THE TRANSFER OF NATIONAL NANOTECHNOLOGY INITIATIVE RESEARCH OUTCOMES FOR COMMERCIAL AND PUBLIC BENEFIT

HEARING

BEFORE THE

SUBCOMMITTEE ON RESEARCH AND SCIENCE EDUCATION

COMMITTEE ON SCIENCE AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

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March 11, 2008

THE TRANSFER OF NATIONAL NANOTECHNOLOGY INITIATIVE RESEARCH OUTCOMES FOR COMMERCIAL AND PUBLIC BENEFIT

TUESDAY, MARCH 11, 2008

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

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

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SUBCOMMITTEE ON RESEARCH AND SCIENCE EDUCATION

The Transfer of National Nanotechnology Initiative Research Outcomes for Commercial and Public Benefit

Tuesday, March 11, 2008
10:00 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

Witnesses

Mr. Robert (Skip) Rung
President and Executive Director
Oregon Nanoscience and Microtechnologies Institute (ONAMI)

Dr. Julie Chen
Co-Director
University of Massachusetts Lowell

Mr. Bill Moffitt (NanoBusiness Alliance)
CEO
Nanosphere, Inc.

Dr. Jeffrey Welser
Director
Semiconductor Research Corporation

Dr. Mark Melliar-Smith
CEO
Molecular Imprints, Inc.

HEARING CHARTER

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

The Transfer of National Nanotechnology Initiative Research Outcomes for Commercial and Public Benefit

TUESDAY, MARCH 11, 2008
10:00 A.M.–12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

1. Purpose

As part of the reauthorization process for the National Nanotechnology Initiative (NNI), on Tuesday, March 11, 2008, the Subcommittee on Research and Science Education will hold a hearing to review the activities of the NNI in fostering the transfer of nanotechnology research outcomes to commercially viable products, devices, and processes. In addition the hearing will review the current federal efforts related to support of research on nanomanufacturing.

2. Witnesses

Mr. Skip Rung, President and Executive Director, Oregon Nanoscience and Microtechnologies Institute (ONAMI)

ONAMI is a cooperative venture between government, academic institutions and industry in the Pacific Northwest and provides open user facilities, research expertise, industry connection to academic research, and gap-funding.

Dr. Julie Chen, Co-Director, Nanomanufacturing Center of Excellence, University of Massachusetts Lowell

The University of Massachusetts Lowell Nanomanufacturing Center of Excellence includes the Center for High Rate Nanomanufacturing, an NSF funded user facility that focuses research on manufacturing technology for nanoproducts.

Dr. Jeffrey Welser, Director, Nanoelectronics Research Initiative (NRI)

The NRI is a consortium of companies in the Semiconductor Industry Association which funds research to demonstrate novel computing devices with critical dimensions below 10 nanometers.

Mr. William Moffitt, CEO, Nanosphere, Inc. and representing the NanoBusiness Alliance

Dr. Mark Melliar-Smith, CEO, Molecular Imprints, Inc.

3. Overarching Questions

- What are the barriers to commercialization of nanotechnologies? How can the NNI enhance technology transfer and help promote the commercialization of nanotechnology?
- Is the current investment in basic research for nanomanufacturing under the NNI adequate? Are the research areas supported under NNI relevant to the needs of industry? How can the Nation's focus on manufacturing techniques position us for global leadership in specific technologies?
- Are user facilities supported under the NNI effective in assisting with the transfer of research results to usable products that benefit the public? Are the current user facilities adequate to meet the needs of the user community in terms of number of facilities and types of instrumentation and equipment available? Are there impediments to the use of federally funded nanotechnology user facilities for industry, such as intellectual property issues or administrative burdens that discourage their use?

- Is there a need for a research and development program under NNI focused on specific problems of national importance?
- Are mechanisms available for industry to influence the research priorities of the NNI?

4. Background

NNI Organization and Funding

The National Nanotechnology Initiative was authorized by the *21st Century Nanotechnology Research and Development Act of 2003* (P.L. 108–153). In accordance with the Act, the National Science and Technology Council (NSTC) through the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee plans and coordinates the NNI. The Act authorized the National Nanotechnology Coordination Office (NNCO) to provide technical and administrative support to the NSET for this coordination. There are currently twenty-six federal agencies that participate in the National Nanotechnology Initiative, with 13 of those agencies reporting a research and development budget. The total estimated NNI budget for FY 2008 was $1.49 billion. Total funding for the NNI in FY 2007 was $1.42 billion.[1] More information on the NNI program content and budget can be found at *http://www.nano.gov/NNI_FY09_budget_summary.pdf* and *http://www.nano.gov/NNI_08Budget.pdf.* Research related to the NNI is organized into eight program component areas including: Fundamental phenomena and processes; nanomaterials; nanoscale devices and systems; instrumental research, metrology, and standards; nanomanufacturing; major research facilities and instrument acquisition; environment, health, and safety; and education and societal dimensions.

The FY 2008 estimated budget for nanomanufacturing research (a component that is closely tied to bridging the gap between basic research and the development of commercial products) was $50.2 million dollars which is 3.3 percent of the total budget. The NNI planned investment in nanomanufacturing research for FY 2009 is $62.1 million, a 23 percent increase. This amount is four percent of the total FY 2009 proposed budget. A working group for Nanomanufacturing, Industry Liaison, and Innovation (NILI) was formed by the NSET to facilitate innovation and improve technology transfer for nanotechnology. NILI has helped to facilitate industry liaison activities for the electronics, construction, chemical, and forest and paper products industries.

User Facilities

The NNI funding agencies support nanotechnology user facilities to assist researchers (academic, government, and industry) in fabricating and studying nanoscale materials and devices. The facilities may also be used by companies for developing ideas into prototypes and investigating proof of concept. The National Science Foundation supports 17 facilities under its National Nanotechnology Infrastructure Network (NNIN), four of which are focused on nanomanufacturing. The Department of Energy maintains five Nanoscale Science Research Centers, each focused on and specific to a different area of nanoscale research. The National Institutes of Health has a Nanotechnology Characterization Laboratory in Frederick, MD and the National Institute of Standards and Technology maintains a user facility in Gaithersburg, MD. The application processes for each facility varies; however, all are open to academic, government, or industry users. In addition to the user facilities, the NNI is carried out in over 70 centers and institutes[2] throughout the country mostly on university campuses, many of which have user facilities that are open to all applicants.

SBIR/STTR Programs

P.L. 108–153 encourages support for nanotechnology related projects through the Small Business Innovation Research (SBIR) and Small Business Technology Transfer Research (STTR) programs by requiring the National Science and Technology Council to "develop a plan to utilize federal programs, such as the Small Business Innovation Research Program and the Small Business Technology Transfer Research Program, in support of the [NNI activities]. . .". Despite the lack of a formal plan, the SBIR and STTR programs have been used as a vehicle to bring nanotechnology research developed by small business concerns closer to commer-

[1] *Summary of the FY 2009 National Nanotechnology Initiative Budget,* February 2008. Available at *http://www.nano.gov/.*

[2] Information of NNI related user facilities and centers and institutes can be found at *www.nano.gov*

cialization. The total SBIR and STTR program spending in all technology areas in FY 2006 was nearly $2.2 billion, of that budget $79.7 million was identified as nanotechnology related research.[3] This was 3.7 percent of the total SBIR/STTR spending in FY 2006 and included nine federal agencies. SBIR/STTR funding is allowable for development of technologies from concept to prototype; however, funding of scale-up to manufacturing does not fall within the SBIR/STTR scope of funding.

Commercialization Issues

Federal Government spending in nanotechnology research and development since 2001 exceeds $5 billion. Global revenues from nanotechnology products are estimated at $50 billion annually, and are expected to reach $2.6 trillion by 2014.[4] Federal R&D funding vehicles traditionally limit funding to basic research through prototype development, leaving private sector funding to bring these emerging technologies to commercialization. A recent report by the U.S. Department of Commerce's Technology Administration cites "funding which favors research over development and commercialization. . ." as one of the most significant barriers to growth in the nanotechnology industry.[5] To bridge this gap, some states are developing gap-funding programs or tax incentives. Globally, countries such as New Zealand and Israel have developed incubator and granting programs that attempt to provide funding for commercial development past the prototype stage. These programs are privately and/or government funded. In addition to federal, State, and local efforts to bring products beyond prototype, industry liaison efforts such as the Nanotechnology Research Initiative[6] of the Semiconductor Research Corporation, and the Agenda 2020 Technology Alliance[7] are bringing scientists and industry partners together.

Nanomanufacturing

Commercialization of nanotechnology is dependent on the development of nanomanufacturing techniques and processes.[8] There are difficulties with scale-up methods for nanotechnology that are unique to nanomanufacturing. Nanomanufacturing processes are difficult to control and can sometimes require more expensive instrumentation for the large scale manufacture of nanomaterials and products. In addition, manufacturing defects that would not affect reliability or performance of macro-technologies can and do render nanotechnologies unusable. Because of these unique challenges, manufacturers can often produce prototypes but the rates to scale-up are slow, and the hurdles for commercialization are often prohibitive. Products that rely on nanoscale building blocks (e.g., carbon nanotubes and nanoparticles) need better manufacturing methods to control variability and better high throughput characterization methods to measure that control.

There is a need for instrumentation for measurement and inspection of nanomanufactured products on-line or at the very least, measurement at a higher rate. Current technologies for device measurement and inspection such as scanning electron microscopy (SEM), transmission electron microscopy (TEM), and atomic force microscopy (AFM) require time and instrumentation expertise and slow manufacturing processes when employed.

5. Witness Questions

All of the witnesses were asked to provide their views on the effectiveness, scope, and content of the current efforts under the NNI to foster transfer of technology and any recommendations they have on ways to improve the process by which nanotechnology is commercialized including, but not limited to, development of prototypes, use of federally funded user facilities, and nanomanufacturing practices and processes. In addition, the following specific questions were asked of each witness:

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[3] *The National Nanotechnology Initiative Supplement to the President's FY 2008 Budget.* July 2007, p. 24.

[4] *Sizing Nanotechnology's Value Chain,* Lux Research, 2004.

[5] *Barriers to Nanotechnology Commercialization,* U.S. Department of Commerce, September 2007, p. 11.

[6] The NRI is a consortium of companies in the Semiconductor Industry Association which funds research to demonstrate novel computing devices with critical dimensions below 10 nanometers that will have application beyond the potential of the current circuit technology (CMOS).

[7] The Agenda 2020 Technology alliance is a project of the American Forest & Paper Association and supports and directs research efforts in nanotechnology to benefit the forest and paper products industry.

[8] *Chemical Industry R&D Roadmap for Nanomaterials by Design: From Fundamentals to Function.* December 2003, p. 83–91.

Mr. Skip Rung

- What are the significant hurdles for companies trying to commercialize nanotechnology? What examples of successful activities to overcome these hurdles has ONAMI seen? What recommendations for federal policy can you make based on the success of the companies affiliated with ONAMI?
- How can policies for access to facilities supported under NNI be structured to provide for increased use by industry and increased transfer of technology and knowledge from federally funded research?
- Are there ways that the NNI could be more effective in assisting the transition of research results to prototype development and full commercialization?
- What kinds of federal programs or activities can help bridge the "valley of death" successfully? How effective have the SBIR/STTR and ATP programs been in this regard?
- Are there any barriers to commercialization imposed by current intellectual property policies at NNI-supported user facilities, and if so, what are your recommendations for mitigating these barriers?

Dr. Julie Chen

- Please review the findings of the 2006 Small Times *Survey of U.S. Nanotechnology Executives* and comment on the results regarding companies' attitudes and views regarding federal support in nanotechnology research and development and needs regarding user facilities.
- What is the current state of nanomanufacturing basic research? What are the basic research needs to provide industry with the tools necessary to move towards high-rate nanomanufacturing?
- How does your center interact with industry in setting research direction?
- Do the companies that interact with your center make use of other facilities available through the NNI? Are current policies under the NNI supportive of such use?

Dr. Jeffrey Welser

- How does the electronics industry interact with NNI supported research activities?
- What is the role of industry in setting research directions through the NRI?
- What role should the NNI play in helping to foster commercialization of nanotechnology?
- Are federally funded user facilities meeting the needs of industry? Are there impediments to their use? How can user facilities be most effective in helping to bring NNI funded research to commercialization?

Mr. William Moffitt

- What are the hurdles to the commercialization of nanotechnology?
- What kinds of federal programs or activities can help bridge the "valley of death" successfully? How effective have the SBIR/STTR and ATP programs been in this regard?
- Are there areas of focus for commercialization that will position the Nation for leadership in that technology?
- Are there any barriers to commercialization imposed by current intellectual property policies at NNI-supported user facilities, and if so, what are your recommendations for mitigating these barriers?

Dr. Mark Melliar-Smith

- Please describe your company's experience with federally funded user facilities (DOE, NSF, etc.)? Are user facilities easily accessible to small and medium businesses? If not, why not, and how would you recommend making improvements? How can user facilities be most effective in helping to bring NNI-funded research to commercialization?
- Is the research now being supported under the nanomanufacturing component of the NNI meeting the needs of industry? Do you believe industry has a voice in determining research priorities for these activities?

- Was your company successful in attracting venture capital? If so, at what stage in your products' development did you obtain VC funding? Are there any federal policies or agency directives that have impacted your ability to obtain VC funding, either positively or negatively?
- Are there ways that the NNI could be more effective in assisting the transition of research results to prototype development and full commercialization?

Chairman BAIRD. Good morning to everyone here in the room and particularly our witnesses today. Our hearing today is entitled *The Transfer of National Nanotechnology Initiative Research Outcomes for Commercial and Public Benefit.* I would like to welcome everyone today on the hearing designed to assess how to ensure that research outcomes from the National Nanotechnology Initiative are transitioned for commercial and public benefit. And I would like to thank all of our witnesses for being here.

The hearing is the third in a series to review various aspects of the National Nanotechnology Initiative, or as we call it the NNI. These hearing will help guide our development of legislation to reauthorize the NNI during the current session of the Congress. In a past hearing, we received testimony on the importance of developing a prioritized research plan and implementation strategy to address the environment, health and safety implications of nanotechnology. In another hearing, we heard about the need to educate students at all levels of education about nanotechnology in order to ensure a workforce for this rapidly growing field.

Today, the Subcommittee will review how well the NNI is supporting activities to make sure that the results of nanotechnology research are translated into commercial products and processes. We will also look at whether the research being supported by NNI in such areas as nanomanufacturing is relevant to the needs of industry.

It is clear to me and this committee that nanotechnology can offer this nation and the world unimaginable benefits in a wide range of fields, including health care, energy efficiency, electronics and water remediation. Like many areas, a federal investment in basic research is critical to nanotechnology's development, but this investment will be squandered if we do not cultivate the technology to usable products or processes. The NNI now supports user facilities and basic research in nanomanufacturing. Also, the agencies participating in the NNI administer SBIR programs that fund projects to advance emerging concepts to commercialization.

Certainly, the commercialization of nanotechnology, like any developing technology, is complex. However, nanotechnology has some unique challenges. The development of nanomaterials and devices most often requires highly specialized and expensive instruments. In addition, the scale-up of nanotech requires unique processes that have very low error rates. Furthermore, quality control in nanomanufacturing requires lengthy evaluations and expensive equipment.

As I mentioned earlier, this morning I hope to assess whether the current investment aimed at technology transfer and commercialization under the NNI are adequate and reflect the most critical priorities. I also want to look at whether the research is relevant to the industry, and in addition I am interested in the views of our witnesses on whether the equipment and instruments available at NNI-supported facilities are adequate and accessible. Finally, I invite any recommendations our witnesses may have on how the NNI could be more effective in helping to bridge the gap between concept and commercialization.

I thank our distinguished witnesses for being here today. I look forward to your testimony.

And before introducing the panel, I would now recognize my good friend, the Ranking Member of the Subcommittee, Dr. Ehlers, for an opening statement.

