprise the world's best. However, while federal funding is important to maintaining U.S. leadership in nanotechnology, it is but one component underlying the strength of this field. For example, private sector innovation, and policies that support this innovation, are of critical importance as well.

Question 3. The Administration has requested $1.1 billion for FY 2003 for nanotechnology. We want to ensure that the efforts are well coordinated. How is that effort coordinated? How does its coordination compare with the coordination mechanisms for the Information Technology Research program? Does it make sense to bring in an advisory committee of outside experts to aid in the coordination?

Answer. The Federal investment in nanotechnology is coordinated through the Nanoscale Science and Engineering Technology (NSET) subcommittee of the National Science and Technology Council (NSTC). NSET is currently chaired by a representative from NSF. Representatives from each agency participating in the NNI, as well as OSTP and OMB, attend regular meetings of the NSET and have a voice in coordinating the programs of the NNI. A National Nanotechnology Coordinating Office (NNCO) serves as a secretariat for the NNI, in a manner directly analogous to the function of the National Coordinating Office (NCO) for the Networking and Information Technology Research and Development (NITRD) program.

Outside input on federal R&D issues is important, and Presidential advisory committees are one mechanism for gaining this input. However, formation and maintenance of a Presidential advisory committee comes at significant cost. Creating an advisory committee dedicated solely to advising on issues related to nanotechnology would necessarily draw funds away from the research and development activities of the NNI. The President's Council of Advisors on Science and Technology (PCAST) is an independent, external advisory body comprised of leaders from industry and academe who provide important extra-governmental input on R&D issues to the President and are clearly qualified to provide advice on issues related to nanotechnology. For this reason, drawing on an existing body such as PCAST represents a preferable means for gaining non-governmental, expert advice on nanotechnology without diverting funds away from research and development activities.

Question 4. How are you tracking and measuring the success of nanotechnology research programs?

Answer. Each agency that participates in the NNCO is responsible for reporting its accomplishments to the NNCO, which then assembles and includes these data in an annual report. Under the NNI, each agency invests in those R&D projects that support its own mission as well as the overarching NNI goals. While each agency consults with the NSET Subcommittee, the agency retains control over how resources are allocated against its proposed NNI plan. Each agency then uses its own methods for evaluating potential projects, and each assesses its NNI research activities according to its own Government Performance Review Act (GPRA) policies and procedures.

Question 5. Your hearing testimony highlighted the economic potential of nanotechnology. Let me play devil's advocate for a moment—if nanotechnology is such a huge, revolutionary area, why should the Federal government invest here? Why can't companies bear this burden, if they are going to be positioned to reap the profits?

Answer. The Federal government supports basic research and development across a broad range of disciplines that advance the frontiers of knowledge. Because the field of nanotechnology is still, in many ways, in its infancy, there is a clear need for fundamental research that answers the most basic questions regarding why materials behave differently when studied at the nanoscale instead of at more conventional scales. Understanding these questions will enable further research, including the type of research and development most important to industry. Given industry's focus on shorter term return on the research investment, the private sector simply will not fund the bulk of this type of long term, basic research. Thus there is a clear role for the Federal government in funding fundamental nanotechnology research, and this has been the priority of the NNI as a result.

Question 6. What do you see as the biggest challenges nanoscience currently faces? In other words, what barriers could potentially keep nanotechnology from reaching its potential?

Answer. The biggest challenges facing nanoscience include the development of new scientific instruments to enable precise measurements and manipulation at the nanoscale; the development of robust, reliable methods for fabricating reproducible structures; and the generation of sufficient numbers of scientists and engineers to make these advances. In addition, the societal impacts of nanotechnology must be addressed. Each of these issues represents an area of focus within the existing framework of the NNI.

Multidisciplinary Education

It appears that nanotechnology is an interdisciplinary science, combining facets of chemistry, materials science, computer science, biology, mechanical and electrical engineering, and physics.

Question 7. How well prepared are our universities to produce the next generation scientists who have the requisite expertise in multiple disciplines in order to ensure that the United States continues to lead in nanotechnology research?

Answer. Academic institutions are routinely engaged in reviews of existing curricula. How best to address the increasing need for scientists and engineers who can function at the intersection of multiple disciplines is a question many academic institutions are grappling with. One role of the Federal Government in this area is to fund the development of innovative educational programs aimed at helping to educate the next generation of scientists and engineers. Examples of federally-funded higher education programs related to nanotechnology include the following: Penn State used NNI funding to implement a new degree program in Nanofabrication Manufacturing Technology; NSF Integrative Graduate Education, Research and Training (IGERT) programs have funded a host of graduate projects on nanotechnology at a range of institutions; and NNI funding has supported education and training centers and networks at Columbia, Rice, Cornell, Harvard, Northwestern, and Rensselaer.

Question 8. What needs to be done to promote a multidisciplinary curriculum at all levels, not just universities, so that we have a properly educated nanotechnology workforce?

Answer. Decisions regarding the adoption of particular curricula at the K–12 level are best made by local entities. Federally-funded nanoscience-specific activities, including some funded through the NNI, are aimed at increasing the scientific and mathematics proficiency of the nation's K–12 students. For example, the NNI-sponsored activities mentioned above also have outreach functions that support K–12 educational programs, and additional K–12 activities at Wisconsin, North Carolina, Arizona State, Rensselaer, the University of Tennessee, Rice and the University of Illinois at Chicago are funded through the NNI. In addition, the National Science Foundation and the Department of Education support the Mathematics and Science Partnerships program. This program, a key element of President Bush's No Child

Left Behind education blueprint, supports partnerships between institutions of higher education and school districts in order to *improve preK–12 math and science achievement for all students, to improve teacher training and professional development in these crucial subjects, and to improve the quality of math and science curricula. In addition, Federal sponsorship of research at universities, including activities mentioned in the previous answer, includes significant support of work that will result in a better educated and larger nanotechnology workforce.*

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. RON WYDEN TO F. MARK MODZELEWSKI

Nanotechnology, Job Creation, Regional Centers

Question 1. How many jobs do you anticipate the nanotechnology industry creating over the next ten years?

Answer. This is a challenging question to answer as no formal studies currently exist. In fact, we urge the Congress to ensure that the U.S. Department of Labor undertakes a study of this question in FY 2003.

The difficulty in developing such a projection stems from the fact that nanotechnology is a *platform* technology—not unlike harnessed electricity, the internal combustion engine and the transistor. As a platform technology that will have a transformative impact on everything from the material sciences to life sciences to information technology and electronics means that in most cases nanotech will expand growth in these industries or reverse downward trends. It is expected that nanotechnology will become completely intertwined in current industries—before creating new ones.

Nanotechnology employment growth trends will scale in much the same way biotechnology, the semiconductor industry, and the Internet sector developed; however, growth is reasonably expected to be sustained over a longer period of time as nanotech's reach is far greater. Current projections predict nanotechnology to represent a value of $1 trillion to the U.S. economy in value in little over a decade, it is safe to say that 10 percent–25 percent of all U.S. jobs in a decade will be directly related to nanotechnology.

On a regional jobs development scale, we can look to history for job growth projections. For instance, Albany, NY recently became home to the next generation of SEMATECH—the semiconductor industry's development program. This project involves nanoscale semiconductor development and is part of the SUNY Albany NanoTech Center. Analysis by the State of New York strongly suggests that this $400 million project (together with the $400 million previously raised from corporate and state interests for the Albany NanoTech Center) will trigger economic development on par with Austin, TX's extraordinary growth initiated by the original SEMATECH project in 1988.

Since arriving in Texas, SEMATECH has been responsible for attracting 11 percent of all jobs in the State—35 percent of manufacturing, 10 percent of service, 13 percent of trade, and 12 percent of construction job growth. Austin-metro region unemployment rate is *one-half* that of the nation at large. Employment in the broad technology sector totals 125,000 and includes approximately 2,000 firms, including:

- More than 200 semiconductor and semiconductor related companies located in the Austin area employing nearly 24,000 people.
- Approximately 120 computer manufacturing and peripherals companies employ more than 43,000 people.
- More than 450 software development companies employing 30,000+ employees.
- Annual R&D expenditures in Austin has risen from less than $200 million prior to 1980 to in excess of $1.4 billion by the private and public sectors with the number of technology patents awarded to the areas inventors nearly doubling since 1991.

Groundbreaking nanotech projects today will mean incredible regional—and national—job growth in the future. Again, serious analysis on this point is needed going further to make proper determination and to aid planning.

Question 2. How can this industry effect areas of high unemployment such as my home state of Oregon?

Answer. Nanotechnology will create jobs in two profound ways:

1. New development of jobs and industries
2. Invigoration of old industries as the opportunities provided by nanotechnology render their continuation and location economically feasible.

Nanotechnology is already fueling development in new methods of drug delivery and medical treatments (in Texas and California); fuel and solar cell development (in New York and Texas); and organic electronics and quantum computing (in California, Colorado and New York).