[The prepared statement of Chairman Baird follows:]

PREPARED STATEMENT OF CHAIRMAN BRIAN BAIRD

Good morning. I'd like to welcome everyone to today's hearing on how to ensure that research outcomes from the National Nanotechnology Initiative are transitioned for commercial and public benefit, and I'd like to thank our witnesses for being here.

This hearing is the third in a series to review various aspects of the National Nanotechnology Initiative, or the NNI. These hearings will help guide our development of legislation to reauthorize the NNI during the current session of Congress.

In a past hearing, we received testimony on the importance of developing a prioritized research plan and implementation strategy to address the environment, health, and safety implications of nanotechnology. In another, we heard about the need to educate students at all levels of education about nanotechnology in order to ensure a workforce for this rapidly growing field.

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I thank our distinguished witnesses from being here today. I look forward to your testimony. Before introducing our panel, I now recognize the Ranking Member of the Subcommittee, Dr. Ehlers, for an opening statement.

Mr. EHLERS. Thank you, Mr. Chairman, and in appreciation of the fact that we are having a nanotechnology hearing, I decided to offer a nano-opening statement so that we can quickly get into the hearing.

Chairman BAIRD. So moved. I will now introduce the witnesses. (laughter)

Mr. EHLERS. The authorization of the NNI is a prime opportunity for the Science and Technology Committee to continue to craft policies that encourage U.S. innovation and maintain our global competitiveness. We have invested more than $8 billion federal dollars into the NNI since it was initiated in 2003. The reauthorization measure will be a very important piece of legislation and deserves the full attention of this subcommittee and the full Science Committee.

There is still much to learn about perfecting nanotechnology manufacturing processes. For those working in nanotechnology, it is evident that there are many challenges unique to the nanomanufacturing supply chain. The conventional balance of basic and applied research and development may not be a good fit for nanomanufacturing because of the high capital investments and substantial fundamental research necessary to overcome obstacles to commercialization.

As we advance the reauthorization of the National Nanotechnology Initiative, this question of appropriate balance must be carefully considered. I look forward to hearing from our witnesses about their recommendations for investment priorities in the reauthorization process.

Thank you, Mr. Chairman. I yield back.

[The prepared statement of Mr. Ehlers follows:]

PREPARED STATEMENT OF REPRESENTATIVE VERNON J. EHLERS

Reauthorization of the National Nanotechnology Initiative (NNI) is a prime opportunity for the Science and Technology Committee to continue to craft policies that encourage U.S. innovation and maintain our global competitiveness. We have invested more than eight billion federal dollars into the NNI since it was initiated in 2003. The reauthorization measure will be a very important piece of legislation, and deserves the full attention of this Subcommittee and Full Committee.

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As we advance the reauthorization of the National Nanotechnology Initiative this question of appropriate balance must be carefully considered. I look forward to hearing from our witnesses about their recommendations for investment priorities in the reauthorization process.

Chairman BAIRD. I thank the Ranking Member. And if there are other Members who arrive, as they tend to do, during the course of the hearing who wish to submit additional opening statement, their records will be added.

[The prepared statement of Ms. Johnson follows:]

PREPARED STATEMENT OF REPRESENTATIVE EDDIE BERNICE JOHNSON

Good afternoon. Thank you, Mr. Chairman, for holding today's hearing on nanotechnology, and the needs of the community as Congress prepares to reauthorize the National Nanotechnology Initiative.

I especially want to welcome Mr. Mark Melliar-Smith, CEO of Molecular Imprints, a Texas-based nanotech company that uses an optical technique to project and print nanoscale patterns.

Texas is an international leader in nanotechnology research and development. I know that the state has made a strong investment in nanotechnology.

University research, spin-off companies, and other small start-ups have been greatly assisted by the pro-research culture in our state.

This subcommittee will be interested to know how to best support the nanotechnology research community.

We want to know if the current funding for research is strong enough, or if some of the money should instead be utilized for user facilities.

In addition, the Committee would like feedback on the barriers to commercialization of nanotechnology products, and whether a greater portion of the total investment should be directed toward that function.

Today's witness panel covers the spectrum, from small company start-ups, to the academic environment, to organizations representing a consortium of businesses.

All bring valuable perspectives to the issue at hand: how federal investments can best support and allow nanotechnology in the United States to succeed and flourish.

Thank you, Mr. Chairman. I yield back the balance of my time.

Chairman BAIRD. At this point, it is a privilege to introduce the witnesses. Mr. Skip Rung is the President and Executive Director of the Oregon Nanoscience and Microtechnologies Institute, who flew a red-eye flight here. Mr. Rung, welcome. I am sometimes referred to as the representative from the Third District of Washington or the Sixth District of Oregon, owing to how many people cross the river each day to work. We welcome you, particularly, here as well. Dr. Julie Chen is a Professor of Engineering at the University of Massachusetts Lowell, and Co-Director of their Manufacturing Center of Excellence. Dr. Chen, welcome. Dr. Jeffrey Welser is on assignment from the IBM Corporation to serve as the Director of Nanoelectronics Research Initiative, NRI, a subsidiary of the Semiconductor Research Corporation. Welcome, Dr. Welser. Dr. William Moffitt is the Chief Executive Officer of Nanosphere, Incorporated, and is also representing the NanoBusiness Alliance. Dr. Moffitt, welcome. And Dr. Mark Melliar-Smith is the Chief Executive Officer of Molecular Imprints, Incorporated. So we have folks from the academic/research sector and the applied-industry/business sector.

As our witnesses should know, spoken testimony is limited to five minutes each, after which Members of the Committee will have five minutes each to ask questions. And as I mentioned earlier, this is a friendly, bipartisan committee, and we really welcome your discussion. We will offer an exchange of questions. Always feel that if there is something critical we have yet to ask, that you can offer insights into that as well.

We will begin our comments from Mr. Rung. Thank you for being here.

STATEMENT OF MR. ROBERT D. "SKIP" RUNG, PRESIDENT AND EXECUTIVE DIRECTOR, OREGON NANOSCIENCE AND MICROTECHNOLOGIES INSTITUTE (ONAMI)

Mr. RUNG. Chairman Baird, and Members of the Committee, I am honored by the opportunity to speak with you today on a subject of great importance for the continued economic and social health of our nation. Winning at science-based innovation is critical for U.S. economic competitiveness, for the supply of jobs with productivity sufficient for the wage levels Americans have come to expect and for the prosperity that pays for all of the social goods, such as health and education, we would like to leave in tact for future generations. Reauthorization of the *Nanotechnology Research and Development Act* presents the opportunity both to re-up on a vital investment, and at the same time, be more intentional about social and economic returns.

Oregon Nanoscience and Microtechnologies Institute, Oregon's first signature research center has so far received $37 million from the Oregon Innovation Council because they know that success and the global competition for jobs and prosperity completely depends on a sector that wins through innovation, fueled by research and entrepreneurship. And so that is the dual mission of ONAMI:

growth in scientific research and growth at Oregon employers commercializing that research.

I think we are an interesting case. We are a small state, but arguably, we have the world's most powerful collection of industrial nanotech R&D assets, Intel and HP's top research site, FEI Company, among others. But we have no wealthy private university, and we are not a traditional venture capital hot spot. Still, we know for certain that our research is competitive, and therefore should be able to grow our entrepreneurial sector.

So therefore, one of ONAMI's core activities is a commercialization fund that provides grants to bridge the very real gap between what research agencies pay for and what pencils out for investors. We have so far enabled three very promising microtechnology companies, and four nanotechnology spin-out companies. Time permitting, at the end of my remarks—and I probably won't—I will say a little bit about our nano group. For now, I will simply note that the support we provide is absolutely critical for these technologies to ever reach customers and create jobs.

Before addressing directly the questions asked by the Committee, I will state my overarching point. Intentional federal investment in, and accountability measures for, entrepreneurial startup-company-driven commercialization of NNI research are just as necessary and important as the research itself, and therefore should be a prominent consideration in the reauthorization. It is interesting that today, in contrast to 30 years ago, most high-risk and disruptive innovation takes place in small companies, many of them venture-backed startups. Venture money originating in pension funds and endowments turns out to be more patient and risk-tolerant than corporate cash, and large companies increasingly innovate by acquisition and open-technology sourcing from small companies. This is why there needs to be intense focus on making U.S. nanotechnology entrepreneurs successful, understanding and addressing the myriad hurdles that they face.

So then, what are those hurdles? They are the greater expense and time required for proof of concept demonstration, comparatively high capital requirements, the need for convenient access to specialized facilities and expertise, and often very complicated technology licensing situations. And this is not to mention the growing burden of regulatory compliance and related uncertainty. Investors see these things as risks, and they act accordingly. For all of these reasons, the appetite of venture capital for nanotechnology has turned out to be less than many hoped and expected. This may not necessarily be the case overseas as hungry global competitors, such as China, place a higher value on economic development.

To address these hurdles, the *Bayh-Doyle Act* has enabled universities to own and out-license federal research results and in that process provide an incentive to faculty inventors. The NNIN has established 13 user facilities at universities, though with no recent additions, and the national labs have various access mechanisms. SBIR and STTR are vital programs and a lifeline for many small businesses, including our own nanotechnology spin-out, Crystal Clear Technologies. The new TIP program looks very promising for companies past the seed stage.

All of these things are very good and should, if anything, be expanded, but they don't take as much advantage as they could of America's many local business and investor communities, so company and job creation still favor the already successful technology communities around the major centers. I would like to suggest to you two concepts based on our experience with shared-user facilities and our gap fund that I believe could increase the commercialization return on the NNIN investment.

The first is to broaden the NNIN concept into what we call the "high-tech extension" service, the modern analog of the invaluable land-grant concept of 150 years ago. We started too late to be part of the NNIN, but boot-strapped private and federal equipment grants with university and State funds to create a network of shared user facilities, which consolidate major equipment and instrument assets in well-utilized and maintained facilities, open to all academic users from any campus on equal terms. They are also open for industry collaborations, and we can provide leased experimental and office space to both large and small company partners. All seven of our current gap-fund companies make critical use of these facilities. Since Oregon is a rural state, and the distance between our sites is up to 110 miles, we have also implemented high-quality webcam and virtual network connections on major tools to enable a very satisfying remote user experience. This also works well cross-country, so we have clients as far away as Florida.

But the key points here are that there are measurable objectives and business models tied to facility utilization by industry, that we share and coordinate acquisitions, statewide to maximize unique capability, and that this approach does not need to be limited to the few NNIN sites, which are too far away for our companies to use on a regular basis. Our concept could conceivably go viral, so to speak, if other State and federal funding policies encouraged it.

We are very proud to have opened our newest facility at the University of Oregon on February 19. It is a 30,000 square-foot underground lab, with about the best vibration performance anywhere in the world, and therefore, the best location possible for the latest in nanotech tools. We are installing, for example, the first of two FEI Titan transmission electron microscopes. We would love for our nanoscience user facilities to be part of the National Network and database of nanoscience assets, with or without NNI funding.

The second concept is dedicated funding for commercialization tied to research centers. As far as we know, we are the only state-funded research centered to have its own dedicated gap fund. This has been running for about 15 months, and if we are sure of anything at this point, it is that the response to this incentive from academics and entrepreneurs has exceeded our expectations and changed the culture and conversation around commercialization. This fund is actively advised by the leading venture-capital partners investing in Oregon, including both small and large funds. The advisors get a heads-up look at potential deal flow and our inventors and entrepreneurs get early time with the best possible investor audience. We ask the advisors one question: if we fund this project, and it meets its technical objectives, can the partner company raise capital within 12 to 18 months and go on to build a successful business in Oregon? We get more insightful answers to this question than we could come up with ourselves and have always followed the advice.

The gap fund has one success metric that the state measures us on: private capital dollars invested in our gap-fund companies. This is a very unforgiving metric and one that is impossible to fudge. Our four nanocompanies are very early stage and have a——

Chairman BAIRD. Mr. Rung, I am going to ask you to summarize here at this point.

Mr. RUNG. Okay, so the gap fund, we think, is a great process to institutionalize with the National Nanotechnology Initiative. And thank you very much.

[The prepared statement of Mr. Rung follows:]

PREPARED STATEMENT OF ROBERT D. "SKIP" RUNG

Chairman Baird and Members of the Committee, I am honored by the opportunity to speak with you today on a subject of great passion for me and also, I believe, of great importance for the continued economic and social health of our nation.

Success at science-based innovation—the current cutting edge of which just happens to be called nanotechnology—is critical for U.S. economic competitiveness, for the supply of jobs with sufficiently high productivity to offer wage levels Americans have come to expect, and for the prosperity that pays for all the social goods, such as health and education, we would like to keep intact for future generations. Reauthorization of the *Nanotechnology Research and Development Act* presents the opportunity both to re-up on a vital investment, and at the same time be more intentional about reaping social and economic returns.

Oregon Nanoscience and Microtechnologies Institute, Oregon's first Signature Research Center, has so far received $37M from the Oregon Innovation Council because they know that success in the global competition for jobs and prosperity completely depends on a traded sector that wins through innovation—fueled by research and entrepreneurship. And that is the dual mission of ONAMI—growth in scientific research by means of deep inter-institutional and industry collaborations, and job growth at Oregon employers commercializing that research. I think we're an interesting case. We are a small state, but have arguably the world's most powerful collection of industrial "small tech" R&D assets—Intel and HP's top research sites, FEI, Invitrogen—Molecular Probes. But we have no wealthy private university and are not a traditional venture capital hot spot. Still, we know for certain that our research quality and creative ideas are competitive with anyone's, and therefore we should be able to grow our entrepreneurial sector.

Thus, one of ONAMI's core activities—coupled with our own set of user facilities—is a commercialization fund that makes grants to bridge the very real gap between what research agencies pay for and what "pencils out" for investors. We have so far enabled three very promising microtechnology spin-out companies and four nanotechnology spin-out companies. Time permitting at the end of my remarks, I'll say a little bit about our nano group. For now, I will just note that this support is absolutely critical for these technologies to ever reach customers and create jobs. Whether it is going to be enough to get us to success remains to be seen.

Before addressing in detail the questions asked by the Committee, I will state my overarching point: **Intentional federal investment in, and accountability measures for entrepreneurial startup company-driven commercialization of NNI research are just as necessary and important as the research itself, and therefore should be a prominent consideration in the re-authorization.**

It is interesting that today, in contrast to 30 years ago, most high-risk and disruptive innovation—not just technology research, but getting to market—takes place in small companies, many of them venture-backed startups. Venture money originating in pension funds, university endowments and the bank accounts of high net worth individuals turns out to be more patient and risk-tolerant than corporate cash, and large companies increasingly innovate by acquisition and open technology sourcing—from small companies. This is why there needs to be intense focus on making U.S. nanotechnology entrepreneurs successful; understanding and addressing the myriad hurdles and challenges they face. A $2M regulatory compliance cost that is easily absorbed by a Fortune 500 company is a deal killer for the entrepreneur who's inventing our future.

Specific to nanotechnology, then, what are the hurdles? They include the greater expense and time required for proof-of-concept demonstration, comparatively high capital requirements, the need for convenient access to specialized facilities and expertise, and often very complicated technology licensing situations. And this is not to mention the growing burden of regulatory compliance and related uncertainty. Investors see these things as risks and act accordingly. For all these reasons, the appetite of venture capital for nanotechnology has turned out to be less than many hoped and expected. This may not necessarily be the case overseas as hungry global competitors such as China place a higher relative value on economic development.

To address these hurdles, the *Bayh-Dole Act* has enabled universities to own and out-license federally funded research results, and in the process provide an incentive to faculty inventors. The NNI has established 13 user facilities at universities—with no recent additions, and the national labs have various access mechanisms, though they are mostly geared for publishable research and expensive for business to use. SBIR and STTR are vital programs and a lifeline for many innovative small businesses, including for our own lead nanotechnology spin-out, Crystal Clear Technologies. The new TIP program is very promising for companies past the seed stage.