An example of a industry that is about to demonstrate explosive growth through nanotechnology is the sensors sector. Sensors have gradually found their way into vehicles and personal appliances, but their size and cost have placed major limitations on their availability and use. The industry was hitherto unable to maximize its extraordinary potential: small and inexpensive sensors to detect pathogens on meat, poisons in the air, diseases and disorders in the body, even tire pressure and stress on an aircrafts wings. Nanotechnology is rapidly providing the opportunity—through capability, size and price—to fuel this development. Barriers to entry in this field from an R&D and manufacturing perspective are very low and areas of Oregon and other regions experiencing economic stress could certainly build and attract efforts in the field.

As to invigorating old industries, nanotech is providing radical innovations to current products: composite materials, coatings, textiles, lighting, batteries and semiconductors, to name a few. at an ever increasing rate, many of these sectors have been transitioning to lesser-developed nations, leaving job loss in their wake. If the U.S. invests sufficiently in nanotechnology, its developments will make these industries economically feasible for the U.S. again.

For example, the textile industry has all but left the United States, leaving major unemployment in its wake. Companies such as Nano-Tex and eSpin are now providing radical improvements to this field with wear resistant and water and stain repellent technologies. The cost of implementing these technologies into the manufacturing processes of textiles is nominal, yet it provides the industry with enormous financial incentives to keep factories in the United States, where such technology is easily available.

New York State explicitly noted that the "Capital District" where the Albany NanoTech is located has both the solid university resources to build around, and a manufacturing base of great potential but now in despair since the relocation of IBM, Philips and other companies operations. The decision to align this nanotechnology development project with this region is purposeful and will allow for R&D to interplay with corporate and employment development.

Focusing on Oregon's major employers we see the following interplay of nanotechnology:

- **Healthcare (Children's Hospital, HMOs, etc):** New drug delivery and treatment techniques using Bucky Balls and Q Dots; new MRI and X Ray technologies using caged atom techniques; new bio-sensor detection methods to spot diseases at their earliest stages.
- **University System (OU, OSU, etc):** Research programs across the spectrum of nanotech—materials science, catalysts, life science and medical, and IT and electronics. Potential to spin off start-ups and collaborate with in-state corporations.
- **Nike:** Health Sensors and monitors; stain and wear resistant nano-fabrics; and composites materials for the soles of shoes and athletic gear.
- **Intel:** Continuation of Moore's law through nanoscale chip development and production technologies.
- **NORPAC Foods:** Sensors to detect pathogens on foods; new, more energy efficient refrigeration; new fuel, and lighting systems technologies.

The NanoBusiness Alliance strongly urges that the Federal Government undertake an effort to determine those regions most likely to experience a major industrial impact from nanotech at the management, research and wage earner levels. Additional studies are needed for PhD, MBA level development, as well as at America's 4-year undergraduate level and at two-year colleges.

Question 3. What does it take to get a successful nanotechnology hub going? What elements do these communities share? How can the Federal government help in that process?

Answer. This question is extremely important, as prevailing economic theory demonstrates the importance of developing such hubs. In his book "The Competitive Advantage of Nations," Harvard Business School professor Michael Porter makes the case for a new approach for both understanding and creating economic success in a global economy. Porter relates the competitiveness of nations and regions directly to the competitiveness of their home industries. Moreover, he argues that in advanced economies today, regional clusters of related industries (rather than individual companies or single industries) are the source of jobs, income, and export growth. These industry clusters are geographical concentrations of competitive firms in related industries that do business with each other and that share needs for common talent, technology, and infrastructure (Mary Watts, ASU). Call it the power of collaboration.—a new competitiveness framework for state economic development.

For any cluster development to work, government, corporations, start-ups, service firms, non-profits, venture capital and start-ups must come together to develop three tiers of interaction and collaboration:

- First Tier: Leading companies and/or research universities
- Second Tier: A myriad businesses that provide supplies, specialized services, investment capital, and research to these companies and others involved in the nanotech field.
- Third Tier: is composed of essential economic foundations (e.g., advanced infrastructure, specialized workforce training, R&D capability, the pool of risk capital available in the region) that are the building blocks of healthy clusters and a competitive economy.

At this point no region has reach true critical mass in developing a nanotechnology cluster. The industry is so nascent and has been developing at an unexpectedly rapid rate that has prevented anyone from developing an insurmountable lead. What my organization, the NanoBusiness Alliance, has attempted to do is jumpstart the creation of nanotech clusters through our NanoBusiness Hubs Initiative. The Alliance Hubs bring together business leaders, researchers, government officials, investors, corporations, service industry principles, start-ups and other interested parties to drive forward the growth of nanobusiness in their regions. The new program kicked-off in New York, San Francisco/Silicon Valley, Colorado, Michigan, San Diego and Metro—Washington DC.

The NanoBusiness Alliance Hub Initiative serves as a localized catalyst to fuel understanding, discussion, planning, and implementation for area specific nanobusiness development. Each Alliance hub undertakes the process of bringing together key stakeholders to develop regional nanotechnology business clusters. In turn we provide them with a top line assessment of their nanotech assets (universities, start-ups, corporate efforts, etc), generalized best practices of other regional development (using past industries efforts and current regional nanotech efforts as a model), organizing meetings with area stakeholders and networking their efforts into our other regional hubs so they can interact. Our goal is not to run these efforts, but to set them in motion and tie them together through our organization.

To be perfectly blunt, our resources at the Alliance have been completely over tasked. We are proud of our work to date and have already gotten major progress under way in the New York and Colorado, substantial movement underway in 4 other regions, as well as other efforts in Chicago and Texas into our network, we are an organization of under 10 employees, on a tight budget raised through corporate membership, events attendance, and report sales and can no way meet the demands of organizations in 35 states and 11 countries that have contacted us to help develop this capacity.

What the Federal Government could do to be a force in jumpstarting the effort to create regional hubs is the following:

- **Education:** Too few political and corporate leaders, as well as the general public know anything about nanotechnology or its economic promise.

  - National NanoBusiness Summit: Hold a high profile national summit in Washington DC to educate the public on the future of nanotechnology as a science, a technology and a business. Make special efforts to educating the youth of America to pursue the study of the physical sciences as a path for their future.

  - Trade Missions/Exchanges: Hold trade missions between the U.S. and other leaders in the nanotechnology field to find opportunities for collaboration and markets for their nanotech developments.

  - Regional Events: It is not enough to hold a large scale event in Washington to spread the word of nanotechnology and its economic impact, efforts must be made to hold events in states and regions to spark excitement.

  - Database: Though databases are being developed for the nanosciences, no effort has been made to create or fund a database of corporations, start-ups, supporting service firms, and investment resources. There is also no platform for existing government resources under one p banner for nanotech—contracts, grants, loan programs. Not only to inform but also to be a platform for collaboration. Regions could also explain their efforts and share best practices.

• Studies: Many basic studies to understand the dynamics of the nanotechnology economy have yet to be performed. The Departments of Labor, Education, Commerce, HUD, and Defense are all necessary components in developing an understanding of the nanotech workforce of tomorrow, its economic impacts and the state of global competition, etc. In addition, as we learned from how foreign markets have addressed GMOs, there is a real aversion to surprises in technology development. Nanotech is about to offer up many such surprises. There is a real need for global studies on the health and environmental effects of nanoscience right now or there may be major consequences later—either real or imagined—that will slow and perhaps cripple important developments.

- **Coordination:** Make the National Nanotechnology Initiative more than just an oversight and funding agency for basic research. The NNI should also be equipped to address the needs of the emerging business of nanotechnology and study the competitive business climate in the U.S. and abroad. There needs to be strong linkages with agencies such as Department of Commerce Office of Technology Policy, the Department of Labor and the Department of Education.
- **Capital:** The timing for the sudden rise of nanotechnology as a business could not be worst in terms of market conditions on Wall Street and in the venture capital sector. Recent corporate announcements by GE and Microsoft noting they saw real opportunities in new future markets (like nanotechnology), and hence were increasing R&D efforts, were met with extremely negative responses on the Street.

  There is no need for the Federal government to become a blank checkbook for the nanotech industry with huge levels of new funding for business. However, the Federal Government would be missing a real opportunity to advance the nanotechnology industry if it did not develop some level of new incentives and, grant and loan programs. In addition, the Federal Government should have a mandate to take existing programs and ensure that they reach out to emerging technologies, such as nanotechnology—particularly at Defense, Agriculture and SBA.

  In addition, though NIST ATP has certainly had its problems and has many opponents, it nonetheless is a program that could be critical to the long term development of nanotechnology. ATP is almost unique in the Federal Government in that it acts as a conduit for funding during the critical middle stage of development—post-basic research/pre-commoditization—when companies are dealing with issues such as packaging, scaling and integration. This is a timeframe that no venture capital firm will fund—and a timeframe they affectionately refer to as the "valley of death."
- **Government Practices:** There are many existing programs and methods employed by the Federal Government if changed could provide much needed assistance and resources to the emerging nanotechnology industry without requiring huge funding outlays. Some examples include:

• *Tech Transfer:* The technology transfer environment in the U.S. is abysmal at the university and government level—though admittedly the government is certainly making greater strides. Efforts should be made to reform the execution of the Bayh-Dole Act or to rewrite it. In addition, government labs, the land grant college system, and any university working on government research grants, should be pushed to post their nanotechnology IP portfolio in a central NNI database along with appropriate contact information to spur use and commoditization of these technologies.

• *Patents:* The U.S. Patent and Trademark Office is among the most highly overburdened organizations in the government. The PTO is expected to receive 350,000 patents applications this year and on top of backlog roughly equal to that number. PTO is the gateway to technology commercialization on America. It must be given the necessary funds (or allowed to retain their fees collected) in order to properly attend to nanotechnology and other emerging technologies.

Case in point, PTO must have the funding to provide training to its examiners in the field of nanotechnology. Nanotech is an extraordinarily cross-disciplinary technology reaching into nearly all sectors of examination at PTO. Efforts must be made to ensure PTO can properly understand and manage the nanotechnology patent application process. In turn, PTO must also work with the nanotechnology industry to help train its researchers and companies so that legal protections are appropriate and timely. At the NanoBusiness Alliance we have begun to work with PTO on these issues, arranging for meetings between industry and officials and bringing in researchers to talk with PTO examiners about their work. Indeed we have found PTO officials to be extraordinarily welcoming and professional. However, this effort needs to be more formalized and extensive.

In addition, it is imperative that Congress address the October 3, 2002 Madey v. Duke decision by the Federal Circuit which ended the so-called research exemption from United States patent law. The effect will no doubt be chilling, essentially ensuring that all corporate collaborative research with universities and other non-profit research institutions will move offshore as every other industrialized country in the world recognizes a research exemption in patent law but the U.S.

Before Madey the research exemption had been unquestioned under the convincing case law line that came from no less an authority than perhaps the leading scholar on the early Supreme Court, Joseph Story, in his landmark opinion in 1813 in *Whittemore* v. *Cutter* which used the now anachronistic term "philosophical" instead of "scientific" to describe the experimental use exemption from patent infringement. This "scientific-philosophical" exemption from patent infringement resides at the very core of the Constitutional mandate for Congress to create a patent system "to Promote the Progress of "the Useful Arts"—an essential component being that those skilled in such Useful Arts are free to use the knowledge imparted by a patent disclosure to create better and newer technologies.

If the United States is to maintain its high level of nanotechnology research—as well as any other emerging field of scientific study whether it be biotech, photonoics, or fuel cells—it is essential that the Congress not wait to see if the Supreme Court intervenes on Madey, and immediately reinstate the research exemption into law. If this is not done immediately, expect corporate research collaborations with America's universities and non-profit institutions in America to come to a near end as this work is exported globally to the major research centers of the world—Kyoto, Zurich or Shanghai.

- *FDA Advisory Committee:* Much like the PTO, FDA is an enormously burdened agency. FDA historically has responded to new directions and techniques rather than being proactive. With such revolutionary developments as bucky ball drug delivery and protease inhibitors, quantum dot disease detection, and pin point cancer detect and removal through gold nano-shells all in advanced laboratory development, it is imperative that FDA be ready to rapidly and properly address and evaluate these developments and not let them languish—at the peril of the American public—for a decade or more of evaluation. That is why we strongly recommend that FDA be compelled and funded to immediately create an internal advisory committee on nanotechnology. This committee would establish education initiatives and relationships in the nanotech research community to ensure that future evaluations of developments are handled with great speed and great caution.
- *EPA:* Because of the rapid development of nanotechnology from science to a business there has been little research done into the health and environmental effects of the technological developments. While all current evidence suggests that c60 is safe for long term use in the body, we don't know definitively. Activist groups, many of which have been involved in limiting the growth of the GMO industry, are already lining up against nanotechnology development, some even calling for moratoriums on commercialization. This can't be allowed to happen.

For the industry to develop and meet its potential, we need study and we need public education to begin now. The NanoBusiness Alliance is working with our European and Canadian counterparts to create a foundation to ensure that a dialog on nanotechnology's health and environmental effects is begun immediately. We are seeking to ensure that studies are undertaken and that public awareness campaigns are begun today. Our organizations are reaching out to the environmental community to work with them to address any concerns they have on nanotech's development. We believe that it is imperative for the Federal Government to be aligned with these efforts—particularly the EPA and FDA.

- *Government Grants and Programs:* Because of the newness of nanotechnology, many researchers, business leaders and officials in the field have little understanding of programs and grants already provided by the government that may help develop nanotechnology. In turn government officials, at say SBA, have little idea of how their programs can be adjusted or administered to serve this emerging industry. Efforts should be made to develop regional outreach events at all major government agencies to ensure a dialog and full participation in existing programs for the nanotechnology community. In addition, the NNI website should become a one stop shop for all government programs and grant information that may be open to the NanoBusiness community.

Another area to address is evaluation criteria. Many self-funded companies in the nanotech arena have complained at length at how SIR criteria—for instance—is unbalanced and better serves venture backed start-ups.

In addition, criteria for evaluating new nanotech centers—whether it be new round of NSF, DoD or DOE centers—should be made to include commercialization planning and regional development planning as a grading criteria so that it does not become merely for research sake.

- *Advisory Board:* The NanoBusiness Alliance and our member organizations welcome the call for the 21st Century Nanotechnology Research and Development Act for the creation of a national advisory board on nanotechnology. We believe that it is imperative that the President and Congress have top advisors from outside the government—people who are on the front lines of nanotechnology' s development—to provide vital feedback and advice on the NNI and overall government nanotech efforts. However, we feel it is essential that such a board reflect the full spectrum of the nanotechnology community and not be a board made up of just the research community. Nanotechnology business leaders—start ups, corporations, even service industry executives must be part of this effort to ensure that it is effective. Also, it is vital that the various regions of the U.S. where nanotech is developing be included fairly, so that traditional tech clusters like Silicon Valley, Boston and greater Washington been't included at the exclusion of other developing regions such as the Pacific Northwest, Chicago, Texas, upstate New York, and others. Lastly, it is of grave importance that the Advisory Board also cover the breadth of the nanotechnology field—life sciences; material sciences; electronics; etc.—and not merely concentrate on one or two areas.
- *NNI Mission:* Lastly, and perhaps most importantly, it is vital that the NOT's mission be expanded beyond the initiation and funding of basic research, and extend to the developing business of nanotechnology and ensure America's leadership in global marketplace.

Government Investment

Question 4. Some critics of the National Nanotechnology Initiative argue that the research portfolio is not in balance, currently favoring readily achievable research goals and not sufficiently supporting high-risk research, such as truly exploratory work in molecular nanotechnology. Do you agree or disagree? Please explain.

Answer. We generally disagree. The NNI portfolio and other government programs such as NIST ATP have been in solid balance funding near, mid and long-term efforts. This should continue. The nanotechnology field includes many long-term visionaries and to be honest, some that harbor extreme ideas on technology development. It is not the government's role in our opinion to fund their fantastic ideas at the expense of real development for the American people and our country's economy.

Currently the most under-funded area of nanotechnology is not the longer-term ideas such as universal assemblers, it is actually the mid-term development stage—the so-called "valley of death." This is the period after basic research but before commercialization. This period of research and application development includes scaling, packaging, and integration. Except for NIST ATP and some DARPA programs, no government effort addresses this period in the life cycle of development. Corporations and VCS also do not normally provide funds for this period. This is an area that particularly the Asia countries excel at—which is why so many Japanese and Korean companies are attempting to license U.S. nanotech research right now. We need a comprehensive effort on the part of the Federal Government to make funds available for this stage of nanotech's development as it will have the greatest impact on our people and our industries.

In this competitive budget environment it is important that funding priorities remain in balance and frankly touch more near term and achievable developments. With that said, as an industry that is projected to have an unrivaled impact of the global economy, we feel that more funding is necessary so that efforts can be enhanced and perhaps some longer term theories can be funded. We would like to see another doubling of the U.S. nanotechnology budget within two years to ensure our nation can compete globally in what is becoming the next industrial revolution.

Question 5. Given that other countries are also investing significant amounts in this field, do you feel that we are doing enough to ensure our leadership in this field?

Answer. No. Nanotechnology is emerging as a truly global technology. Unlike the many waves of technological development, nanotechnology is not dominated by the United States. In several areas of nanotechnology the U.S. is being outpaced by foreign competition. The Japan, EU, Russia, Korea, and China are all significant players in the field of nanotechnology.

A recent report from the Journal of Japanese Trade & Industry notes that the Japanese government views the successful development of nanotechnology as the key to "restoration of the Japanese economy." They are not alone. Funding has grown at unprecedented rates across the globe over the last three years.

The upside of 2000's NNI announcement was that it provide the U.S. with a rallying point as well as additional funding for nanotechnology development. The downside was it set off a global competition not seen since the space race of the 1960's. In addition, most of these foreign efforts include strong corporate interaction, unlike the U.S. NNI effort that for the most part is a basic research program.

The EU just announced a new $685.4 million budget for research in nanotechnology and the formation of the EU Nanotechnology Industrial Platform. When individual country spending is added to the EU mix, overall spending is nearly double that of the U.S. EU corporate spending has remained generally on par with ours.