All of these things are very good and should continue—if anything, they should be expanded. But they don't take as much advantage as they could of America's many local business and investor communities, so company and job creation still favor the already-successful technology communities around the major centers. I'd like to suggest two concepts, based on our experience with shared-user facilities and our gap fund, that I believe could increase the commercialization return on the NNI investment around the Nation.

The first is to broaden the NNIN concept into what we call the "high tech extension service"—the logical modern analog of the invaluable land grant concept of 150 years ago. Starting too late to be part of the NNIN, Oregon boot-strapped federal and private equipment grants with university and State funds to create a network of shared user facilities—the Northwest NanoNet—which consolidate major instrument and equipment assets in well-utilized and maintained facilities open to all academic users from any campus on equal cost and access terms. They are also open for industry collaborations, and can provide leased experimental and office space to both large and small company partners. All seven of our current gap companies make critical use of these facilities. Since Oregon is a rural state, and the distance between our sites is up to 110 miles, we have also implemented high-quality web cam and virtual network connections on major tools to enable a very satisfying remote user experience. This also works well cross-country, so we have clients as far away as Florida. But the key points here are that there are measurable objectives and business models tied to facility utilization by industry, that we share and coordinate acquisitions statewide to maximize unique capability, and that this approach does not need to be limited to the few NNIN sites, which are too far away for our companies to use on a regular basis. Our concept could conceivably "go viral" if other State and federal funding policies encouraged it.

We are very proud, by the way, to have opened our newest facility at the University of Oregon, on February 13. It is a 30,000 square foot underground facility with just about the best vibration performance in the world, and therefore ideal for the latest SEM, microprobe, XRD, SIMS, FIB and TEM tools. And yes, we are bringing up the first of two FEI Titans! We'd love for our nanoscience user facilities to be part of the national network and database of nanoscience assets, with or without NNIN funding.

The second concept is dedicated funding for commercialization tied to research centers. As far as we know, we are the only State-funded research center with specific technology themes to have its own dedicated gap fund. This has been running for about 15 months, and if we are sure of anything at this point, it is that the response to this incentive from academics and entrepreneurs has exceeded our expectations and changed the culture and conversation around commercialization. The fund is actively advised by the leading venture capital partners actively investing in Oregon—including both large and small funds. The advisors get a well-screened (by ONAMI staff) heads-up look at potential deal flow, and our inventors and entrepreneurs get early time with the best possible investor audience. We ask the advisors one question: "If we fund this project and it meets its technical objectives, can the partner company raise capital within 12–18 months and go on to build a successful business in Oregon?" We get more insightful answers to this question than we could have come up with ourselves, and have always followed the advice. The gap fund has one success metric that the state measures us on: private capital $$ invested in our gap fund companies. This is a very unforgiving metric, and one that is impossible to fudge. Our four nano companies are very early stage and have excellent prospects, and we should have first results on our metric this year. I can assure you that it keeps me and our gap fund manager, Jay Lindquist, intensely focused.

So the suggested concept here is to have some portion of NNI funds—perhaps in association with large multi-year awards—tied to commercialization, perhaps in the form of a gap fund, with a short-term outcome measure of leveraged private capital investment.

As I mentioned at the beginning, we've so far funded seven gap projects, of which four are nanotechnologies. These are:

1. A bi-functional-ligand nanocoating technology for low-cost drinking water purification in collaboration with Crystal Clear Technologies. CCT is an NSF Phase II SBIR awardee and also $100K California Clean Tech Open winner. They are sampling major corporate partners with breakthrough material that we hope will result in large orders and a very fundable company.
2. Dune Sciences is another outgrowth of our well-recognized green nanotechnology program. They are already supplying—to NIST and other customers—unique TEM analysis grids that are ideal for nanoparticle analysis, which helps to fund strategic development of their unique nanoparticle linking technology. Confidential partnerships addressing large markets are being set up.
3. NanoBits is yet another green nano company, this time from the point of view of highly efficient production of precision nanomaterials in low-cost, flexible microreactors. This is very early-to-market technology, so it is fortunate that there are also some opportunities to improve the efficiency and safety of specialty chemical manufacture for the pharmaceutical industry, among others.
4. Lastly, newly formed startup Inpria is our commercialization partner for breakthrough inorganic solution-processed nanomaterials for printed and transparent electronics. We think this could be big, and that is all the detail we can share at this time.

In summary, I believe that intentional focus—with targeted funds and incentives—on commercialization of National Nanotechnology Initiative research, can and should be a prominent feature of the second five years of the *Nanotechnology Research and Development Act.* A broader national network of shared user facilities and federally-assisted gap funds that leverage the business and investor communities across the Nation—all managed according to the principle "what gets measured gets done"—are my key recommendations for maximizing NNI's social and economic returns.

Thank you again for the opportunity to speak with you today. I am submitting some additional written material that amplifies some of these points, and will also try to be as helpful as I can in answering any questions you may have.

Attachment

21st Century Nanotechnology Research and Development Act 2.0

PROTECTING AND DELIVERING ON THE PROMISE OF THE U.S. INVESTMENT IN NANOTECHNOLOGY

Oregon Nanoscience and Microtechnologies Institute, which has developed an increasingly successful model for growing collaborative research, industrial partnerships and technology commercialization in both existing companies and new startups, is pleased to offer the following perspectives and recommendations as Congress considers reauthorization of P.L. 108–153.

First, it should be noted that while the concepts of nanoscience and nanotechnology are no longer new (or as mysterious as they were at first) to a substantial and growing fraction of the U.S. population, the following things remain true:

1. Nanoscale science and engineering represent the cutting edge of a majority of endeavors in the applied chemical, physical and biomolecular sciences.
2. No "next new thing" has emerged to replace "nano" on this cutting edge.
3. Innovation based on advances in materials science is, increasingly, the only means by which high-wage (relative to emerging industrialized nations) jobs in the U.S. manufacturing sector can be retained—or, perhaps more accu-

rately, kept fresh by earliest adoption of the most advanced technologies for product performance and operational productivity.

4. Americans are generally positive and optimistic about nanotechnology (in spite of various attempts to persuade them otherwise). But they may not remain so if it appears that a great deal of money is being spent with little result, or if any major (real or perceived) adverse EHS incident should occur.

Thus, there is simply no imaginable alternative to pressing on with the U.S. investment in nanotechnology, unless we are prepared to sacrifice our high relative standard of living and the social goods (education, health care, security) that it renders affordable.

Together, this lack of newness and the ever more pressing global competitiveness issue call for a "refresh" of the NNI and NNCO mandates, with the following key objectives and considerations uppermost in mind;

1. **Commercialization:** Harvesting the fruits of past years of basic research by understanding and addressing the cultural, financial and legal hurdles to commercialization of technology developed under federal funding. While the commitment to basic research, particularly in universities, must continue, it is important to increase the translational (social and economic) benefits of this investment.
2. **Green Nanotechnology and NanoHealth:** Addressing the "EHS" issue in a proactive and comprehensive manner that results in increasingly powerful methods for achieving desired nanomaterial and nanostructure performance—while optimizing manufacturing efficiency and minimizing potential health hazards, occupational risks, and long-term environmental impact.
3. **Collaboration and Resource Leverage:** Recognizing that achieving either of the two above objectives in today's fast-paced and competitive world requires agile and adaptive collaborations among similar and different institutions, and that the era of "stove-piped" approaches to major initiatives is over.

These three themes and illustrative examples, including ONAMI's own experience and accomplishments, are briefly discussed below. Amplification is available upon request.

Commercialization: *Harvesting the fruits of research by overcoming hurdles*

It is a good generalization to say that breakthrough technology development usually occurs in two ways: (1) *Evolutionary:* an established company or industry consortium with significant internal resources invents "on demand" to satisfy customer demand for improved products (e.g., semiconductors in 2007), and (2) *Revolutionary/disruptive:* a new idea/new market niche that finds no fit with large company strategies is pioneered by an entrepreneurial startup/spin-out company. Most such efforts fall short of revolutionary expectations, but the few that succeed in a large way (e.g., semiconductors in 1957) make all the difference in the long run.

Both of these modes are relevant to nanotechnology, but a number of hurdles also exist, some of which are new and some of which are perennial:

1. Break-through materials/process technology can take 5–20 years before deployment in mass production or mission-critical situations.
2. Specialized and expensive human expertise and characterization equipment is required, with the latter in particular being out of reach for all but the largest companies to own.
3. Federal and non-commercial private research funding is oriented toward first-time discovery and publication, not product development and "go-to-market," which take much longer and cost much more.
4. Academic, national laboratory, and other non-commercial research institution cultures and reward systems respond to funders' purposes (see above) and further emphasize individual (or at most, small group) careers and accomplishments rather than organizational achievements.
5. Commercial and research institution approaches to publicity and intellectual property are different in many ways—as would be expected due to differences in their fundamental purposes (return to shareholders vs. dissemination of knowledge and training).
6. Venture funds must show a superior return to their limited partners (which include the retirement plans of many, if not most, Americans), and this is very difficult to do without a clear proof-of-concept for a product (not re-

search result) that is not more than five years from (a) profitable commercial sales in the $10M/year or more, or (b) a high-multiple acquisition by a large company.

The above conditions together mean that the "gap" or "valley of death" is particularly wide for nanotechnology (and at a time when tax and regulatory policies are increasingly unfavorable toward entrepreneurship in the U.S.).

ONAMI experience and accomplishments: Strongly urged by our Board of Directors, we have put significant funds and management resources to work for our commercialization program. We have deployed ~$3.5M (including interest) in an expert-managed and VC-advised (partners in 5–6 funds plus one Battelle consultant) gap fund—with the explicit goal of enabling companies to raise private capital funds. We have so far funded seven university-startup projects (three "micro" and four "nano" all of which use the ONAMI shared-user facilities). We expect that our lead nanotechnology company will be a very attractive candidate for a multi-$M A-round investment and will have substantial POs from major customers following acceptance of initial units. Many other proposals are pending. In addition, it has been essential that ONAMI partner institutions work closely together on IP matters. In fact, the Oregon research universities have just announced a common Innovation Portal featuring technologies from four campuses.

COMMERCIALIZATION - What the re-authorization should consider:

1. To assist with commercialization in established companies, provide for research-industry partnerships in the form of graduate student internships, facility-sharing and relaxation/elimination of private use restrictions for sponsored/collaborative research & development. (Currently, these restrictions make collaboration between industry and public universities problematic. If only wealthy private universities are fully free to engage in commercialization, we are missing a large part of the opportunity to realize a return on the NNI investment. States need to take action here as well, and a recent NGA report suggests that they are starting to do so.)
2. To assist with commercialization in new ventures, require and fund "gap" grant vehicles along with other "broader impacts" activities. The ONAMI model involves professional investors (VCs) and has proven to be effective, motivating and agile.
3. Require reporting on measures of success for commercialization. The best early ones are license revenue and equity gains to the research institution, and capital raised by enabled new companies.
4. Emphasize and reward commercialization from the national laboratories, encouraging affordable rates for industry work, entrepreneurial leave programs and other mechanisms to connect business people to these major facilities.
5. (Possibly outside PL 108-153 jurisdiction) Provide a tax credit to investors in early stage nanotechnology companies, which will normally require many

Green Nanotechnology and NanoHealth: *Proactively addressing the EHS issues and enabling application at the same time*

This "problem" is actually an outstanding opportunity, and the ONAMI Green Nanotechnology approach, embodied in our Safer Nanomaterials and Nanomanufacturing Initiative with AFRL is a recommended model. The essential tenets are:

1. "Application" and "implication" work must be coordinated—just as they are in the industry-funded world of commerce. Application without attention to implications harbors unacceptable risk, and implications without applications will be a waste of effort—only what actually goes on to marketplace demand and high volume manufacturing is going to matter.
2. The long-term goal is rational, "right the first time" design of nanomaterials that are high in performance, low in hazard, and efficient to manufacture (e.g., "E-factor": minimized material and energy consumption in manufac-

turing). This is a complex and multifaceted undertaking and so requires judicious and insightful planning to coordinate:

a. Understanding the biological interactions of well-characterized engineered nanomaterials (ENM) through careful application of experimental standards and knowledge bases.
b. Development of heuristics, then predictive models and design rules for ENM properties and performance.
c. Simultaneous optimization of accurate characterization tools and efficient fabrication processes.

3. The benefits of this approach go well beyond risk identification and reduction. A common fundamental understanding of nanomaterial-biological interactions will enable unprecedented productivity in product development, especially for medical and environmental applications.

A very promising development in which ONAMI is integrally involved is the NIEHS- and NIBIB-led NanoHealth Enterprise Initiative:

http://www.niehs.nih.gov/research/supported/programs/nanohealth/index.cfm

. . .which seeks to join the Foundation for NIH, industry, academia and numerous federal agencies in a public-private partnership aimed at effectively organizing and administering the accomplishment of this task. One important consideration is that, unlike the pharmaceutical industry, which funds much of the similar Biomarkers enterprise, the nanomaterials industry is newer, smaller, and more diverse/fragmented—so probably not able or willing to fund this effort to the same degree.

ONAMI experience and accomplishments: We were among the first to see the vital connection between the principles of green chemistry and nanoscience, and to emphasize deep collaboration between EHS-oriented research and nanotechnology product development ("implication" and "application"). After inventorying assets among our collaborating institutions and building a relationship with the Air Force Research Laboratory, we believe we have the strongest Green Nanotechnology program in the world. We are participating in the ANSI TAG to ISO–229 WG3 (EHS), and were asked to be one of the few regional centers involved in organizing the NanoHealth Initiative. Finally, we hold an annual ONAMI Greener Nano conference in March, which brings to together national experts from research and industry on all the major topics related to nano-EHS.

EHS - What the re-authorization should consider:

1. Filling the gap between tallied "nano EHS" funding and the 10% (of the NNI total) called for by the NanoBusiness Alliance and other voices. The multi-agency NanoHealth Public Private Partnership would be an excellent candidate to fill that gap.
2. Assigning leadership/ownership in the federal government for nanomaterials nomenclature/ontologies and characterization standards to an appropriate agency (possibly NIST), closely integrated with the NanoHealth Enterprise and any other similar efforts. An organized effort here would surely strengthen the U.S. at ISO.
3. Possibly co-fund a Department of Defense Center for Green Nanotechnology, which would leverage DoD's extensive in-house expertise, research community connections, and application focus.
4. Research in support of industrial best practices (preferred) and risk-based

Collaboration and Resource Leverage: *Required for such a broad and cross-cutting effort to be both successful and efficient*

It may be true that nanotechnology represents the largest single federal research effort since the Apollo moon program, but unfortunately it is not (and almost certainly cannot be) as tightly focused as "landing a man on the Moon and returning him safely to Earth." It will soon influence/penetrate over 10 percent of GDP and has relevance to the mission of at least 25 federal agencies, of which 13 have R&D budgets for nanotechnology (*www.nano.gov*). The NNI, led by the NNCO, has indeed broken new collaborative ground with interagency collaboration, even though it has no budget or real decision-making authority. This progress needs to accelerate.

There are also established trends in industry and the academic/research community (though not yet as pronounced or driven by need there) to form partnerships where tasks and sub-tasks in a larger effort are assigned to a global network of suppliers/contractors selected competitively based on capability, cost and other terms and conditions. The purpose is to provide the best product or service to a global customer base at the lowest cost in the shortest period of time.

Of great importance to small/medium business and entrepreneurial startups is access to talent (not necessarily on a permanent/full-time basis) and to sophisticated research equipment and facilities—particularly for measurement and characterization. The term "high tech extension" is used at ONAMI for this concept and suggests that there really needs to be greater geographic distribution and more local outreach than is currently possible for the 13 sites of the NNIN if the benefits of nanotechnology entrepreneurship are to occur in all but a few locations in the U.S. Universities and national laboratories are an ideal home for this mission, but only if they locate, organize and operate their major laboratory assets as "shared user facilities" that are truly open and available to all researchers and for industry collaborations (at appropriate market rates). It is also true that this shared/open business model makes better and more efficient use of federally funded equipment.