The Japanese are outspending us from a government perspective and their corporations are far more aggressive than ours in R&D and investment. There are few U.S. based start-ups in the nanotech field that have not been contacted by Japanese investors. Also in Asia, China in adjusted dollars is clearly outspending the U.S.—and Korea, Singapore, Taiwan and others all have very significant programs underway. Add to this that the majority of U.S. nanotechnology grad students and post-docs are non-U.S. citizens from Asia.

If one is to add to this construct the current U.S. business environment of R&D cuts, Wall Street in a severe downturn, and a stagnant VC market, the U.S. nanotechnology market is in need of serious attention and assistance from the Federal Government.

To turn this around the U.S. government must consider the following:

- Increased funding for research and centers; additional incentives and contract opportunities for nanotech business; and extending current and adding new loan and assistance programs for nanotech businesses.
- Additional coordination between agencies and among government programs to reach out to the nanotech research and business community.
- Information development in terms of monitoring and developing reports on global competitiveness; regional development; best practices; etc.
- Promote regional development through information databases.
- Promote business development through omnibus government database of resources.
- Refashion the NNI to include a strong commercialization and industry development platform.
- Improve the current state of technology transfer in the U.S.
- Provide educational and organizational resources for PTO, FDA, and other agencies at the front line of developing the U.S. nanotechnology industry.
- Develop model curriculums for U.S. schools for nanotech. Create programs to promote careers in the nanotechnology field to get more U.S. kids into this field now before it is too late.

Question 6. What role could a Nanotechnology advisory committee of academic, finance, and industry experts serve in improving and grounding the Federal government's nanotechnology research? Would you support the creation of such an advisory committee?

Answer. The NanoBusiness Alliance and our member organizations welcome the call for of the 21st Century Nanotechnology Research and Development Act for the creation of national advisory board on nanotechnology.

We believe that it is imperative that the President and Congress have top advisors from outside the government—people who are on the front lines of nanotechnology's development—to provide vital feedback and advice on the NNI and overall government nanotech efforts. We feel it is essential that such a board reflect the full spectrum of the nanotechnology community and not be a board made up of just the research community. Nanotechnology business leaders—start-ups, corporations, even services industry executives must be part of this effort to ensure that it is effective. Also, it is vital that the various regions of the U.S. where nanotech is developing be included fairly, so that traditional tech clusters like Silicon Valley, Boston and greater Washington been't included at the expense of other developing regions such as the Pacific Northwest, Chicago, Texas, Upstate New York, and others. Lastly, it is of grave importance that the Advisory Board also cover the breadth of the nanotechnology field—life sciences; material sciences; electronics; etc.—and not merely concentrate on one or two areas.

As to the role of the board:

- Advice and real world feedback as to the industry's needs and the effects of current government efforts.
- Assist with the overall NNI coordination between government, academia and industry.
- Bench marking, review and evaluation of government nanotechnology efforts.
- Development and review of reports, studies, and surveys on the field.
- Promotion of the science and business of nanotechnology.

Intellectual Property.

Question 7. Mr. Modzelewski, in your testimony, you expressed concerns over the current state of intellectual property and the U.S. Patent and Trademark Office.

Answer. Can you provide specific recommendations on how to improve the Patent Office system so that it does not hamper nanotechnology growth and innovation?

The U.S. Patent and Trademark Office is among the most highly overburdened organizations in the government. The PTO is expected to receive 350,000 patents applications this year and on top of backlog roughly equal to that number. PTO is the gateway to technology commercialization on America. It must be given the necessary funds (or allowed to retain their fees collected) in order to properly attend nanotechnology and other emerging technologies.

Case in point, PTO must have the funding to provide training to its examiners in the field of nanotechnology. Nanotech is an extraordinarily cross-disciplinary technology reaching into nearly all sectors of examination at PTO. Efforts must be made to ensure PTO can properly understand and manage the nanotechnology patent application process. In turn, PTO must also work with the nanotechnology industry to help train its researchers and companies so as that legal protections are appropriate and timely. At the NanoBusiness Alliance we have begun to work with PTO on these issues, arranging for meetings between industry and officials and bringing in researchers to talk with PTO examiners about their work. Indeed we have found PTO officials to be extraordinarily welcoming and professional. However, this effort needs to be more formalized and extensive.

It should be noted that the signing of H.R. 2215 will make it easier for nanotechnology companies to eliminate mistakenly granted patent claims that would otherwise hinder their business development efforts. Other possible efforts can include accelerated patent examinations for a reasonable fee should be permitted to enable nanotechnology companies and other high-tech companies to bypass the backlog of cases at the U.S. Patent Office.

In addition, it is imperative that Congress address the October 3, 2002 Madey v. Duke decision by the Federal Circuit which ended the so-called research exemption from United States patent law. The effect will no doubt be chilling, essentially ensuring that all corporate collaborative research with universities and other non profit research institutions will move offshore as every other industrialized country in the world recognizes a research exemption in patent law but the U.S.

Before Madey the research exemption had been unquestioned under the convincing case law line that came from no less an authority than perhaps the leading scholar on the early Supreme Court, Joseph Story, in his landmark opinion in 1813 in *Whittemore* v. *Cutter* which used the now anachronistic term "philosophical" instead of "scientific" to describe the experimental use exemption from patent infringement. This "scientific-philosophical" exemption from patent infringement resides at the very core of the Constitutional mandate for Congress to create a patent system "to promote the progress of the useful arts"—an essential component being that those skilled in such "Useful Arts" are free to use the knowledge imparted by a patent disclosure to create better and newer technologies.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. RON WYDEN TO DR. SAMUEL I. STUPP

Bayh-Dole

Question 1. In testimony before the Subcommittee, Dr. Stan Williams of HP stated that due to U.S. universities' interpretation of intellectual property sharing regime created under Bayh-Dole, it is easier to work with foreign universities rather than U.S. academic institutions. How would you respond to this criticism from the academic side? Does Bayh-Dole need an overhaul? If so, what would you specifically suggest?

Answer. My personal view is that U.S. universities have been extremely proactive on technology transfer over the past decade, and I do not see any obvious problem with the system. If you look for example at the large number of successful start up companies in biotechnology and other fields that have emerged from technology transfer activities at universities, you see definite evidence of a healthy system. Many of these companies are now public and as far as I know no other country in the world is as successful as we are in this respect. I have no doubt that this proactive trend will continue into the nanotechnology era over the next few decades and I certainly do not see a justification for U.S. industry to flock to foreign universities to acquire technology. Of course there will always be exceptions, when very specific technologies are available for licensing overseas or when going a broad will be the only way to strike a "good deal" for large U.S. corporations. I do not know what experience Mr. Williams has had that would lead him to hold his opinion.

Before opening a public forum on the subject, one would need to back up with good stastistics the alleged inappropriate practices by U.S. universities on technology transfer. My feeling is that stastistics will not support the case, and that the Bayh-Dole act does not need an overhaul. Furthermore, I would add that even ignoring technology transfer, the billions of dollars invested in research at U.S. universities have yielded over the course of decades the best technical/scientific work force in the world. This has been a critically important return for the economic success of our country. Furthermore, now that large U.S. corporations have downsized their research and development infrastructure, mostly for financial reasons in my view, universities are the ones leading the way to technical innovation as well as playing the role they always played of educating our scientists and engineers. Is it appropriate to tamper now with Bayh-Dole, I don't think so.

Promises of Nanotechnology

New revolutionary technology often promises to "change the way we live." Often times visionaries tell of how these technologies will enable better, more improved lives. There have been a number of promises about the bright potential of nanotechnology. For example, I have heard that with the ability to manipulate atoms, we can completely forgo smelting and instead essentially "grow" steel. While this is undoubtedly promising, it sounds rather fantastic.

Question 2. Can you distinguish for me between what is reasonably achievable and what are exaggerations?

Answer. I think growing steel because we have now demonstrated the ability of manipulating individual atoms is an exaggeration. Smelting will be around for a very long time. That said, nanotechnology has undoubtedly the potential to change the way we live. My favorite examples are its potential impact on health care and personal as well as homeland security. Making nano-sized objects that can deliver medicines or genes to the specific cells that need them is definetely something that can happen and it would have remarkable impact on our ability to cure certain diseases and also controld the side effects of medication, including the life-threatening consequences of cancer chemotherapy. Regeneration of tissues, including the spinal cord, the heart, the retina which impact on dreams such reversing paralysis and blindness, or returning to a completely normal life after heart attacks. Along with advances in biology and medicine, nanotechnology will impact this field because regenerative medicine will require directing cells with nanostructured devices and materials. It is also reality that we can build with nanotechnology powerful machines to map out genomes very fast compared to current capabilities. This of course will have innumerable consequences in disease prevention and cure, but it will also advance biology faster. It is also real that we can achieve with nanotechnology the fabrication of single molecule detectors. This would have a profound impact on our security alerting us of dangerous events a lot earlier than we can today. There is no doubt that nanotechnology can also get us into a completely different regime of the information age giving us faster, smaller, and softer computers. On the lighter side it is also real that nanotechnology will help us look better and healthier—we are only starting to see what wonders nanotechnology can bring to the world of cosmetics. The real vision of nanotechnology will no doubt include other things that we cannot anticipate now that may deeply touch transportation and energy technologies.