Successful and highly-valued ONAMI collaborative efforts and experiences to date have included:

1. *A network (NWNanoNet™) of complementary facilities open to all researchers on an equal cost/access basis, and available for industry collaborations and small company assistance. These facilities include:*
    a. *Microproducts Breakthrough Institute (emphasizing micro-energy and chemical systems, including nanomaterial fabrication)*
    b. *Center for Advanced Materials Characterization (2/19/08 public grand opening of one of the world's best and quietest facilities for SEM/eSEM, STEM, HR–TEM, FIB, SIMS, XRD and more)*
    c. *Center for Electron Microscopy and Fabrication (SEM, TEM, FIB, NT/NW fabrication and characterization*
    d. *Additional facilities emphasizing microscopy/analysis for bioscience and nanoscale fabrication) are planned.*
2. *Technology (e.g., web cams, virtual network connections) to enable effective interactions with remote research or industry clients.*
3. *Dramatic growth in collaborative projects (and overall tripling of ONAMI-affiliated research volume between FY04 and FY07), and even sharing of graduate students between campuses.*
4. *Formal and informal education (both children and adults) collaborations with community colleges and NISEnet member Oregon Museum of Science & Industry (OMSI). In particular, joint public forums on the benefits and risks of nanotechnology have been highly effective, showing that "average citizens" are accepting/enthusiastic about nanotechnology when they understand that the experts are conscientiously weighing these factors.*

Closing Comments and Additional Considerations:

Nanotechnology represents the convergence of chemistry, condensed matter physics, and biology at the nanometer scale, so it is essential that the structure and management of the federal NNI investment reflect the multi-disciplinary interaction and collaboration implied in this convergence. This should be true of all agencies in the NNI, not just the five named in P.L. 108–153 (NSF, DOE, NASA, NIST, EPA). Multi-disciplinary initiatives involving multi-disciplinary proposal review are recommended to the extent possible.

At least one other critical cross-cutting topic (in addition to EHS) deserves to be called out for special attention: nanoscale metrology—for both physical and chemical measurements. This is of sufficient criticality that a significant extramural funding program (i.e., to capture the creativity at universities) is warranted.

P.L. 108–153 called for certain specific centers to be established (i.e., American Nanotechnology Preparedness Center, Center for Nanomaterials Manufacturing). If the reauthorization is organized around the concept of center solicitations, topics deserving of special mention include:

Chemical Imaging and Measurement at the Nanoscale

Nanotechnology and Nanobiotechnology (with emphasis on commercialization and industry collaborations)

Green Nanomanufacturing

All three of the above topics would be excellent fits for leadership from the Pacific Northwest, especially institutions in Oregon and Washington.

ONAMI President & Executive Director Skip Rung and members of the ONAMI leadership team will be happy to answer questions or participate in discussions related to these recommendations.

BIOGRAPHY FOR ROBERT D. "SKIP" RUNG

Mr. Rung is a senior high technology R&D executive with over 25 years of R&D management experience in CMOS process technology, application-specific integrated circuit (ASIC) design and electronic design automation (EDA), IC packaging, MEMS, microfluidics, and inkjet printing.

Mr. Rung was asked in December 2003 to serve as the initial Executive Director of the Oregon Nanoscience and Microtechnologies Institute (ONAMI), Oregon's first "Signature Research Center" and an unprecedented collaboration among Oregon's research universities and the Pacific Northwest National Laboratory. ONAMI's dual mission is to grow "small tech" research in Oregon and commercialize technology in order to extend the success of Oregon's world-leading "Silicon Forest" technology cluster, which includes the most advanced R&D and manufacturing operations for leading companies such as Intel Corporation, Hewlett-Packard Company, FEI Company, Invitrogen, Electro Scientific Industries, Planar Systems, Xerox Office Products, Tektronix, ON Semiconductor and many dynamic smaller firms. ONAMI has so far received $37M in State investment and approximately doubled Oregon's annual federal and private research awards in the fields of nanoscience, green nanotechnology, nanoscale metrology, and microtechnology-based energy and chemical systems (MECS).

Following his retirement from Hewlett-Packard in 2001, Mr. Rung consulted in the areas of innovation management, technology business development, and intellectual property. He is a co-author of the 2004 Oregon Research Competencies study commissioned by the Oregon Economic and Community Development Department and the author of the initial business plan for the Oregon Nanoscience and Microtechnologies Institute, successfully recommended for funding as Oregon's first Signature Research Center by the Oregon Council on Knowledge and Economic Development. OCKED's determination was aided and influenced by Mr. Rung's 2002 consulting study of Oregon's most commercially promising and industrially relevant research.

Mr. Rung was a member of the Oregon Engineering and Technology Industry Council from 1999–2003 and a co-founder of the New Economy Coalition. He is currently a technical advisor to Northwest Technology Ventures, an Oregon seed-stage venture capital firm, a director of the Oregon Entrepreneur's Forum, Vice-Chair of the Corvallis–Benton County Economic Development Partnership, and active in several other community development efforts.

From 1987 to 2001, Mr. Rung was the Director of Research and Development at Hewlett-Packard's Corvallis, Ore. facility, responsible for the development of future generations of HP's world-leading thermal inkjet technology, and for developing future business opportunities enabled by HP's microelectronics, MEMS, and microfluidics competencies. During Mr. Rung's 14 years as R&D director, inkjet printing became HP's largest and most profitable business, maintaining worldwide technical leadership through several major new generations of technology and holding market share nearly twice that of the next largest competitor. Prior to his work on inkjet, Mr. Rung was the R&D Manager for HP's Northwest Integrated Circuits Division in Corvallis, which achieved worldwide ASIC technology leadership in 1986 with a one-micron process comparable to those used for DRAM. Mr. Rung's organization also developed novel and performance-leading in-house IC design automation systems and custom IC packaging technologies (hybrids, flat packs, TAB) to enable calculators and other HP products.

Mr. Rung began his industrial career in 1977 at Hewlett-Packard Laboratories in Palo Alto, CA, performing advanced research in the areas of CMOS process device isolation, latch-up, and comparison with alternative silicon and compound semiconductor technologies. In 1981–1982, Mr. Rung was selected by HP to be a technology exchange engineer with Toshiba Corp. in Kawasaki, Japan, where he continued his research inside the world's leading semiconductor memory engineering group. He is the holder of two U.S. Patents, author or co-author of over 14 refereed journal or conference papers on IC technology, four invited papers (two at leading international meetings), and four invited presentations on inkjet printing technology.

Mr. Rung received his BSEE and MSEE co-terminally in 1976 from Stanford University, where he was elected to both Phi Beta Kappa and Tau Beta Pi in his junior year. His Master's thesis concerned the experimental determination of semiconductor doping profiles, and was part of the Stanford research on process simulation that was seminal for the rapid growth of computer simulation for solid state electronic processes and devices.

Chairman BAIRD. Thank you very much. We will likely follow up with some questions about that. Excellent testimony.

Dr. Chen.

STATEMENT OF DR. JULIE CHEN, PROFESSOR OF MECHANICAL ENGINEERING; CO-DIRECTOR, NANOMANUFACTURING CENTER OF EXCELLENCE, UNIVERSITY OF MASSACHUSETTS LOWELL

Dr. CHEN. Thank you Chairman Baird and the other Committee Members for inviting me here today. I am Julie Chen. I am a Professor of Mechanical Engineering at the University of Massachusetts Lowell, and I am also co-director of a state-funded Nanomanufacture Center of Excellence. I would be remiss not to pass along the best wishes and greeting of our university's new chancellor, and your former colleague, Marty Meehan.

UMASS is also part of a very unique equal partnership with Northeastern University and the University of New Hampshire in a National Science Foundation-funded Center for High-rate Nanomanufacturing. This is one of only four such centers in the United States focuses on developing tools and processes for high-volume, high-rate production. The center has partnership with over two dozen companies, and these companies represent the full spectrum of industry sectors and company size, everything from start-up to Fortune 100.

Mr. Chairman, we have seen that from drug therapies and efficient energy sources, to protection for our war fighters, innovative nanotechnology is going to be important for this nation. We are not the only country to recognize the possibility of nano. Several nations in Europe and Asia have made nano a national priority and have invested heavily in its expansion. As with much of the U.S., the City of Lowell has seen it share of industry strength and loss, from the textile industry to minicomputers to biotechnology. As a nation, we cannot afford to have a laissez faire approach to technology transfer of the research coming out of nanotechnology.

Today, I would like to concentrate my specific comments on four points. The first one is company attitudes. I am aware of two major surveys that have been done of business leaders and their attitude toward the nanomanufacturing industry, the most recent, one conducted in 2006, by a team lead by Barry Hock, with collaboration between the UMASS Lowell Center for Economic and Civic Opinion and *Small Times Magazine,* the prior survey conducted by NSF was conducted in 2005. The results are consistent. Of the respondents, almost 90 percent felt that the Federal Government should participate or take the lead in fostering R&D and providing commercializing incentives. On both surveys, items like the high cost of processing, perception of lengthy times to market, and process scalability were cited as key areas. It is clear that industry believes that Federal Government funding is really a key to closing the gap between the early successes that we have had in the lab and delivery of products. An additional note is that 89 percent of these business leaders also stated the importance of EHS risks the Committee has addressed. At Lowell, we have EHS researchers working side by side with nanomanufacturing researchers, measuring potential levels of exposure and making suggestions in terms of the chemicals and materials that could be used to ensure that the products that we develop in the future, and the processes, are greener in their development. It is this type of multi-disciplinary partnership that we need to foster and to encourage to help move this technology forward.

The second point is in terms of basic research. Over the past decade, we have made significant advances in fabrication of the building blocks, the nanotubes, the nanoparticles, and we are getting a better understanding through experimentation and modeling of how forces interact with these building blocks. We have only scratched the surface, though. We haven't yet gotten to the point to where we can sit down and design the process and the product for a nanotechnology-related product.

Here, what I would like to do is emphasize that we need to think of nanotechnology not as a single-industry sector or a single way of making products. Differences that we see, in fact, today, in manufacturing between making steel, making a medical device, making an electronic device, carries over through nanotechnology, and we can see from the foreign NSF centers that that is true. Many different mechanisms are being used, and we need to recognize that there is a broad array of techniques.

So I am going to talk about three examples in terms of basic research that cut across these different processes, rather than a specific one. The first example is in-line metrology. To paraphrase one of my colleagues, Professor Carrol Barry at UMASS Lowell, you can make 100 products an hour, but it is going to take you a week to find out if any of them are any good. You need end-line rapid measurement in order to move process development forward. Example B, processing equipment, it takes more than just making the filament to make the light bulb. You need to make the filament, the bulb, the battery, the switch, and put that all together. We need more efforts in terms of the processing equipment to integrate these things. And the third area is models. We see from nature that things are not perfect. In a spider web, you have radial lines, nice circular lines, but they are not all perfect, and yet the web is still able to catch the fly. We need to understand from modeling how perfect do we have to be in order to truly make commercial products.

My third point is in terms of university industry interaction. We believe that a percentage of funds needs to go towards technology demonstration projects in the form, perhaps of an STTR program, but allowing both small and large companies to participate because nanotechnology is really going to be important to both. The other thing that we would say is that the bulk of federal support should not be targeted. We cannot prevent the discovery not yet envisioned from being funded, but the small percentage of funding for these technology-demonstration projects will help to focus and drive the research forward and will help to dispel any concerns from venture capitals about the commercial viability of nanotechnology.

My last point is in terms of user facilities. Over 90 percent of the business leaders stated that user facilities were critical to their advancement, although smaller companies are more likely to use user-facilities because of lack of resources. But again, user facilities should not just be limited to the traditional characterization and lithography based. We found many different ways of making things, and we want to make many different types of facilities available across the country, so the idea of not just selecting a few but allowing any facility that shows that there is industry interest to have some funding to provide for that administrative support is important for moving this forward.

In conclusion, Mr. Chairman, and Members of the Committee, I would like to thank you again for the opportunity to testify. I believe that there is an important role that NNI and the Federal Government can play in fostering this technology transfer. The bulk of funding for R&D must remain at the basic research level to conceive the emerging technologies of the future, but a few of these targeted funds, in terms of university-industry partnerships for technology demonstration for developing tools and processes are going to be important to move forward this technology. Thank you.

[The prepared statement of Dr. Chen follows:]

PREPARED STATEMENT OF JULIE CHEN

ABSTRACT

Nanotechnology is facilitating the advancement of new applications across many fields and industries. While many major commercial applications of nanotechnology are still five to ten years out, private sector investors seek much shorter-term investment returns. Business leaders overwhelmingly identified challenges of high cost of processing, process scalability, perception of lengthy times to market, and Environmental, Health, and Safety (EHS) unknowns as barriers to commercialization. While a portion of the NNI's funds have been targeted towards efforts such as nanomanufacturing, R&D facilities and EHS research, much more needs to be accomplished in these areas. The United States remains the leader in nanotechnology R&D and maintaining this position and continually advancing nanotechnology is a major goal of the NNI. While the bulk of the federal funding for R&D must remain at the basic research level to ensure future discoveries and emerging technologies, some federal funding is needed to provide incentives for the university-industry partnerships that are needed—(1) to accelerate technology demonstration efforts; (2) to develop and expand the accessibility of new tools for rapid, in-line measurements and new processing equipment; and (3) to address concomitant issues such as environmental, health, safety, and intellectual property. Increased federal support for basic research and development and for technology transfer incentives is essential to maximize nanotechnology's potential and to maintain America's competitive advantage in the global marketplace.

INTRODUCTION

Thank you, Mr. Chairman and the other Committee Members for inviting me here today to discuss the state of nanomanufacturing research and the National Nanotechnology Initiative's (NNI) efforts in fostering the transfer of our research and development efforts toward commercial products and greater economic competitiveness of the United States. While informed by discussions with many colleagues, the statements in this testimony are my personal opinions.

I am a Professor of Mechanical Engineering at the University of Massachusetts Lowell and I am Co-Director of the Nanomanufacturing Center of Excellence. I would be remiss not to pass along the best wishes and greetings of our University's new Chancellor and your former colleague, Marty Meehan.

In addition to being designated a State-funded Nanomanufacturing Center of Excellence, UMass Lowell is part of a unique equal partnership with Northeastern University and the University of New Hampshire in the National Science Foundation (NSF) sponsored Center for High Rate Nanomanufacturing (CHN).[1] Funded as part of the NNI, this Center is one of only four NSF Centers in the country that focuses on nanomanufacturing. The Center has as its overarching goal, the creation of tools and processes that will enable high-rate/high-volume, template-directed assembly of nano-building blocks, such as carbon nanotubes and polymer nanostructures. The CHN thrives by integrating complementary expertise in semiconductor and MEMS (micro-electrical-mechanical systems) fabrication, plastics processing, chemical synthesis and functionalization, and environmental health and safety. This theme of multi-disciplinary and multi-institutional partnerships is one that I will revisit throughout my testimony.

An important component of the NSF nanomanufacturing centers is external partnership—for example, the CHN has partnerships with over two dozen companies, other universities, government agencies including the Army Research Lab and Lawrence Livermore National Laboratory, and international collaborators. These companies represent the full spectrum of industry sectors—e.g., defense, electronics, biomedical, transportation—and sizes—e.g., from startup companies to Fortune 100 companies. One of the specific goals of all of the NSF nanomanufacturing centers, as well as our Center of Excellence, is to help industry overcome the technical barriers to commercial applications of nanotechnology innovations.