Government Investment

Question 3. Some critics of the National Nanotechnology Initiative argue that the research portfolio is not in balance, currently favoring readily achievable research goals and not sufficiently support high risk research. Do you agree or disagree. Please explain.

Answer. I would agree that the NNI portfolio needs to fund more high risk long term research. This was one finding of the National Research Council's review of the initiative. In my own opinion, our research funding system is in general not very conducive to long term research because, budgets for the agencies fluctuate a lot leading to year-to-year programmatic changes, there is insufficient NSF funding, and the NIH has too much money and only a tiny piece of it is invested in long term technology-based research.

Question 4. Given that other countries are also investing significant amounts in this field, do you feel that we are doing enough to ensure our leadership in this field?

Answer. In my opinion, we are not doing enough in nanotechnology research. In order to keep a balanced portfolio within the NNI that targets both short range development of nanotechnology products and at the same time maintain funding stability for long range nanoscience we need to be ramping up rapidly to a budget of at least one billion dollars a year. Our report shows for example that Japan's nanotechnology budget is similar to ours. Normalizing by our GDP it is clear that we do not have equal capabilities. This is particularly important given that large industries are not contributing as much as they would have two decades ago to the research and development infrastructure. One critical issue is to raise the budget of the NSF, and get the NIH to engage in research programs on nanotechnology that are out of their box.

Question 5. What role could the Nanotechnology advisory committee of academic, finance, and industry experts that was suggested by the Academy panel serve in improving and grounding the Federal government's nanotechnology research?

Answer. This panel would be able to perform several critical functions. One of them is to guide the NNI's development in the context of ongoing scientific interests and discoveries in the international community. They could be a very important science and technology "radar" to ensure that programs being funded couple to the most promising directions rather than to the internal interests and concerns of the various federal funding agencies. They will police for a more effective development of nanoscience and nanotechnology. Another important function will come from the members of this board associated with industry. These individuals can guide the programs to areas of interest to our economy in the global competition, ensuring that adequate programs of this type are always part of the NNI. This board should also develop the appropriate metrics to judge the success of the NNI and the changing needs for investment in this initiative year to year.

Question 6. All of us have called out the economic potential of nanotechnology. Let me play devil's advocate for a moment—if nanotechnology is such a huge, revolutionary area, why should the Federal government invest here? Why can't companies bear this burden, if they are going to be positioned to reap the profits?

Answer. Companies, particularly the large ones that have traditionally had the greatest resources, cannot develop effectively the nano era of science and technology because they have by now nearly destroyed their R&D laboratories guided by Wall Street forces, merges and acquisitions. Most industrial labs are focused on short term product development and improvement. The most promising activities with regard to industry lie in start companies and these are often associated with universities. Once these grow and become successful they will hopefully use their wealth to remove at least part of the burden from the Federal Government. Thirty years ago maybe the argument would have been valid but at this time we need to move quickly in the global competition and there is no time to wait for industry to rebuild its long term research infrastructure. Funding to universities and small companies would be at this time the fastest route to success at this time.

Question 7. What do you see as the biggest challenges nanoscience currently faces? In other words, what barriers could potentially keep nanotechnology from reaching its potential?

Answer. One barrier in my view would be a weak economy because we will then loose any chance of engaging industry for development that uses technology transfer from our academic and government laboratories. Another barrier is of course political instability in the world which is of course a real threat at this time. Nanotechnology development will benefit from meaningful international partnerships and flow of scientific information and people among communities in different parts of the world. Another possible barrier has to do with our educational systems.

In this regard the interdisciplinary culture in which young scientists are conditioned and challenged to work on complex problems is a very important element for nanotechnology development to its optimal potential.

Multidisciplinary Education

It appears that nanotechnology is an interdisciplinary science, combining facets of chemistry, materials science, computer science, biology, mechanical and electrical engineering, and physics.

Question 8. How well prepared are our universities to produce the next generation scientists who have the requisite expertise in multiple disciplines in order to ensure that the United States continues to lead in nanotechnology research?

Answer. Programs at our universities are changing rapidly toward the interdisciplinary mode which is very critical to nanotechnology development. However, they are still sub-optimal and very deep cultural changes need to occur for the various scientific communities to learn to recognize and respect the value of interdisciplinary activity in science. Most scientists are hesitant to operate outside their comfort box, but starting early on with young students we can encourage those with interdisciplinary intelligence to stick to this mode throughout their careers and eventually natural selection will produce the right community for optimal nanotechnology development. The broad scientific scope of nanoscience and also its broad range of applications requires very definitely individuals who are themselves interdisciplinary and can work at interfaces among fields. Multidisciplinary teams, the current common mode in universities is not effective for interdisciplinary activity. It only serves to hide individuals that cling on to traditional modes of scientific thinking and results in ineffective investment in nanoscience which is a pervasive revolution across all of science. The nanotechnology board can play a key role in helping the agencies catalyze the process with innovative programs.

Question 9. What needs to be done to promote a multidisciplinary curriculum at all levels, not just universities, so that we have a properly educated nanotechnology workforce?

Answer. We need to create programs from the top (OSTP for example) that offer significant resources to inter-agency programs at all levels that will attract what one might describe as individuals with interdisciplinary intelligence. The hope is that these populations of strong interdisciplinary scientists will eventually dominate the community demonstrating their ability to make key discoveries on complex phenomena and invent new things. This is a natural selection problem that nonetheless needs guidance from the top.

Measurement Tools

Dr. Stupp, the Academy panel pointed out the need to develop the tools and measurements to support nanotechnology in order to spur nanotechnology innovation.

Question 10. Please explain this recommendation. What agency or agencies are best known for this field? Are we allocating enough resources in this area?

Answer. The development of new tools is key for nanotechnology. In fact it was new instruments enabled by microtechnology and software that spearheaded many of the activities we now label as nanotechnology. Agencies such as the Department of Energy and the NSF have always played a pivotal role on tool development. These agencies cannot afford to fund sufficient research activity on tool development. This is clearly a budget problem, and no we are not allocating sufficient resources to this objective. The NIH and possibly DoD should take a stronger interest in funding outstanding teams and even international collaborations to develop new tools for measurement, manipulation, and characterization of nanoscale systems. Clearly DOE and NSF need greater budgets to be able to address this problem.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. RON WYDEN TO R. STANLEY WILLIAMS

Bayh-Dole.

Question 1. In your testimony before the Subcommittee, you stated due to U.S. universities' interpretation of intellectual property sharing regime created under Bayh-Dole, it is easier to work with foreign universities rather than U.S. academic institutions. What would it take for you to work with U.S. universities? Does Bayh-Dole need an overhaul? If so, what would you specifically suggest?

Answer. I believe that it is still possible for leaders of good will from U.S. academia and industry to agree on a workable compromise that is fair and equitable to both parties and that satisfies the intent and the letter of the Bayh-Dole act.

Unfortunately, we have seen significant polarization between attorneys representing these groups, and the level of acrimony has risen to the point that I despair that we can work together in the future. Typically at present, negotiating a contract to perform collaborative research with an American university takes one to two years of exchanging emails by attorneys, punctuated by long telephone conference calls involving the scientists who wish to work together. All too often, the company spends more on attorneys' fees than the value of the contract being negotiated. This situation has driven many large companies away from working with American universities altogether, and they are looking for alternate research partners.

On the other hand, many high quality foreign universities are very eager to work with American companies, and by keeping attorneys out of the discussion completely they have streamlined processes to allow a successful negotiation to take place in literally a few minutes over the telephone. It is possible to specify what one wants to a professor at a university in China or Russia and then issue a purchase order to obtain a particular deliverable. The deliverable is received and verified to be satisfactory before the American company pays for it, and in this case the American company owns all rights to the deliverable and the process by which it was created. Often, such transactions can be completed in a few months, a fraction of the time required to just negotiate a contract with an American University, which will insist on owning all rights to whatever is produced. Thus, just as American companies were long ago forced to deal with high quality and low priced foreign competition, American universities will either have to modify their behavior or lose their industrial customers.

In my opinion, the root of the problem is in the desperate financial situation of most American universities. In the physical sciences and engineering, the support from the U.S. government for academic research has been decreasing in real terms for over a decade. This has forced the universities to try to raise funds from other sources. Since a few universities have made a large amount of money from a piece of valuable intellectual property, this has encouraged nearly all universities to attempt to duplicate this success. However, this strategy is rather like planning ones retirement on winning the lottery. The vast majority of those adopting this strategy will lose.

In negotiations between American universities and large companies, the term "Bayh-Dole Act" comes up frequently to justify an extreme position taken by universities with respect to intellectual property. Most universities claim that the Bayh-Dole Act requires them to retain complete control of all intellectual property produced at the university. This then leads to the position by a university that a company needs to pay for research that is being done up front in a collaborative project, to pay the costs for any patents that are filed as a result of the research, and then to enter into a separate negotiation with the university to license the intellectual property that is created. In many cases, the root idea originated with the sponsoring company in the first place, not the university. Companies take the view that they are thus forced to pay three times for their own intellectual property, which puts them at a significant disadvantage with respect to a company that doesn't spend anything to sponsor university research. Some companies have agreed to this arrangement in the past, but there are several instances where intellectual property that was supported and generated in collaboration with one company was then licensed to a different company, often a start-up that is owned by the professors who participated in the research. Again, this behavior is defended as being necessary because of the Bayh-Dole Act. However, I contend that this is an extreme interpretation of the Act, and in fact there are fair and equitable compromises that can be made that in the long run will benefit universities much more than the disastrous short-term strategies they are now following. Universities will in general receive far more funding in the form of research contracts from high tech companies than they will by licensing technology, because of the short life of such technologies and the fact that it is always possible to substitute one technology for another.

If we look at the actual language of the Bayh-Dole act itself, it is difficult to understand where university-industry cooperative work is impacted. However, the Council on Government Relations (*COGR—"An association of research universities—* COGR's primary function is to help develop policies and practices that fairly reflect the mutual interest and separate obligations of federal agencies and universities in federal research and training") has created a set of guidelines for university behavior: *The Bayh-Dole Act—A Guide to the Law and Implementing Regulations* (http://www.cogr.edu/bayh-dole.htm) . In these guidelines, we find the statement "In their marketing of an invention, universities must give preference to small business firms (fewer than 500 employees), provided such firms have the resources and capability for bringing the invention to practical application," which is the justification for channeling IP rights to university-based start-ups. Unfortunately, these start-ups almost always fail to get their technology to the market, since they lack the resources to do so and the market itself moves too quickly for them to be ready. The next sentence of the COGR guide states "However, if a large company has also provided research support that led to the invention, that company may be awarded the license." The natural compromise position is this: in recognition of the fact that other research support created the institution and the general environment where any large-company funded research leads to intellectual property, that large company should be awarded a **nonexclusive** license, and the university should have the right to sell nonexclusive licenses to any other companies interested in buying them. This will be by far the most efficient means of actually getting a technology into the market place—by creating a competitive environment with multiple entities vying to get the technology to market.

If we fail to find a broad consensus agreement between research universities and companies on IP licensing, then I would recommend amending the Bayh-Dole act to restrict the ability of a private institution that receives federal funding to award exclusive licenses.

Government Investment

Question 2. Some critics of the National Nanotechnology Initiative argue that the research portfolio is not in balance, currently favoring readily achievable research goals and not sufficiently supporting high-risk research. Do you agree or disagree? Please explain.

Answer. I agree with this criticism, but this issue of sandbagging research proposals is not restricted to nanotechnology research alone—it is endemic within the entire academic and national lab research enterprise. Again, the problem is the scarcity of research funds. Individual professors believe that the risk of failure is too high, so they only propose projects that they know will succeed (or indeed projects that they have already completed). To have a 'failed' project could mean that the professor never gets another grant funded, which is the equivalent of academic death. Thus, nearly all projects 'succeed', but at a very small scale. This extreme risk aversion is now characteristic of nearly all research in the physical sciences and engineering. It means that in general we are not seeing many big breakthroughs, but mainly incremental progress along easily predicted directions. In order to escape from this risk-averse environment, it must be possible for university researchers to gamble big and not receive the equivalent of an academic death sentence if things do not work out exactly as they predict—we need to reward grand visions whether they turn out to be viable or not. It was possible to do that in an era where grant funding was plentiful—it can also be possible in an era of restricted funding if agencies decide to play long shots consistently, understanding that only a small fraction of them will pay off. This is the very nature of the way Venture Capital works, and I think that funding agencies should adopt some of the practices of VC's when constructing their research investment portfolio.

Question 3. Given that other countries are also investing significant amounts in this field, do you feel that we are doing enough to ensure our leadership in this field?

Answer. The European Union is currently boasting that they own a commanding lead in nanotechnology research, that they will invest at least twice as much for basic research in this crucial area as the United States in 2003, and that the entire field is "Its Ours to Lose" (title of an October 3, 2002 report issued by the European Nanobusiness Association). The Japanese government plans to invest 40 percent more than the presently announced U.S. National Nanotechnology Initiative (NNI) budget for 2003, and has consistently demonstrated a strong resolve to raise the ante every time the U.S. provides budget figures for the NNI. Given the local purchasing power of a dollar, the $200 M budget announced by China is already supporting what is probably the world's largest nanotechnology effort in terms of the number of young scientists working in the field. Make no mistake about it: we are in a global struggle to dominate the technological high ground, and thus a large portion of the economy, of the 21st Century. The U.S. cannot outspend the rest of the world on research and development this time, so we must be by far the most productive at creating new technologies and the most efficient at bringing them to the marketplace. This will require coordination and cooperation across a wide variety of institutions and disciplines such as we have never seen before in the U.S.. To fail places the wealth and security of this nation at serious risk.

We certainly can and must invest more in basic research, primarily to ensure that all the excellent proposals coming into the funding agencies are being supported. My suggestion is that the U.S. should increase funding for the NNI at the rate of 30 percent per year for the next three years, and monitor the field to make sure the investment is well utilized. However, the only hope that we have to dominate this field is if we can be much more effective than anyone else with the research dollars we spend. Nanotechnologies will all be subject to exponential improvements for decades, which means that a sustained lead of just one-year in any area by one country can be an insurmountable barrier to entry of commercial products for all others. We need to have a balanced portfolio, with a reasonable number of well-placed long shot investments. Our real strength in American science and technology lies in our diversity of institutions: our research universities, our National Laboratories and our great corporate research labs. As to the latter, much has been made of corporate America's de-emphasis of basic research, but in fact we have invested heavily and consistently in applied research and development over the past twenty years, and in general we have developed the world's best institutions for turning technology into products. To win globally in nanotechnology, these strategic assets must work together as partners. This will require a significant engagement among these institutions to build trust and working relationships, which in turn will require wise and consistent policies that remain stable and are emphasized over many years. We will have to come to a better understanding of intellectual property and its value to each of these stakeholders, and attempt to understand how to adequately reward each partner while creating the maximum total benefit for the country. This is a difficult task, and in my view we are presently moving in exactly the opposite direction. Our current policies are driving American companies to look overseas for their research partners, which eventually will lead to the relocation of corporate R&D labs to be close to those partners.

Question 4. What role could a Nanotechnology advisory committee of academic, finance, and industry experts serve in improving and grounding the Federal government's nanotechnology research? Would you support the creation of such an advisory committee?

Answer. I am always wary of creating a new bureaucracy, but in this case the stakes are so high that I think we should do so on an experimental basis. However, this advisory committee has to include real decision-makers, people who can come to agreements and obligate their institutions to abide by those agreements. Otherwise, it will just be a lot of hot air that winds up being more fodder for attorneys and multi-year debates. These decision-makers should create model agreements for their institutions that would then hopefully be adopted as standards for all university-government-corporate research interactions. It will take a few bold and brave visionaries to lead the way out of our current rather miserable situation. However, I believe that once some sensible new practices are established, they will become such a strong competitive advantage that the rest of the American institutions not leading way will have to follow the leaders.

PREPARED STATEMENT OF DR. CRISTINA ROMÁN, EXECUTIVE DIRECTOR, EUROPEAN NANOBUSINESS ASSOCIATION

It's Ours to Lose—An Analysis of EU Nanotechnology Funding and the Sixth Framework Programme

Executive Summary

With funding for the Sixth Framework Programme (FP6) due to come into effect in a few months, comparisons have been made between U.S. and European nanotechnology funding that suggest that the U.S. is investing significantly more in this important area than the European Union.

In fact, a closer look at the figures, performed here through the mechanism of three scenarios, suggests that European Union spending on nanotechnology research is not just comparable to that of the U.S. but will probably exceed it by a factor of two or more for 2003. Moreover, the reason that the 'hidden' European funding is not obvious may arguably lead to more results per dollar or euro spent. Although the increased focus on multidisciplinary endeavours that nanotechnology requires does argue for dedicated nanotechnology spending, there is also, no doubt, value in framing spending decisions in terms of high-level goals, in which nanotechnology will figure only if merit dictates, rather than being pre-ordained. The 'hidden' FP6 spending is of this nature, being directed according to the Framework Programme's 'thematic priorities'. This balanced approach may well yield dividends.

According to our analysis, EU nanotechnology funding alone, which constitutes between 4 percent and 20 percent of total European research funding, will exceed the recently proposed 2003 U.S. nanotechnology budget. Given that EU spending often does not cover the infrastructure and manpower that U.S. spending does, this being met by individual nations, and given that European research funding represents a much smaller fraction of total European funding than U.S. federal funding does of total U.S. funding, European nanotechnology funding may exceed U.S. funding by a factor of 2 in 2003, or greater if funding from individual EU nations is taken into account.

Though this analysis demonstrates that Europe recognises the long-term economic potential of a strong nanotechnology research base and is acting accordingly, it should not lead to complacency as there are still areas that warrant further attention if we want to maximise Europe's ability to perform not just world-leading research but to translate that into economic benefits. These are outlined below.