Mr. Chairman, from the drug therapies to clean water to more efficient energy sources to addressing the critical force protection needs of the war fighter, the transfer of innovative nanotechnology research to applications of commercial and public benefit is a primary objective of the National Nanotechnology Initiative. More personally, as a researcher and an engineer, my goal and that of many of my colleagues, is one of discovery but with the desire to see that knowledge creation lead to products that will benefit society. Unfortunately, such pathways to commercialization must navigate the commonly referenced "valley of death" between R&D and the marketplace. Even successful technologies can take decades to reach the marketplace. Yet, we see the lifetimes of technological advantage continue to shrink with the decreases in time to market and increases in global competition for manufacturing. For example, Lowell has seen its share of industry strength and stagnation from the textile industry to minicomputers to biotechnology. Biotechnology is one of the region's economic drivers, but the fierce competition can be seen by the aggressive presence of over 30 international delegations with pavilions at the 2007 BIO International Convention held in Boston.

What does this global competition mean for the more nascent nanotechnology field? Since its inception in 2001, federal funding for nanotechnology research and development has more than doubled. While this is an impressive start, we are not the only country to recognize the remarkable societal and economic possibilities of nanotechnology research. Several nations in Europe and Asia have made nanotechnology a national priority and have invested heavily in its expansion. As a nation, we cannot afford a *laissez-faire* approach to technology transfer of R&D.

RESPONSES TO SPECIFIC QUESTIONS

Today, I would like to concentrate my specific comments on four areas:

1. Companies' attitudes towards the need for federal support of nanotechnology and the critical areas of investment
2. Areas of basic research that need greater support to move industry towards high-rate nanomanufacturing
3. Interaction between universities and industry for setting research direction
4. The role of user facilities in advancing technology transfer

1. Companies feel strongly about the need for federal support of R&D in high-rate/high-volume nanomanufacturing and commercialization incentives for nanotechnology

I am aware of two major surveys that have been conducted on the attitudes of companies towards the developing nanomanufacturing industry. The most recent, conducted in 2006 by a team led by Barry Hock, was a collaboration between the UMass Lowell Center for Economic and Civic Opinion and *Small Times Magazine*[2].

[1] CHN Director, Ahmed Busnaina (Northeastern), CHN Deputy Director, Joey Mead (UMass Lowell), and CHN Associate Director, Glen Miller (UNH) are the leads at their respective institutions. (*www.uml.edu/nano, www.nano.neu.edu, www.nanotech.unh.edu*)

[2] B. Hock, et al., "Survey of U.S. Nanotechnology Executives," full report available on *http://www.masseconomy.org/html/3_0ceo_ceosurvey.html#nanoexec* (accessed March 3, 2008) and summary article available in *Small Times Magazine,* Jan/Feb 2007 (and online at *http://*

Continued

Where relevant, I will also comment on comparisons to a prior NSF-funded survey conducted in 2005 by Dr. Manish Mehta and the National Center for Manufacturing Sciences (NCMS).[3] The former analyzed responses from phone surveys of roughly 400 business leaders in nanotechnology-identified companies, while the latter compiled results from online survey responses of roughly 600 industry executives.

Of the respondents in the 2006 survey, 45 percent felt that the Federal Government should take the lead in fostering R&D and providing commercialization incentives, while an additional 43 percent favored participation, but in a limited fashion. These results mirrored those of the 2005 survey, where over 90 percent favored "Federal Government involvement in the commercialization of nanomanufacturing." In the 2006 survey, when asked what single area of R&D needed the most strengthening, "high volume manufacture of nanotechnology materials and products" was selected by 39 percent of the respondents, with the second highest area (basic, long-term research) coming in much lower at 15 percent. Again, this aligned well with the 2005 survey where "high cost of processing," "perception of lengthy times to market," and "process scalability" represented three of the top five barriers to commercialization. It is clear that industry believes that Federal Government funding is critical to closing the gap between the early successes in the lab and the delivery of products.

Surprisingly, environmental, health, and safety (EHS) was selected as a critical R&D area by only a small percent of respondents, even though the same executives overwhelmingly (89 percent) stated that it was very important for the government to address EHS risks associated with nanotechnology and that little was known about the risk (64 percent). One possible explanation for this apparent discrepancy is that given the option of selecting only the single most important area, industry executives felt that R&D-fueled advances in high volume manufacturing would more directly impact their ability to make products. Nevertheless, the strong response on EHS risks, coupled with the testimony at the Research and Science Education Subcommittee's October 31, 2007 hearing on environmental and safety impacts of nanotechnology, clearly state the need for federal support for EHS research. This EHS research should be conducted, not in isolation, but rather in combination with R&D on new nanomanufacturing processes and targeted nanotechnology applications. At Lowell, we have EHS researchers in the lab, working side-by-side with the nanomanufacturing researchers, measuring potential levels of exposure and suggesting "greener" chemical and materials choices, as new processes are being created. It is through this type of multi-disciplinary partnership that we can better ensure safer new products.

2. Areas of basic research that need greater support to move industry towards high-rate nanomanufacturing include the need for research advances in supporting fields, such as metrology, multi-scale integration, modeling, and EHS.

Over the past decade, we have made significant advances in fabrication of carbon nanotubes, nanoparticles, and other such nano-building blocks, as well as in methods for depositing nanoscale layers of material. Through experimentation and molecular-level modeling, we have a better understanding of the interaction of forces, whether they are optical, electrical, magnetic, fluidic, chemical, etc., with nanoscale elements. We have, however, still only scratched the surface towards ultimately being able to predict and design the process and the end-product performance for a breadth of nanotechnology applications. Thus, while today, an engineer could sit down at a computer and design the mold, material, and process conditions to manufacture miniature plastic medical device parts or the layout of a semiconductor chip for your phone, we still have many challenges to address to achieve the same at the nanoscale.

Here, I would first like to state that to think of nanomanufacturing or nanotechnology as a single industry sector would be a mistake. Unlike the biotechnology industry or the semiconductor industry, companies incorporating nanotechnology into their products do not all identify themselves as nanotechnology companies. Rather, nanotechnology and nanomanufacturing are methods to create more competitive products for automotive, aerospace, communications, electronics, energy, medical, and many more applications. Thus, the vast differences in the current processes for manufacturing steel or catheters or the iPhone, are also rep-

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www.smalltimes.com/display_article/281851/109/ARTCL/none/none/1/Survey-says:-Manufacturing,-government-keys-to-US-success/, accessed March 3, 2008).

[3] M. Mehta, "2005 NCMS Survey of Nanotechnology in the U.S. Manufacturing Industry," full report available on *http://www.ncms.org/publications/PDF/05NCMSNanoFinalReport.pdf* (accessed March 3, 2008).

resented in the many different approaches towards nanomanufacturing research taken by the four NSF Centers—e.g., the University of Illinois in nanofluidics,[4] UMass Lowell/Northeastern/UNH on template-assisted assembly, UMass Amherst using self-assembled block co-polymers,[5] and UC–Berkeley/UCLA in plasmonic lithography.[6] While technology roadmaps have been useful for industries such as the semiconductor industry, one would need to have multiple roadmaps, tying related product types to nanomanufacturing approaches. Therefore, here I have limited my brief remarks to challenges that cut across multiple processes and where I believe a significant federal investment in basic research will yield dividends over the next three to five years:

- **In-line Metrology—**The NNI has sponsored several workshops over the years to identify critical barriers and grand challenges in nanomanufacturing.[7] In every case, the lack of measurement tools for in-line, large-area measurement of product characteristics is cited as a barrier. To paraphrase one of my Co-Directors at UMass Lowell, Professor Carol Barry, "you can mold 100 parts in an hour, but it will take you a week of microscopy to figure out if what you have is any good." Clearly, off-line, labor-intensive electron (SEM, TEM) and atomic force microscopy (AFM) is not the answer for process development and product quality control in these early stages. Just as the development of the scanning tunneling microscope (STM) in the early 1980's enabled the growth of nanotechnology by allowing us to "see" and manipulate atoms at the nanoscale, there is a need for new tools that can extend our measurement capabilities to the manufacturing environment.
- **Processing equipment for multi-scale and hierarchical manipulation, assembly, and integration—**Similarly, while we can manipulate individual nanoparticles and molecules in the laboratory using AFM and STM, doing so is not a practical approach to manufacturing. Hence, much of the current nanomanufacturing research focuses on self-assembly or directed self-assembly using chemical, electrical, optical, fluidic and other forces. While we can use these indirect forces to manipulate many nano-building blocks into place, fabricating a whole device or structure typically involves connecting one component or layer to the others. Thus, precise positioning and manipulation of each component or layer relative to the next is needed. The semiconductor industry has extensive expertise in this type of precision for 2D-layer-by-layer lithography-based manufacturing processes, but other methods must be developed for a full 3D capability. Some funding is available for research on the fundamental mechanisms, but funding for innovative processing equipment development is extremely limited.
- **Models incorporating statistical variation (robust and redundant designs)—**Being able to control material structure at the nanoscale means that we can start to approach fabrication of truly multifunctional structures. While such control can be achieved over small areas, it is difficult to maintain the same level of control over much larger areas. Precise patterns begin to exhibit some variations. For commercially-viable products, the answer is not to require precision and exact replication over large volumes. Rather, just as in nature, variation is acceptable as long as functionality is maintained. For example, as beautiful as a spider web is with its radial and circumferential lines, all of the lines are not perfectly spaced nor are they perfectly oriented. Nevertheless, the web is still effective at capturing the fly, and a break in one radial line does not cause the collapse of the entire web. Functionality is often maintained through redundancy. To achieve this level of robustness in our engineered materials and devices, our understanding of exactly what degree of variation, defect, or damage is acceptable must improve. Models that incorporate statistical variation and uncertainty can help to define the precision required in manufacturing.
- **Life cycle analysis of environmental, health, and safety—**EHS was discussed already in reference to the survey, so I will only make one additional comment here. While we are actively looking at measuring exposures and quantifying oxidative stress in cells due to exposure, another component of

[4] *http://www.nano-cemms.uiuc.edu/* (accessed March 6, 2008).
[5] *http://www.umass.edu/chm/* (accessed March 6, 2008).
[6] *http://www.sinam.org/* (accessed March 6, 2008).
[7] J. Chen, H. Doumanidis, K. Lyons, J. Murday, M.C. Roco, "Manufacturing at the Nanoscale," NNI Workshop Report, *http://www.nano.gov/NNI_Manufacturing_at_the_Nanoscale.pdf* (accessed March 3, 2008).

the EHS question is understanding in what form nanomaterials will exist through their entire life cycle, i.e., from processing to disposal. For sustainability, one generally hopes that products tossed into a landfill do biodegrade, but we must also understand what intermediate separation of nanoparticles from the bulk material may mean in terms of exposure.

3. Universities and industry need to communicate better on setting research directions and on scalable approaches to addressing the challenges—a few key technology demonstrations would accelerate the R&D progress as well as sustain interest from capital investments and the public.

Continued funding of basic research is critical to harvest the long-term benefits of the past and current investment in nanotechnology. Recognizing that even after over 50 years of studying heart disease we still much to learn, long-term basic research support is needed for emerging technologies. This must combat the trend of attention spans getting shorter and shorter. Funding sources for R&D and capital investments looking for the next big thing must recognize that we have yet to harvest the real promise of nanotechnology. Current first and second generation nanoproducts—pants that don't stain, golf balls that fly straighter, cars that are lighter—represent harvesting fruit trees to build a shelter—important for survival, but not reaping the full benefits. By continuing to care for and plant more trees for cross-pollination, we can eventually harvest the fruit from the trees for food and for future sustainability. For nanotechnology, we need to continue to fund basic R&D and to provide incentives for high-quality cross-pollination from university-industry partnerships.

One approach would be to allocate a percentage of funds towards technology demonstrations or industry/university testbeds. The key to these testbeds is that they must be an active collaboration between the industry sponsor and the university researchers. Specific technical challenges and measurable targets must be identified that will lead to a commercially-viable product. For example, there are researchers working on sensors at every research university in the U.S.; yet, why do so many not make it to the marketplace? In many cases, there is a large gap between demonstrating a sensing mechanism that works in the lab and actually manufacturing a sensor with power, input/output signals, and robust sensing and packaging for a harsh environment. By encouraging researchers and sensor manufacturers or users to work together, the development can occur in a parallel and more effective fashion.

The Center for High-rate Nanomanufacturing and the Nanomanufacturing Center of Excellence have taken an aggressive position in involving industry in our work. This is in part due to our research focus on nanomanufacturing but is also in part due to history of UMass Lowell and Northeastern and UNH working with industry, both regionally and nationally, on collaborative research to address real businesses' real needs. To initiate discussions of research directions with industry, we have active industrial advisory boards, host and participate in trade shows, conferences and workshops to introduce industry to our faculty, facilities and research, and solicit and secure industry funded research that extends a general discovery towards the needs of a specific application area. For example, as part of our Army Research Laboratory sponsored Nanomanufacturing of Multi-functional Sensors program, we are working closely with the Army and with companies on developing manufacturable sensors to protect the war fighter.

In general, the bulk of federal support of R&D should not be tightly targeted or directed, as this will inhibit the important discovery not yet envisioned. Nevertheless, a small percentage of funds supporting a few such technology demonstrations can serve many purposes: (1) they help to focus and drive the research forward more rapidly for a particular application; (2) they help to dispel concerns from sources of investment capital about the general feasibility of nanotechnology by providing examples of commercial successes; and (3) they help to capture the imagination of the general public, and communicated correctly, can help to generate continued support for R&D. Such incentives for technology demonstration partnerships between industry and academia could be a modified form of the STTR program, but with participation from small and large companies.

4. User facilities (and complementary expertise) are needed to advance technology transfer, especially in support of small businesses.

The 2006 survey responses towards use of university (mostly federally-sponsored) user facilities reflected the likely need for a broad range of equipment to develop nanotechnology products. Over 90 percent rated access to unique equipment and facilities as very important. Although almost 60 percent rated their own infrastructure as excellent or very good, a similar percentage also indicated their company planned to use university user facilities. This suggests that companies are likely to have specialized equipment in-house that is critical to their product space, but that supplementary equipment for characterization or scientific and engineering support needed on a limited basis would be sought at universities or other user facilities.

These survey results match well with our experiences. We have had success working with industry, but we have also encountered some challenges, primarily because of intellectual property (IP) concerns. Smaller companies are much more likely to collaborate with universities because they cannot afford to have all the facilities, such as a clean room, or the breadth of equipment that the university has built up. The piece that often is overlooked in the discussion of user facilities, however, is that it is the expertise associated with how to use the equipment, how to interpret the results, and how to move forward based on those results that can lead to success, not just the physical equipment. While many user facilities such as the NNIN have procedures where facility use does not require companies to share IP, revolutionary advances require the type of in-depth, open discussions between researchers who are at the cutting-edge and their industry counterparts that can be inhibited by IP concerns.

Although the high cost of equipment tends to favor consolidation of facilities, it should be recognized that even with the power of the internet, distance is a factor. We find that companies located within our region are much more likely to collaborate with us because of the opportunity for face-to-face interaction, even though our capabilities could help companies across the country. Another consideration in establishment of user facilities is that there are many types of manufacturing approaches, with different equipment and facility requirements. For example, the earlier version of the NNIN was heavily focused on lithography-based processes and characterization. The NNIN has since added more bio-based capabilities with the inclusion of the University of Washington and other new partners, but there are dozens of other types of facilities that could be of use towards advancing technology transfer. Sharing these facilities with other universities and companies involves additional costs in terms of staff time and maintenance. It is difficult, however, to hire the one-third or one-half of a staff person needed to assist the first few industry partners. One model that could be explored would be similar to the NSF Industry–University Cooperative Research Center Program (IUCRC) where NSF provides funding to cover administrative support, provided enough companies demonstrate their interest in the Center through direct funding of projects. Therefore, if a university could demonstrate enough industry interest in a particular characterization or processing facility—e.g., a multi-layered extrusion, nanocomposite dispersion, or nano-molding facility—then federal funds could be made available to provide initial stability for the additional staffing needed. The federal funds could then be phased out or adjusted as the facility grows the number of users. This would ensure that federal funds are going to facilities that are in demand and that user facilities have an incentive to grow their number of users.