Recommendations

In order to enable European industry to continue to be competitive on a global basis, attention is required in areas beyond providing adequate funding under FP6. These need to be tackled at national levels and at the European level, both from within the existing European structures and through organisations such as the ENA.

- **Basic R&D and Fundamental Science:** The EU cannot, for political and budgetary reasons, coordinate all European research. It is essential for all European countries to increase their efforts to fund both basic and applied nanotechnology research. Individual countries have the ability to react much faster to changing scientific and economic conditions than the EU, and should use this to their advantage. By implementing local measures based on local conditions, abilities and market requirements, Europe as a whole can maintain its current leading position. While some European countries have recognised this challenge and are meeting it head on, others could do more.
- **Business Climate:** The climate for nanotechnology business start-ups across Europe varies from friendly to positively hostile. This applies both to government regulations and funding bodies, both private and public.
- **Technology Transfer:** The wide variations across Europe will lead to a technological divide. While academic research is of a generally excellent standard across the continent, technology transfer is not. This will have an impact on both the corporate funding of academic research and start-up activity, these being concentrated in areas where technology transfer is most efficient for business. The recipe for successful technology transfer will vary from one member state to the other and some creativity will be required to come up with the best solutions for areas that currently lack effective mechanisms. Analysis of the mechanisms that have already shown success should be the starting point.
- **Public Perception:** The widespread perception among both the business community and the general public that nanotechnology is still science fiction does little to encourage industry to take advantage of it. An appropriate appreciation of the realities and potential of nanotechnology is taking root more slowly in much of Europe than in the rest of the world. The European Union, the ENA and individual governments need to continue to work on improving the perception of nanotechnology among the business community and the public.
- **Government Inaction:** While some European countries are already taking proactive measures, many, especially in southern Europe, seem to be taking a wait and see approach or ignoring the area completely. Applying this philosophy to microelectronics and the Internet has led to a wide economic gap between technology-based and agrarian/tourism-based economies. Nanotechnology will be much more fundamental to economic performance than any previous technological revolution and will have a part to play even in predominantly agrarian economies. All governments within Europe should be encouraged to understand what nanotechnology can do for them.
- **Education:** From Korea to the Irish Republic there have been many examples in recent history of countries being rapidly transformed into technological powerhouses by virtue of a well-educated and relatively cheap work force. The agrarian/tourism-based economies of Europe do offer low labour costs and many offer attractive climates and lifestyles. Thanks to European Union efforts they also offer good infrastructure. The final piece in the jigsaw that might allow such economies to transition to being more technology-based is education—it is essential that a significant pool of technically highly educated workers is maintained throughout Europe. An increased emphasis on natural science training is urgently required for European institutions to be able to absorb the planned funding. Equally important are mechanisms for attracting more students into science-related subjects. This is a problem that is being tackled with some suc-

cess in a few European countries but the lessons learned need to be heeded elsewhere.

- **Communication:** It is intrinsically difficult to get messages across in an economic block composed of many countries with different languages and cultures. However, researchers, entrepreneurs and the public at large must be made aware of the significant opportunities that are available to them in Europe so that they don't get the impression that the opportunities are greater elsewhere when this is not in fact the case. Combined efforts from the ENA, such as this report, and the European Union should be able to address this issue.

Introduction

A figure against which nanotechnology funding is often benchmarked is the budget of the U.S. National Nanotechnology Initiative. At first glance this appears to suggest that Europe's often quoted 1.3 billion over 4 years is tiny compared to the 2003 NNI budget of $710.2 million (0.72 billion). Our analysis indicates that the top level figures do not reveal the whole story, that many of these headline figures are in fact misleading, and that European nanotechnology spending may in fact be significantly higher than that of the U.S.

Two criticisms are commonly levelled at endeavours such as this. One is that variations in funding mechanisms in different economic areas are complex, and varying definitions of nanotechnology add to this such that any comparison of numbers will always require certain assumptions and may be open to alternative interpretations. However, the comparisons can certainly give an indication of the approximate state of play.

The other criticism is that putting numbers on nanotechnology spending is a pointless exercise, a little akin to putting numbers on spending for research into chemistry. Meaningful comparisons, the argument goes, would be at higher, application-oriented levels, such as cancer research, alternative energy, etc.

The need for some sort of figure for nanotechnology spending, even if expressed as a range of figures in which the true figure probably falls, comes from the fact that businesses and academics look to these headline numbers and make decisions based upon them. If academics feel that the funding environment for nanotechnology is better in another region, they may be inclined to relocate. Equally, businesses will favour locations where grants may be more accessible and a greater pool of qualified individuals is present. For this reason, some attempt must be made to produce meaningful numbers.

Global Nanotechnology Funding

Europe

Table 1. Final budget breakdown (in millions of euros) for the Sixth Framework Programme for 2002 through 2006. (Source. CORDIS).

Commission's final budget	June 2002 Final
INTEGRATING AND STRENGTHENING THE ERA	
1. Focusing and integrating Community research	13345
1.1 Thematic priorities	11285
1.1.1 Life sciences, genomics and biotechnology for health	2255
1.1.2 Information society technologies	3625
1.1.3 Nanotechnologies and nanosciences, knowledge-based multifunctional materials and new production processes and devices	1300
1.1.4 Aeronautics and space	1075
1.1.5 Food quality and safety	685
1.1.6 Sustainable development, global change and ecosystems	2120
1.1.7 Citizens and governance in a knowledge-based society	225
1.2 Specific activities covering a wider field of research	1300
Non-nuclear activities of the Joint Research Centre	760
2. Structuring the European Research Area	2605
3. Strengthening the foundations of the European Research Area	320
SPECIFIC PROGRAMME NUCLEAR ENERGY	1230
TOTAL	17500

USA

Table 2. Breakdown (in millions of dollars) of NNI spending for FY 2001 (appropriated and actual), 2002 (appropriated) and 2003 (congressional request). Note: the 'total' includes funding reported on 2/4/02 p/us funding in associated nanotechnology programmes. (Source: National Nanotechnology Initiative)

Department/Agency	FY2001		FY 2002 Appropr. Total	FY 2003 Request Total
	Appropr.	Actual		
Department of Defense	110	123	180	201
Department of Energy	93	87.95	91.1	139.3
Department of Justice		1.4	1.4	1.4
Department of Transportation (FAA)		0	2	2
Environmental Protection Agency		5	5	5
National Aeronautics and Space Administration	20	22	46	51
National Institutes of Health	39	39.6	40.8	43.2
National Institute of Standards and Technology	10	33.4	37.6	43.8
National Science Foundation	150	150	199	221
U.S. Department of Agriculture		1.5	1.5	2.5
Total	422	463.85	604.4	710.2

Asia

Table 3. Estimated Japanese government nanotechnology R&D expenditures (in millions of dollars). (Source: National Science Foundation, Nanoscale Science, Engineering and Technology).

	1997	1998	1999	2000	2001	2002	2003
Japan	120	135	157	245	465	~750	~1000

Other Asian countries have also allocated large budgets to nanotechnology although many of these figures are not associated with clear timescales. However, given the increased purchasing power in many Asian countries, e.g. a researcher in China costs much less than one in Amsterdam, the funding is none the less significant.

In the Japanese case, the annual 50 percent increases cast doubt upon the accuracy of these figures. While there is no question that funding will increase, increasing the number of researchers available to absorb this extra funding does not seem possible on an annual basis.

Furthermore, given the difficulty of even agreeing on what constitutes nanotechnology, many of these numbers must be treated with caution. An example would be the recent assertion from the Taiwanese government that 800 companies in that country will soon be involved in nanoscience. This figure does not square with estimates from other sources of between 700 companies involved in nanotechnology (including multinationals) and 1000 nanotechnology start-ups worldwide (this latter figure quite likely uses an overly broad definition of nanotechnology).

Table 4. Asian nanotechnology budgets (in millions of dollars). (Source: CMP-Cientifica; Asia Pulse).

Country	2002
Japan	750
China	200
Taiwan	111
Korea	150
Singapore	40
Total	1251

EU Funding

EU funding for nanotechnology is contained within the 6th Framework Programme, which runs from 2002 to 2006 and has an overall budget of 17.5 billion. (The discussion will be focused on 'thematic priorities', which is the area where nanotechnology can have a significant impact. Notice that almost a quarter of the budget goes to: Euratom; strengthening the European Research Area (ERA); and other, non-research-related, activities.)

The official EU figure for nanotechnology, as quoted by Research Commissioner Philippe Busquin, is 700 million over 4 years, if nanotechnology is defined as only processes involving the manipulation of atoms and molecules. However, the EU does not have a standard definition of nanotechnology, preferring to use an upper limit of 50 nm, or 'exploitation of mesoscopic and quantum effects at the macroscale' or 'the manipulation of atoms and molecules'.

A more detailed analysis of EU spending is given below in table 5. Following detailed discussions with Commission officials, an upper and lower limit for the nanotech percentage was assigned to each thematic priority. It is immediately obvious that the headline figure of 1.3 billion is in fact incorrect as thematic priority 1.1.3 is only partly dedicated to nanotechnology.

Table 5. Budget percentage corresponding to Nanotechnology for each thematic priority of the 6th Framework Programme for 2002–2006 (in millions of euros). (Source: EU Commission officials.)