CONCLUDING STATEMENT

Mr. Chairman, Members of the Committee, I would like to thank you again for the opportunity to testify before your committee. I believe that there is an important role that the NNI and the Federal Government must play in fostering the transfer of technology from the research lab to the marketplace. While the bulk of the federal funding for R&D must remain at the basic research level to ensure future discoveries and emerging technologies, some federal funding is needed to provide incentives for the partnerships that are needed—university-industry partnerships to accelerate technology demonstration efforts, to develop and expand the accessibility of new tools and processing equipment, and to address concomitant issues such as environmental, health, safety, and intellectual property. That concludes my prepared remarks and I look forward to answering any questions you may have.

BIOGRAPHY FOR JULIE CHEN

Dr. Julie Chen is currently one of the three Co-Directors[8] of the UML Nanomanufacturing Center (she is responsible for the NCOE[9] component) and the Co-Director of the Advanced Composite Materials and Textile Research Laboratory at the University of Massachusetts Lowell, where she is a Professor of Mechanical

[8] With Professors Joey Mead and Carol Barry.

[9] The Nanomanufacturing Center of Excellence (NCOE) is a state-funded center with the mission of fundamental scientific and applied, industry-collaborative research on environmentally-benign, commercially-viable (high rate, high volume, high yield) manufacturing with nanoscale control.

Engineering. Dr. Chen was the Program Director of the Materials Processing and Manufacturing and the Nanomanufacturing Programs in the Division of Design, Manufacture, and Industrial Innovation at the National Science Foundation from 2002–2004. Dr. Chen has been on the faculty at Boston University, a NASA–Langley Summer Faculty Fellow, a visiting researcher at the University of Orleans and Ecole Nationale Superieure d'Arts & Metiers (ENSAM–Paris), and an invited participant in the National Academy of Engineering, Frontiers of Engineering Program (U.S., 2001, U.S.–Germany, 2005, and Indo–U.S., 2006). In addition to co-organizing several national and international symposia and workshops on composites manufacturing and nanomanufacturing for NSF, ASME, ASC, and ESAFORM, Dr. Chen has also served on editorial boards, advisory committees, and review panels for several journals and federal agencies, including NSF, NIH, the National Academies, ARL, and AFOSR.

Dr. Chen received her Ph.D., MS, and BS in Mechanical Engineering from MIT. She has over 20 years of experience in the mechanical behavior and deformation of fiber structures, fiber assemblies, and composite materials, with an emphasis on composites processing and nanomanufacturing. Examples include analytical modeling and novel experimental approaches to electrospinning and controlled patterning of nanofibers, nanoheaters, and forming, energy absorption, and failure of textile reinforcements for structural (biomedical to automotive) applications.

Chairman BAIRD. Mr. Welser.

STATEMENT OF DR. JEFFREY WELSER, DIRECTOR, NANOELECTRONICS RESEARCH INITIATIVE

Dr. WELSER. Good morning. My name is Jeff Welser, and I am on assignment from the IBM Corporation to head the Nanoelectronics Research Initiative, or NRI. I appreciate the opportunity to testify today on behalf of the NRI, the IBM Corporation, the Semiconductor Industry Association, and the Semiconductor Research Corporation.

Let me start by noting that as its name implies, NRI is focused on nanoelectronics, which is the application of nanotechnology to the electronics field, including the semiconductor devices and chips which fuel our economy today from supercomputers to laptops to cell phones to automotive electronics. This industry has been built on constantly shrinking the size of these components and arguable was the first industry to begin exploit nano for commercial products. But now, we are quickly approaching the fundamental limits of the current technology, and we will need to find entirely new devices to continue these unprecedented technological advances. It is not just about shrinking things anymore. It is about taking advantage of the physics that comes with small sizes to create new functionality, the same promise nanotechnology hold for so many other fields of science as well.

And since so many of the advances in these other fields, as well as in the economy as a whole, will depend on semiconductors, our success will be crucial to America's overall competitiveness. Simply put, whichever country is first to market with the new chip technology will lead in the coming nanoelectronics area the way the U.S. had led for half a century in the microelectronics era.

In the next five minutes, I would like to focus my remarks on two key questions submitted by the Committee. I will answer these in the context of how our initiative is advancing and commercializing nanoelectronics, but I feel strongly that the partnership model and approach we employ can be utilized across all of the areas of nanotechnology that the NNI addresses.

First, given our industry's grand challenge of finding a new semiconductor device, how to we interact with government to set research directions and manage research activities? The NRI's model is to do goal-oriented, basic research. This model balances the need for a broad range of research into many different science phenomena with the need to drive the research in the most productive directions for future commercialization. All of the NRI's research is done at multi-university centers, and we are currently supporting work at 25 universities in 13 states.

Centering the work at universities rather than in our own industrial labs or at national labs is important, not only for driving the research, but also to expand the number of involved students which will up a future workforce and leverage related university work. To engage the largest number of top researchers across the U.S., we have set up three centers already, in the West, the Northwest, the Northeast, and Southwest, and are looking to open a fourth in the Midwest later this year. Building a strong university capability for nanotechnology research in general is crucial in increasing American competitiveness for all industries.

Utilizing both the federal NNI funding and State initiatives, we currently partner government in three different ways. First, our centers are strongly supported by funding from the lead state in each case, California, New York, and Texas. These states recognize that close industry-government-university partnership leads to faster commercialization of the research, thereby increasing the potential for future economic-development activity. In short, they see the impending technology transition point to grow an entirely new industry around their university base, the same way Silicon Valley grew up around the transistor.

Second, NRI and NSF provide supplemental co-funding of nanoelectronics projects at existing nanoscience and engineering university centers. Our industry liaison team then interacts with the centers and gives industry input on the individual projects as well as the overall center research. This leverage has a significant NSF investment in these centers, guiding that work towards areas we think will have large potential for future commercialization and giving us a broad view of many emerging areas of research.

Third, NRI and NIST started a new partnership last September to extend the NRI Center work. NRI and NIST now jointly choose projects to fund, conduct joint reviews, and hold monthly meetings to direct the ongoing program. In addition, NIST labs and researchers can interact directly with university professors to support the nanotechnology work, leveraging the lab's capabilities for advance nanometrology and helping to guide their continued work, internally, on new revolutionary tools that can have the most impact on future commercialized products. This partnership model is unique and utilizes the best of university and government partners to produce results most likely to benefit future products.

This leads, naturally, into the Committee's second question: how can NNI help foster commercialization of nanotechnology? First, increase funding across the agencies for nanotechnology equipment and research at universities. This is similar to what NSF has been doing with the National Nanotechnology Infrastructure Network, but expanding the equipment base to enable nanomanufacturing and prototyping of early devices will facilitate a more rapid transition from the lab into a commercial product.

Second, encourage direct partnership with industry to pursue this research. Industry involvement leads, naturally, to identifying early commercialization opportunities for technology, such as the recent introduction of nano self-assembly to fabricate air-gap wiring in IBM's computer chips, based on work being done at the Albany Nanotech Center. And industry involvement can even help direct basic research in the most promising directions. As an example, at a 2006 NRI review, a physics professor presented work on a new phenomenon he dubbed pseudo-spintronics, which occurred far below room temperature. After discussion with industry research engineers about the potential for utilizing this phenomenon in a future device, by the next review, he was showing us how the phenomenon could be made more robust for higher temperature operation and even had a novel idea of his own for a new transistor based on this affect. This is the university-industry synergy that NNI should strive to achieve in all areas of nanotechnology research.

In my written testimony, I have given five specific recommendations to the Committee, but the two key points I hope to leave you with today are, one, we would like to see the NNI reauthorization increase federal funding for both equipment and research at universities and strongly encourage government, university, and industry partnerships to guide this research into commercial applications rapidly; and two, we would like to see the NNI reauthorization include a strong focus on nanoelectronics in particular, including it as a priority program activity across the agencies.

In closing, I would like to point out that the magnitude of the effort we face, finding a new transistor, is equivalent to what was done in the 40s and 50s as we developed the first semiconductor device that replaced the vacuum tube. Research on this scale, both in terms of time and money, is more than individual companies can possibly fund. It is also more than universities, alone, can conduct with current, limited federal funding; thus, close collaboration among industry, academia, and government is absolutely necessary in order to solve this grand challenge and ensure that the U.S. remains the leader in the nanoelectronics era.

Thank you, and I look forward to answering any questions you might have.

[The prepared statement of Dr. Welser follows:]

PREPARED STATEMENT OF JEFFREY WELSER

Good morning. My name is Jeffrey Welser, and I am on assignment from the IBM Corporation to serve as the Director of the Nanoelectronics Research Initiative (NRI). I am testifying today on behalf of the NRI; the IBM Corporation; the Semiconductor Industry Association; and the Semiconductor Research Corporation.

The Nanoelectronics Research Initiative (NRI) is a research consortium that supports university basic research in novel computing devices to enable the semiconductor industry to continue technology advances beyond the limits of the CMOS[1] technology that we have been using for the past four to five decades. The NRI leverages industry, university, and both U.S. state and Federal Government funds to support research at universities that will establish the U.S. as the world leader in the nanoelectronics revolution. Fundamental breakthroughs in physical sciences and engineering resulting from NRI leadership will ensure that the U.S. remains a world leader in high-technology.

[1] Complementary Metal Oxide Semiconductor

At IBM, we lead in the business of innovation. IBM takes its breadth and depth of insight on issues, processes and operations across a variety of industries, and invents and applies technology and services to help solve its clients' most intractable business and competitive problems.

The Semiconductor Industry Association (SIA) has represented America's semiconductor industry since 1977. The U.S. semiconductor industry has 46 percent of the $257 billion world semiconductor market. The semiconductor industry employs 216,000 people across the U.S., and is America's second largest export sector.

The Semiconductor Research Corporation is a world class university research management consortium that seeks to solve the technical challenges facing the semiconductor industry and develop technical talent for its member companies. SRC manages several semiconductor research programs, including the NRI. Since its founding 25 years ago, the SRC has managed through its core program in excess of $1 billion in research funds, supporting 6,976 students and 1,598 faculty at 237 universities, resulting in 39,536 technical documents and 302 patents. In July 2007, SRC was awarded the National Medal of Technology by President Bush with a citation recognizing the unique value of this organization: "For building the world's largest and most successful university research force to support the rapid growth and 10,000-fold advances of the semiconductor industry; for proving the concept of collaborative research as the first high-tech research consortium; and for creating the concept and methodology that evolved into the International Technology Roadmap for Semiconductors."

Executive Summary

- Semiconductor technology advances have been credited with driving the increased productivity that the U.S. economy has enjoyed since the mid-1990's.
- The Nanoelectronics Research Initiative (NRI) leverages industry, university and government resources (both State and federal) to fund university research that will keep America at the forefront of the nanoelectronics revolution. NRI, in partnership with the National Institute of Standards and Technology (NIST), currently works largely through three regional university centers headquartered in California, Texas, and New York, as well as with some of the National Science Foundation (NSF) Nanoscience centers across the country.
- The interaction of industry, government, and university researchers in the NRI facilitates the sharing of ideas, enables each partner to focus on its particular strength—such as NIST's expertise in metrology, allows efficient utilization of expensive nanoelectronics equipment, and promotes increased student interest in nanoelectronics. This partnership ultimately will result in faster commercialization of the research results.
- The semiconductor industry strongly supports the reauthorization of the National Nanotechnology Initiative (NNI) to ensure continued critical research and interagency activities in the area of nanoelectronics, specifically. Since current semiconductor technology is approaching its physical and other limits, a new electronic switch must be identified to replace the current technology if the U.S. is to continue receiving the benefits of smaller, faster, and denser electronic devices. The country whose companies are first to market with a new logic switch likely will lead in the nanoelectronics era for decades to come, the way the U.S. has led for the last half a century in microelectronics.
- Current federal funding levels for nanoelectronics-focused research are inadequate in light of the enormity of the research challenge in this area.
- Specifically, the NNI reauthorization should:
    1. Explicitly include as a priority program activity the support of nanoelectronics research;
    2. Include a request for the National Nanotechnology Coordination Office to develop and implement a plan to ensure U.S. leadership in nanoelectronics;
    3. Request that the National Academies include a nanoelectronics study as part of its triennial external review of the NNI;
    4. Include specific and higher-than-current authorization levels for nanoelectronics-focused appropriations from within total NNI authorization amounts;
    5. Address the need for nanoelectronics research infrastructure, i.e., equipment and equipment operating funds, at universities and national laboratories;

6. Specifically encourage direct industry-government partnerships in support of nanoelectronics research at universities and national laboratories.

NNI should be reauthorized, and include specific and increased authorizations for nanoelectronics

Let me state at the outset that the semiconductor industry strongly supports the reauthorization of the National Nanotechnology Initiative (NNI) to ensure continued critical research and interagency activities on nanotechnology.

The legislation should include specific and higher-than-current level authorizations for nanoelectronics research and equipment. This, in turn, would enable the U.S. to be the first in the world to demonstrate a nanotechnology-based electronic logic switch that is able to replace the solid state transistors that store and process information in integrated circuits. Finding a new switch should be a priority area for the NNI.

Before discussing the importance of the NNI, I should note that the industry's support for increased federal research funding is part of our complete set of competitiveness recommendations, which include increased availability of green cards and H–1Bs visas through immigration reform; increased numbers of science, technology, engineering and math (STEM) graduates; improved K–12, undergraduate and graduate STEM education; enactment of a permanent and enhanced R&D credit; and increased awareness of the impact of foreign tax incentives.

Federally funded basic research, and in particular, funding for nanoelectronics research, is vital to America's future economic growth and global competitiveness. **Simply put, as we approach the fundamental limits of the current technology that has driven the high tech industry, the country whose companies are first to market in the subsequent technology transition likely will lead the coming nanoelectronics era the way the U.S. has led for half a century in microelectronics.** NNI can play a critical role in ensuring that America earns this leadership position.

Today I would like to address four topics:

- the technical challenges we have as we move to the nanoelectronics era;
- why U.S. leadership in nanoelectronics is vital to our nation;
- the Nanoelectronics Research Initiative (NRI), as an example of industry-government collaboration that can be furthered by the NNI; and
- policy recommendations that should be included in the NNI to help maintain U.S. leadership in nanoelectronics.

To continue semiconductor technology advances, we must find a new switch

Semiconductors are the enabling technology for computers, communications, and other electronics products that, in turn, have enabled everything from Internet commerce to sequencing the human genome.

Better, faster, and cheaper chips are driving increased productivity and creating more jobs throughout the economy. For over three decades, the industry has followed Moore's Law, which states that the number of transistors on a chip doubles about every eighteen months. The transistor is the basic building block within the semiconductor chip and can be thought of as an electronic switch or as a device to retain one bit (a one or a zero) in memory. The transistor is composed of a series of precisely etched and deposited layers of materials, and with as many as two billion transistors integrated on a single silicon chip, modern computer chips are the most complex product manufactured on the planet.

The phenomenal advances in technology may slow drastically as semiconductor technologists have concluded that we will soon reach the fundamental limits of Complementary Metal Oxide Semiconductor (CMOS) technology, the process that has been the basis of innovation for the semiconductor industry for the past 30 years. By introducing new materials into the basic CMOS structure and devising new CMOS structures and interconnects, further improvements in CMOS can continue for the next ten to fifteen years, at which time, CMOS begins to reach its physical (layers only a few atoms thick) and power dissipation limits. For the U.S. economy to benefit from continued information technology productivity improvements, there will need to be a "new logic switch" to replace the current CMOS-based transistor.

There are a number of candidates for the new switch, including devices based on spintronics (changing a particle's spin) and molecular electronics (changing a molecule's shape). Scientists must address many challenges in many different basic research fields (chemistry, physics, electrical engineering) in the search for the new switch. The challenges include:

- measuring the dimensions, shapes, and electrical characteristics of individual molecules;
- manipulating and measuring the spin of individual electrons;
- fabricating whole new classes of materials with unique electronic properties, and then characterizing their fundamental physical behavior and their long-term reliability;
- inducing novel chemical compounds to self-assemble into the precise structures needed by the new devices and architectures, and doing so in a way that can be manufactured at commercial volumes;
- developing complex circuits to take advantage of, or overcome limitation of, the properties of the new devices; and
- finding ways to interconnect the devices and integrate them into our technology infrastructure in a cost-effective manner, which will enable us to continue the historical cost and performance trends for information technology.

Note that addressing these challenges not only will require the best minds from industry and academia, but it also requires new equipment for fabricating and characterizing these nanostructures. While existing facilities at university centers already enabled by NSF's continuing investment in the National Nanotechnology Infrastructure Network (NNIN) can be used, significant *additional* investment in new specialized equipment is required, particularly to enable the realistic prototyping of new nanoelectronic devices and circuits. This will be crucial to transitioning these into both commercial and manufacturing environments.

U.S. leadership in nanoelectronics is vital to our nation

As stated earlier, the country that finds a new logic switch undoubtedly will lead in the nanoelectronics era. Moreover, this leadership will have widespread impact across our entire technology and science-driven economy, since nanoelectronics have significant applications in information technology, communications, medicine, energy, and security.

Research investments to continue the increased circuit density described in Moore's Law have immense benefits to the U.S. economy. Moore's Law has resulted in a 65 percent drop in the price of a computer over the past 10 years, while increasing the computer's speed, memory, and functionality. Harvard economist Dale Jorgenson has noted, "The economics of Information Technology begins with the precipitous and continuing fall in semiconductor prices." Professor Jorgenson attributed the rapid adoption of IT in the U.S. to driving substantial economic growth in the U.S. gross domestic product since 1995, concluding, "Since 1995, Information Technology industries have accounted for 25 percent of overall economic growth, while making up only three percent of the GDP. As a group, these industries contribute more to economy-wide productivity growth than all other industries combined." [2]

To see the impact of the productivity gains on a single sector, it is instructive to consider the benefits the government (federal, State, and local) receives as a consumer of semiconductors. The Department of Commerce's Bureau of Economic Analysis has data indicating that the government sector of the economy purchased $8 billion of computers in 2006, but that it would have had to spend $45 billion for that same amount of computing power if it were paid for in 1997 prices. The cumulative benefit from technology improvements and resulting price declines from 1997 to 2006 is $163 billion of "free" computing. In this tight budget environment, it is important to remember that federal investments made to support basic research not only are beneficial to the overall U.S. economy, but they also allow the government itself to do more with less as a result of falling computing costs.

Nanoelectronic computing also will have benefits in medicine and energy. It is not an overstatement to say that mapping the human genome is as much a success of computer science as biology, and future challenges such as modeling protein folding and creating cheaper and clearer MRIs and 3D X-ray imaging will require continued advances in computing speed. The Technology CEO Council has documented the effects of improved information technology on improving energy efficiency, which advances U.S. energy security and climate change policies. While automobiles' miles per gallon have improved 40 percent since 1978, and replacing a 1978 incandescent bulb with today's compact fluorescent bulb improves the lumens per watt by 339 percent, the improvement in computer systems' instructions per second per watt

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

since 1978 has increased 2,857,000 percent.[3] Continuing these trends into the nanoelectronics era is absolutely essential to continue the improvements in U.S. energy intensity (increased economic output per unit of energy). In addition, many of the technologies developed to further the semiconductor chip industry now are utilized in new innovations for the renewable energy sector, most notably to develop cheaper and more efficient solar cells.

So too, nanoelectronics computing is important for national security. Precision weapons, satellite imaging, submarine detection, secure global communications, monitoring of adversaries' communications, and real time identification of allies' positions to avoid friendly fire casualties are but a few of the examples of why many people consider leadership in semiconductor technology to be in the Nation's security interests. Indeed, the original semiconductor diode was implemented as a mission-critical project at universities and industrial labs in the 1940's, funded largely by the Department of the Defense because it recognized the urgency of being the first country to have this technology in its weapon systems.

Finally, it should be emphasized that all of these commercial benefits only will be realized if we invest heavily *now* in basic nanoelectronics science and engineering. Many of the breakthrough products and innovations we see today are being built on basic research that was done in the 1990's. With more federal money focused on near-term—rather than long-term—research projects, the country runs the risk of under-funding the basic research pipeline which our industries rely on for future innovations.

Fortunately, the House Appropriations Committee recognized nanoelectronics as a priority area when it singled out NSF's work with the Nanoelectronics Research Initiative in its FY 2008 committee report, stating:

> "Given the economic importance and pervasive impact of semiconductors, the Committee supports NSF's continued sponsorship of the Nanoelectronics Research Initiative and other programs to advance semiconductor technology to its ultimate limits and to find a replacement technology to further information technology advances once these limits are reached. The Committee encourages NSF to continue its support for such research in fiscal year 2008."[4]

The NRI is an industry-university-government partnership to find a new switch

As the laws of physics narrow the potential for the kind of scaling that historically has characterized the semiconductor industry, attention has turned to the discovery of a new logic switch as a means to continue the progress depicted by Moore's Law. To take on the daunting task of identifying and demonstrating the commercial feasibility of a new logic switch, the SIA launched the Nanoelectronics Research Initiative (NRI).

The NRI pulls together semiconductor companies,[5] the National Science Foundation, the National Institute of Standards and Technology, State governments, and 25 universities in 13 states with about 60 professors and 70 students/post-docs. The industry contribution through the NRI is over $5 million per year; this is in addition to about $60 million that the semiconductor industry invests in universities through other research consortia, with millions more invested directly by individual companies.

The research activity is organized within three NRI university centers that were established in 2006, plus NRI and NSF supplemental co-funding of nanoelectronics projects at 10 existing NSF university centers. The three NRI university centers are virtual centers, grouped largely by geography. While all of the centers are working on research aimed at discovering a new logic switch, the focus of the programs at each center has its own specific character:

The Western Institute of Nanoelectronics (WIN) is headquartered at UCLA and includes UC–Berkeley, UC–Santa Barbara, and Stanford University. WIN focuses solely on spintronics and related phenomena, extending from material, devices, and device-device interaction all the way to circuits and architectures. In addition to its NRI funding, this center receives additional direct support from Intel and California's UC Discovery program.

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[3] Technology CEO Council, "A Smarter Shade of Green—How Innovative Technologies are Saving Energy, Time, and Money," 2008.

[4] House Report 110–240—Commerce, Justice, Science, and Related Agencies Appropriations Bill, 2008.

[5] The semiconductor companies funding the NRI are Advanced Micro Devices, Freescale, IBM, Intel, Micron Technology, and Texas Instruments.

The Institute for Nanoelectronics Discovery and Exploration (INDEX) is headquartered at the State University of New York–Albany (SUNY–Albany) and includes the Georgia Institute of Technology, Harvard University, the Massachusetts Institute of Technology, Purdue University, Rensselaer Polytechnic Institute and Yale University. INDEX focuses on the development of nanomaterial systems; atomic-scale fabrication technologies; predictive modeling protocols for devices, subsystems and systems; power dissipation management designs; and realistic architectural integration schemes for realizing novel magnetic and molecular quantum devices. INDEX also receives additional direct support from IBM and New York State.

The South West Academy for Nanoelectronics (SWAN) is headquartered at the University of Texas–Austin and includes UT–Dallas, Texas A&M, Rice, Notre Dame, Arizona State and the University of Maryland. SWAN focuses on a variety of new devices, including spin-based switches, nanowires, nano-magnets, and devices which use electron wave or phase interference. In addition, work is being done on modeling; novel interconnects, such as plasmonics; and nano-metrology techniques. In addition to its NRI funding, SWAN receives additional support from Texas Instruments and the Texas Emerging Technology Fund.

In addition to these centers, NRI and NSF co-fund supplemental grants for NRI-related research at existing NSF nanoscience centers, Nanoscale Science and Engineering Centers (NSECs), Materials Research Science and Engineering Centers (MRSECs), and the Network for Computational Nanotechnology (NCN). We currently are supporting 12 projects at 10 NSF centers, which range from advanced computer simulation of spin-based devices to measurements of non-equilibrium coherent transport in single-layer graphene sheets to directed self-assembly of quantum dot and wire structures for novel devices. The goal in making this joint investment with NSF is not only to complement the work going on in the NRI centers, but also to jointly leverage the knowledge gained from work going on in both NSF and NRI centers.

NSF's involvement with nanoelectronics was highlighted by the recent announcement of the Science and Engineering Beyond Moore's Law initiative in the President's FY 2009 budget request. The $20 million request "will support research to develop the next generation of materials, algorithms, architectures and software with capabilities far beyond those available today, and governed by new empirical laws. With these advances, computing power will become even more concentrated, integrated and ubiquitous."[6]

In 2007, NIST concluded an open competition by entering into partnership with the NRI to accelerate research in nanoelectronics. Under the partnership, NIST and NRI will jointly provide $18.5 million over five years toward high-priority university research projects identified by industry and NIST researchers. NIST scientists and engineers have been leaders in nanoelectronics research, especially in the science of measurement. The partnership implements the conclusion of NIST's major February 2007 report which called for the development of measurement techniques for frontier technologies such as post-CMOS electronics.[7]

The NRI complements another government-industry partnership, the Focus Center Research Program (FCRP). This program is cosponsored by the semiconductor industry and the Department of Defense to fund research at 38 universities. It seeks to advance the current CMOS chip technology to its ultimate limits, while the NRI's objective is to go beyond the limits of the current technology. Both the NRI and FCRP are administered by the Semiconductor Research Corporation (SRC), a nonprofit consortium of companies representing of the full spectrum of the semiconductor industry. The SRC also administers the Global Research Collaboration (GRC), which funds a large research program focused on addressing the challenges in the nearer-term semiconductor roadmap, crucial to continuing the rapid rate of industry innovation.

While still in its early stages, the NRI already is beginning to show results with over 100 technical publications and five patent disclosures. As the research begins to come to fruition, prior industry involvement will facilitate technology transfer, even before the ultimate goal of finding a new switch is realized. An example of this kind of early commercialization due to close industry-university work outside of NRI is the air gap wiring announcement made by IBM in 2007, based on work being done at the Albany Nanotech Center. It is a very early application of self-assembly, which has been actively researched for many years, in a real product in an unexpected way, and it points out the importance of universities and industry working

[6] Remarks by NSF Director Arden Bement, Jr.; Presentation of the NSF FY 2009 budget request to Congress; February 4, 2008.

[7] NIST, "An Assessment of the United States Measurement System," February 2007, *http://usms.nist.gov*.

together. Rapid commercialization of academic research is in the interest of universities and government funding agencies, as well as industry, as it directly contributes to American competitiveness. The NRI is building on 25 years of experience by its parent, the SRC, in managing university research, in partnership with industry and the government.

Industry-Government-University Roles in Nanoelectronics Research

From the beginning, the NRI has welcomed input from the government on our overall program, and it would like to see these partnerships increase going forward. NSF, DARPA, and NIST attend the NRI's Governing Council meetings. The Council provides executive oversight to the program. Due to the magnitude of the scientific challenges ahead and the large diversity of scientific disciplines required, government expertise and resources are absolutely critical.

The overall model for the NRI is to do mission-focused basic research at multi-university centers. This best balances the need for a broad range of research into many different science phenomena with the need for a clear goal to drive the research in the most productive directions. Five research vectors are used to provide a concrete framework for the mission focus, as well as focus the work on the overall goal of finding a new logic switch. These vectors, distilled from an initial list of thirteen, were considered the top research priorities based on a series of industry-government-university workshops and studies conducted by SRC, SIA, and NSF.

Centering the work at multi-university centers—rather than in industry or national labs—is crucial not only for driving the research, but also to expand the number of students and the capability of universities engaged in nanoelectronics-related research. This will sustain and expand the industry in new directions in the future. It is equally important to set up several of these centers across the U.S. to engage the largest number of top researchers at many different universities. To this end, we are currently looking to open a fourth NRI center later this year in the Midwest, complementing the three existing centers in the East, West, and Southwest.

We have used two models to enable the multi-university work. With the NSF, we jointly fund research in existing NSF nanoscience centers. These projects are chosen by independent reviews by the NRI industry team and the NSF itself. An industry liaison team is assigned to interact with the centers and give industry input on the individual projects as well as the overall center research. This model works well for leveraging the significant NSF investment in these centers, helping to guide that work towards areas we think will have large potential for future commercialization and giving us a broad view on many emerging areas of research.

At the NRI centers themselves, we take this partnership model even further, both for joint funding and technical guidance, with the hope of accelerating the discovery process. Initially, the multi-university centers were set up geographically, and strong partnerships were developed with State governments for funding the work. The state partnership is unique in that states not only are providing several million dollars annually to their universities to support the NRI research, but they also are investing hundreds of millions into new Nanoelectronics buildings, centers and infrastructure to enable the next generation of this research. Examples includes the New York Albany NanoTech center (*www.albanynanotech.org*), the California NanoSystems Institute (*www.cnsi.ucla.edu*), as well as major support for recruiting and endowing new faculty for Nanoelectronics research in Texas. These investments are focused not simply on enabling the research, but also on enabling the rapid commercialization of any new technologies that emerge from the research. Hence, this support is crucial to translating discovery into product innovation.

And the states are investing for the same reason the NNI needs to be investing: economic competitiveness. The transition to a new switch will be challenging and uncertain, meaning that the companies, states, and universities that benefited from the previous technology era may not be the ones to lead in the new era. State governments see this transition point as an opportunity to grow an entirely new industry around their university base to drive their economies, the same way Silicon Valley grew up around the transistor.

The NIST agreement extends the work in the NRI centers to now include a federal partner in a unique technical, management, and funding role. We think this should be a model for future engagements. A Technical Program Group (TPG), consisting of members from both NIST and industry, evaluates the project proposals to determine where the funds from both groups will be invested in the universities, as well as oversees the on-going research through a variety of mechanisms. The TPG has monthly meetings to make decisions on the overall program, and subteams from the TPG meet monthly with the lead professors from each of the NRI centers to discuss the progress of the technical work and center logistics in detail. Moreover, the industry has full-time assignees working alongside the professors and students at each of the centers to provide daily input and guidance on the research. In addition to the usual publication of results in technical journals and conferences, the centers also hold annual on-site reviews and produce semi-annual reports for both the NRI industry members and NIST. Lastly, we intend to strongly leverage the expertise and facilities within the NIST labs themselves, by having university researchers at the NRI centers work directly with the labs on projects to advance the NRI mission.

Nanometrology and characterization are key to any advances in nanoelectronics—particularly in trying to link experimental work to theory. The partnership with NIST should open the door not only to utilizing the existing NIST facilities, but also to help guide their continued work on new characterization tools to those most vital for developing and characterizing the next generation of nanoelectronic devices. For example, it is now becoming possible to measure the spin of an individual electron, but to truly characterize spintronic devices, we would want to be able to track that spin's evolution as it is manipulated in the switch itself. This is precisely the kind of grand challenge that NIST is uniquely suited to undertake. By working closely with NRI university and industry researchers, the results of this new capability will have much more rapid impact on new device and product development.

While the NIST labs—and the other national labs—offer a very valuable resource for enabling nanoelectronics research, we continue to believe it is equally important to invest federal funding in state-of-the-art facilities directly at the universities themselves. While some work, such as characterization utilizing large neutron or synchrotron radiation, can be done most efficiently at the national lab facilities, much device and materials research relies on daily work in a facility local to the university, where the students are working directly with their professors and other group members. This cannot easily be replicated remotely. To balance the desire to have easy access by the largest number of faculty and students with the large investment costs, having an extended network of nanoelectronics infrastructure capable of fabrication, characterization, and early prototyping at a number of multi-university centers (such as NNIN) is particularly effective. And with the NRI model, the states and universities are already doing their part to invest in new buildings and base infrastructure. What they need is expanded federal funding to match their investments for equipment and on-going support.