Thematic priorities budget	June 2002 Final	Min (percent)	Total	Max (percent)	Total
1.1.1 Life sciences, genomics and biotechnology for health	2255	1.0	22.6	2.5	56.4
1.1.2 Information society technologies	3625	7.0	253.8	9.0	326.3
1.1.3 Nanotechnologies and nanosciences, knowledge-based multifunctional materials and new production processes and devices	1300	25.0	325.0	30.0	390.0
1.1.4 Aeronautics and space	1075	0.2	2.2	0.2	2.2
1.1.5 Food quality and safety	685	0.2	1.4	0.2	1.4
1.1.6 Sustainable development, global change and ecosystems	2120	0.2	4.2	0.2	4.2
1.1.7 Citizens and governance in a knowledge-based society	225	0.2	0.5	0.2	0.5
TOTAL	11285		609.7		781.0

While the above table justifies Commissioner Busquin's statement on EU spending, the figures should be treated as conservative. While institutions such as the European Space Agency have failed to match the NASA lead (and the $51 million 2003 budget) in applications of nanotechnology, it is clear that any materials-dependent applications such as those prominent in aerospace will have a nanotechnology component far higher than 0.2 percent. Food quality and safety are seeing packaging applications based on nanotechnology already on the market and a variety of sensor technologies look set to hit the market soon, which also argues that the nanotechnology component in research would be significantly higher than 0.2 percent. Sustainable development is equally an area where recent nanotechnological developments show significant promise. Life sciences, genomics and health are already seeing major impacts from microtechnology, with nanotechnology looking to play a larger role very soon, in areas ranging from bioanalysis to drug delivery.

In fact, some EU officials expect the percentage of nanotech across all items to be as high as 30 percent, as taken in the 'nano inside' scenario outlined below.

So there is good reason to believe that the 0.7 billion figure given in the table above is a serious underestimate, and that the 30 percent figure is probably a better reflection, although this may, of course, be optimistic.

The aim of the FP6 is to produce breakthrough technologies that directly benefit the EU, whether economically or socially. In order to achieve this, the research programme contains broad thematic areas, such as health, which are then broken down into sub-components for research funding. Instead of funding nanotechnology and nanoscience directly, an issue which is addressed in the nanotechnology thematic priority, the focus is on breakthroughs. By focusing on breakthroughs, nanotech funding is targeted at applications rather than pure science. Similar applications are being pursued in government programmes in the U.S. and in Europe; the fundamental difference between the European approach and that of the U.S. and some other countries is the way the applications are grouped—the EU structure makes considerations of benefits the priority by embodying them in the highest level of the funding structure. The NNI in the U.S. starts with a nanotechnology budget, then apportions this to various departments representing thematic areas.

In order to decode the European Union's spending plans on nanotechnology three scenarios have been examined. While none of these approaches is entirely adequate to explain the complexities of European funding, they do at least allow an approximate level of European commitment to nanotechnology to be determined.

Scenario 1—'Nano Inside'

Applying the view of some within the EC who believe that nanoscience and technology will play a large part in producing the breakthrough technologies of FP6, for example in drug delivery and biodetection, leads to the assumption by certain programme officials that 30 percent of all spending will be nanotechnology-related. This fits well with NNI estimates, which reach the fabled $1 trillion market size for products and services affected by nanotechnology by assuming that nanotechnology will have a part to play in almost everything.

This 30 percent estimate for the nanotechnology component of the funded projects for FP6 is an average across all the thematic priorities and is described as 'nano inside'.

Of course, the true nanotechnology component may be higher or lower than 30 percent and it will not be possible to extract it until a final review of the FP6 is complete after the end of the programme.

If this 30 percent figure is applied to the European funding figure of 11.28 billion, then 3.4 billion, or 850 million a year, may well be spent on nanotechnology.

Scenario 2—Mobilised Capital

Many EU-funded programmes are not entirely supported by the EU. In the case of university research 100 percent of the marginal cost, e.g. for additional researchers or equipment, but not for those already in place, is funded, but for many other projects matching funds are provided by national governments or participating companies.

The main instruments of FP6 are integrated projects (IP) and networks of excellence (NoE) proposed under FP6. For each NoE the EU funds up to 50 percent of the project. For each IP the EU only funds up to 25 percent of the project, requiring a minimum national contribution of 75 percent. Given the 400 million allocated for IPs and the 300 million allocated for NoEs, the amount of capital released by EU funding may be in the region of 2.4 billion, or 600 million a year.

Taking another EU definition, that of 'the manipulation of atoms and molecules', which commission officials estimate to be around 1 billion, would give a mobilised capital figure of 3.43 billion or 857 million per year.

Scenario 3—Pro-rata Comparison

There are several fundamental differences between the EU approach and that of the U.S. and Japan. While a detailed analysis of U.S. and Japanese funding mechanisms is beyond the scope of this report, an appreciation of these differences changes the relative balance of funding.

As previously discussed, the EU structure makes considerations of benefits the priority by embodying them in the highest level of the funding structure. Another fundamental difference is that rather than assigning a fixed budget for nanotechnology in health care, as the NNI is doing via the National Institutes of Health (NIH), the EU assigns a budget for health.

A further difference arises as the EU funding only covers marginal cost, i.e. the extra funding required for researchers, equipment etc. The cost of infrastructure and that of paying academics already in place is borne by the national governments (but will generally not be a part of the budget for their own nanotechnology initiatives). This is in marked contrast to the U.S. system where the NNI generally wholly supports the institutes dedicated to nanotechnology. In fact, the National Science Foundation funding includes almost 10 percent of its budget for research infrastructure.

However, the most significant difference is that the FP budget represents about 4 percent of the total European public research budgets (see, for example, ftp://ftp.cordis.lu/pub/nanotechnology/docs/nanoscience__presentation__022002__en.ppt).

This is, however, an average figure. In high-technology areas such as aerospace, the figure is closer to 20 percent, while in others, such as cancer research, it is substantially less than 4 percent. Thus, assuming a similar nanotech proportion in other budgets, and an EU contribution of 10–20 percent, the conservative estimate of 700 million over 4 years could result in spending of between 3.5 billion and 7 billion over 4 years, or 0.88–1.75 billion per year.

This figure would, of course, need to be compared with a U.S. figure that included funding from individual states. However, current U.S. state spending suggests it may exceed the NNI budget by a factor of two, not, as in the EU, by a factor of 10–25. In fact, to date, total nanotechnology funding by individual U.S. states has so far not approached the levels allocated nationally by the NNI.

Table 6. Total EU nanotechnology funding for the period 2002–2006. Comparison of the three described scenarios (in billion of euros).

Scenario	Nano Inside	Mobilised Capital	Pro-rata Comparison
EU Funding (Total FP6)	3.4	2.4–3.43	3.5–7.0
EU Funding per year	0.85	0.60–0.86	0.88–1.75

It is also arguable that by targeting some funding to specific thematic priorities, in addition to providing funding specifically for nanotechnology, which is probably necessary to effectively tackle the new cross-disciplinary issues it presents, EU funding may prove more effective in terms of results per dollar or euro spent.

Given the huge differences between the EU and U.S. funding programmes, a direct comparison between them is difficult to make. An analysis of European researchers and patents by Commission official Dr. Ramón Compañó, published in the journal Nanotechnology (volume 13, number 3, June 2002) indicates that European researchers are performing as well as their U.S. counterparts, with apparently far less funding. This is a further indication that the headline figures are not telling the whole story.

Conclusions

On balance, it looks as if Europe has a significant edge at the moment. However, it should be remembered that since discussions about FP6 started the U.S. NNI budget has almost doubled. Once the economic benefits of U.S. funding begin to be felt, whether in new company start-up activity, or progress towards military or social goals, U.S. funding is expected to increase rapidly. In addition, the FP6 budget is now fixed until 2006, at which point the balance may have changed dramatically. This is where the initiatives of individual European governments become important, as outlined in the recommendations at the start of this report.

While European funding appears to be adequate to match the U.S. and Japanese initiatives, it is simplistic to divide the funding figures by 4. Simply turning on the funding will cause problems unless the scientific infrastructure is there to absorb that funding. Europe cannot just suddenly double the number of physics students being produced because the funding is there for their PhD and post-doctoral work. We will see more of an exponential ramp-up.

The EU, national governments and organisations such as the ENA need to continue to focus on: improving the business climate in member states; developing strategies for improving technology transfer and increasing the number of students embarking on scientific training, to ensure an adequately trained labour pool; ensuring that public and business perception of nanotechnology is realistic; encouraging local governments that have not yet recognised the importance of nanotechnology to do so; making sure the opportunities in Europe are adequately communicated; and ensuring that national governments have nanotechnology R&D policies that allow a more rapid reaction to changing opportunities than is possible from the Europe-wide programmes.

While much of the headline news is made by the EU, we expect European funding will be picked up where it goes with the grain of member states' own programmes. Given that EU funding represents only 4 percent of Europe's total, the efforts of member states are likely to be the deciding factor in the eventual competitiveness of European funding.

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