To summarize, we feel the NRI model for direct partnering between industry, government, and universities is the most effective way to conduct mission-oriented basic research that most rapidly leads to new product innovations. And far from hindering basic science research, this close early industry involvement can actually accelerate it in promising directions. As an example, at one of the first NRI reviews, a professor presented work on a new phenomenon he dubbed "pseudospintronics." As a physics professor looking to understand the basic science, all of his work had been at very low temperatures. After discussions at the review with other engineering professors and industry researchers on the potential for this phenomenon to be utilized in a future device, he continued his basic research, but he also focused on understanding its extendibility to room temperature. By the next review, he not only had several exciting new insights into the science, but he had ideas about how it could be made more robust for higher temperature operation. He even had a novel idea for a new logic switch based on the effect. This experience is precisely the kind of new thinking that comes from conversations between the science and engineering worlds (and the industrial and academic worlds) that NRI hopes to foster, and it ultimately will result in faster commercialization of the ideas it produces.

Building on the government-industry NRI partnership: recommendations for the NNI

As outlined above, the obstacles for identifying a viable new switch are daunting, but the benefits of being the leader in this new technology are huge. The semiconductor industry supports the reauthorization of the National Nanotechnology Initiative to ensure continued critical federal research and interagency activities on nanotechnology. The industry specifically recommends that Congress include the following:

1. The NNI reauthorization should explicitly include as a priority program activity the support of a research, development and demonstration program in nanoelectronics.
    - The National Nanotechnology Coordination Office and the federal agencies that participate in the National Nanotechnology Initiative should be asked to develop and implement a plan for the above activity, with the goal of ensuring that U.S. researchers are the first in the world to demonstrate a nanotechnology-based electronic logic switch that is scalable,

reliable, low-power, capable of being manufactured in commercial volumes, and potentially able to replace solid state transistors in integrated circuits.

2. The NNI reauthorization should require that the National Academies include, as part of its triennial external review of the NNI, a study on nanoelectronics research opportunities. The study should identify the most promising research opportunities in the application of nanotechnology to electronic logic switches. The study also should include a recommended research and development roadmap for federal agencies that conduct or support nanoelectronics research.
3. The NNI should include specific and higher-than-current-level authorizations for nanoelectronics appropriations from within the NNI authorization amounts for the NSF, NIST, and Department of Energy. The authorizations should reflect the pervasiveness of information technology in the U.S. economy, IT's impact on U.S. economic growth, and the magnitude of the challenges involved in identifying and demonstrating an electronic switch capable of replacing our current technology.
4. The NNI reauthorization should address the need for nanoelectronics research infrastructure, i.e., equipment and equipment operating funds, in addition to funding for research. This applies not only to authorizations for NSF to support infrastructure at our nation's universities, but also to NIST for equipping and operating the equipment for the nanoelectronics research at the Gaithersburg and Boulder labs.
5. The NNI Reauthorization should specifically encourage direct industry-government partnerships in support of nanoelectronics research at universities and national laboratories. These partnerships promote cross-fertilization of ideas, facilitate technology transfer and ultimately commercialization of nanoelectronics devices, as well as promote potential economic development around nanoelectronics research clusters.

Summary

Discovering, developing, and implementing a new logic device is a daunting task, but it is not unprecedented. In the 1940's, when vacuum tubes were state-of-the-art but reaching their own limits, the U.S. Government realized a critical need for finding smaller, faster, and lighter devices for its radar and guided missile systems. The result was not only technology to enable advanced weapon systems, but the birth of the solid-state transistor, which became the foundation of the information technology revolution that drives our economy to this day. It was the combination of the best basic science research coming out of the universities, the practical guidance and mission-focus of the industrial labs, the significant research funding from the government, and the collaborative interaction of all of these groups that enabled both the scientific breakthroughs and the reduction to practical implementation necessary for such a project to succeed.

As we look for a switch to replace our current CMOS transistor, we now face a similar transition. We are just beginning this research, and the initial efforts are small in comparison to what was done in the 1940's and 1950's. It is critical we grow these efforts significantly over the next several years, and finding flexible models for industry and government to interact will be critical to success. To this end, increasing attention and research funding in the nanoelectronics area are absolutely essential if we are to continue our accelerated economic growth and productivity, thereby enabling America to lead in the coming nanoelectronics era.

Biography for Jeffrey Welser

Dr. Jeffrey Welser is on assignment from the IBM Corporation to serve as the Director of the Nanoelectronics Research Initiative (NRI), a subsidiary of the Semiconductor Research Corporation (SRC). The NRI supports university-based research on future nanoscale logic devices to replace the CMOS transistor in the 2020 timeframe.

Dr. Welser received his Ph.D. in Electrical Engineering from Stanford University in 1995, and joined IBM's Research Division at the T.J. Watson Research Center. His graduate work was focused on utilizing strained-Si and SiGe materials for FET devices. Since joining IBM, Jeff has worked on a variety of novel devices, including nano-crystal and quantum-dot memories, vertical-FET DRAM, and Si-based optical detectors, and eventually took over managing the Novel Silicon Device group at Watson. He was also working at the time as an adjunct professor at Columbia University, teaching semiconductor device physics. In 2000, Jeff took an assignment in Technology group headquarters, and then joined the Microelectronics division in 2001, as project manager for the high-performance CMOS device design groups. In May 2003, he was named Director of high-performance SOI and BEOL technology development, in addition to his continuing work as the IBM Management Committee Member for the Sony, Toshiba, and AMD development alliances. In late 2003, Jeff returned to the Research division as the Director of Next Generation Technology Components. He worked on the Next Generation Computing project, looking at technology, hardware, and software components for systems in the 2008–2012 timeframe. In mid-2006, Jeff took on his current role for NRI, and is now based at the IBM Almaden Research Center in San Jose, CA.

Chairman BAIRD. Mr. Moffitt.

STATEMENT OF MR. WILLIAM P. MOFFITT, CHIEF EXECUTIVE OFFICER, NANOSPHERE, INCORPORATED

Mr. MOFFITT. Thank you Mr. Chairman, Ranking Member Ehlers, and Members of the House Research and Education Subcommittee of the Committee of Science and Technology, for the opportunity to testify on this important issue. I am Bill Moffitt, Chief Executive Officer of Nanosphere, Incorporated. Nanosphere develops, manufactures, and markets an advance molecular diagnostics platform, the Verigene System, that enables simple, low-cost, and highly sensitive genomic and protein testing on a single platform. Our mission is to improve the diagnosis and treatment of disease by enabling earlier access to and detection of new and existing biomarkers of disease.

Nanosphere was founded in 2000, based upon nanotechnology discoveries made by Dr. Robert Letsinger and Dr. Chad Mirkin at Northwestern University and Evanston, Illinois. We have taken basic science, funded by NIH and NSF out of the university research setting and translated it into a diagnostics platform that delivers three distinct value propositions across a variety of fields, the ability to economically move complex genetic testing into mainstream medicine; second, early detection of diseases, such as cardiovascular disease, cancer, and neurodegenerative diseases, as nanoparticle probes improve detection sensitivity by orders of magnitude; and third, the potential to test for disease where no test exist today. Moreover, while we are focused on medical diagnostics, this same technology platform is applicable to biosecurity, agriculture and food safety testing and industrial contamination control. Nanotechnology has a potential to shift markets on a global economy and replace or greatly modify existing leadership positions. As such, it represents both a challenge and an opportunity for American competitiveness.

With that as the context for my remarks, I would like to share with you my thoughts on the four on which the Committee has sought input. First, the hurdles to commercialization of nanotechnology. First and foremost is the lack of early stage capital for cutting-edge, translational research. Much of the government's direct spending in nanotechnology has been on scientific discovery. It takes extensive capital to translate nanoscience discoveries into platform technologies and demonstrate potential and commercial viability in order to attract the capital required for commercialization. For example, at Nanosphere, up to the point first commercial product launch, we invested over $100 million in converting nanoscience to scalable product technology platform. Many great nonscientific discoveries fail to attract the extensive capital required for commercialization, and for this reason, the gap between the research lab and the product prototype is often referred to as the Valley of Death. There is a great need to balance spending on basic research and translational work or goal-oriented development programs and to focus such programs on specific areas with the greatest promise of benefit to national interest.

Another hurdle to commercialization of nanotechnology is the difficulty in finding technical talent. Nanotechnology has need for highly trained scientists from multiple disciplined. These highly paid, high quality jobs are difficult to fill because of the well-documented decline in STEM graduates. In addition to Ph.D.s, nanotech companies also need trained and skilled laboratory and manufacturing technicians. There are currently very few technical-training programs that fill this need. We can address both issues by developing vocational curricula and deploying them at community colleges and encouraging internships by high school and college students that expose them to nanotech as a career.

The second question was federal programs that can help bridge the Valley of Death and how effect SBIR, STTR, and ATP programs have been. Conceptually, these programs have helped in this process, but often these grants fail to provide a sufficiently significant amount of capital. Of the $100M in high-risk capital spent by Nanosphere in its March 1 commercial launch of products, approximately $7M was provided by government-funding sources. However, if I subtract the biosecurity contract, the total government support has been less than $2 million.

To some degree, the competitive process of grant-review and award provides third-party verification of the potential value of the science, especially in the early-development phases where capital is high risk. What the government can do to address this need is to provide additional incentive for private-sector investment in the form of a program of tax and investment credits will help mitigate risk for early capital and provide additional incentive for investments directed at goal-oriented research and development programs. Focusing investment and tax-credit programs at specific problems enables the governments to broadly direct investment while placing the onus of efficiency and effectiveness of investment on the private sector. Since private investors use a competitive, market-driven mechanism to select companies, these tax and investment credits will benefit those companies with the most potential to produce meaningful applications.

The third question was whether or not there are areas of focus for commercialization that will position the Nation for leadership. These goal-oriented development programs will translate much of this new science into platform technologies that will likely impact several industries, but clearly there are two areas of focus where the U.S. has strong potential: energy and health care. Our growing energy needs are evident, and in health care, we are both the largest provider and largest consumer in the world. Historically, health care has not scaled the way other industries have, driven by innovations and technology. Where is the leverage? Nanotechnology holds promise for impacting every aspect of medical care from research, to diagnostics, to imaging to therapeutics. Nanosphere's molecular diagnostics platform is but one example of nanotechnology enabling breakthroughs in medical diagnostics, replacing technologies that are decades old.

In conclusion, the U.S. must retain its leadership in this industry, changing technology, which has the potential to realign global competitiveness. The U.S. Government must set the gold standard in supporting an efficient and productive climate, not only for discovery, but also for commercializing nanotechnology innovation. Not only will such an initiative enhance American competitiveness, but it will also address significant issues that will impact generations to come. Thank you, Mr. Chairman and Members of the Committee.

[The prepared statement of Mr. Moffitt follows:]

PREPARED STATEMENT OF WILLIAM P. MOFFITT

I would like to thank you, Mr. Chairman, Ranking Member Ehlers, and Members of the House Research and Education Subcommittee of the Committee on Science and Technology for the opportunity to testily on this critically strategic question.

My name is Bill Moffitt and I am the Chief Executive Officer of Nanosphere, Inc. Nanosphere develops, manufactures and markets an advanced molecular diagnostics platform, the Verigene® System, that enables simple, low cost and highly sensitive genomic and protein testing on a single platform. Our mission is to improve the diagnosis and treatment of disease by enabling earlier access to, and detection of, new and existing biomarkers.

Nanosphere was founded in the year 2000 based upon nanotechnology discoveries made by Dr. Robert Letsinger and Dr. Chad Mirkin at Northwestern University in Evanston, Illinois. Among other achievements, these discoveries made possible the reliable production of functionalized gold nanoparticles that have molecules such as DNA, RNA or antibodies attached to them. These functionalized gold nanoparticle "probes" very specifically bind to nucleic acid and protein targets of interest thereby creating a platform for accurate and sensitive diagnostic applications.

Since its founding, Nanosphere has made continuous enhancements to the original technology advances by coupling the gold nanoparticle chemistry with multiplex array analysis, microfluidics, human factors instrument engineering and software development to produce a full-solution, molecular diagnostics workstation, the Verigene® System. The underlying core nanotechnology imparts characteristics to diagnostic tests that result in a platform that is very sensitive, easy to use, accurate and inexpensive, thus further enabling decentralization of complex diagnostic tests while lowering the cost of such testing.

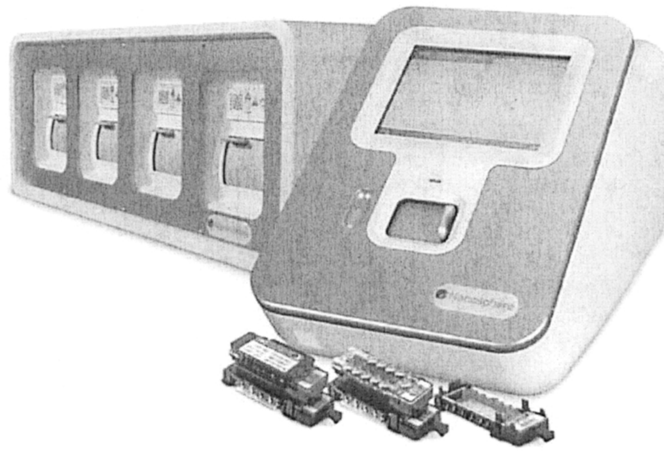


Figure 1. Verigene® System

Nanosphere is now a fully-integrated diagnostics company with established cGMP manufacturing operations, leading edge research and development teams, and veteran customer service and support teams.

In November 2007, Nanosphere received FDA clearance to market the Verigene System and the first warfarin metabolism test ever cleared by the FDA. Warfarin-based anticoagulants, perhaps more commonly known by a leading brand name, Coumadin, are widely prescribed to treat thrombosis, abnormal clotting of blood, which can lead to stroke and other life-threatening conditions. While this is an effective drug, it is also the second leading cause of all adverse drug reactions, second only to insulin. Adverse reactions include excessive internal bleeding which can lead to complications including hemorrhagic stroke and death. According to the FDA, tens of thousands of such adverse reactions occur each year. The Nanosphere warfarin metabolism test, which detects certain genetic mutations in patients, is used to guide appropriate initial dosage to ensure safety in patient care. This is one example of a complex genetic test that must be readily available to physicians on a timely basis. This is just one example of how nanotechnology is addressing significant issues in health care.

These nanotechnology probes also create an ability to detect proteins, the building blocks and warning signs of the body, at a level at least 100 times more sensitive than current technologies, which may enable earlier detection of and intervention in diseases associated with known biomarkers and may also enable the introduction of tests for new biomarkers that exist in concentrations too low to be detected by current technologies. We are currently developing diagnostic tests for a variety of medical conditions including cancer, neurodegenerative, cardiovascular and infectious diseases, as well as pharmacogenomics, or tests for personalized medicine.

There is a growing demand among laboratories to implement molecular diagnostic capabilities but the cost and complexity of existing technologies and the need for specialized personnel and facilities have limited the number of laboratories with these capabilities. We believe that the Verigene System's ease of use, rapid turnaround times, relatively low cost and ability to support a broad test menu will simplify work flow and reduce costs for laboratories already performing molecular diagnostic testing and will allow a broader range of laboratories including those operated by local hospitals, to perform molecular diagnostic testing.

Our effort at Nanosphere to improve diagnostic testing and provide for earlier detection of diseases ranging from cancer to Alzheimer's to cardiovascular disease is but one example of the potential for nanotechnology. Developments in science support the prospects for nanotechnology to have a significant impact on many industries. Nanotechnology has the potential to shift markets in a global economy and replace or greatly modify existing leadership positions. As such it represents both an opportunity and a challenge for American competitiveness.

The U.S. currently leads in science, but could lose the commercialization race. While we are bearing the burden of fundamental research a significant global investment in development programs to commercialize nanotechnology is occurring in Asia. In fact, when purchasing power and exchange rates are accounted for, Asia now leads the world in nanotech funding.

In decades past, large corporations had significant internal translational research efforts, but the landscape has changed. Investments tend to be made in shorter-term improvements to existing product platforms, while relying upon acquisitions of start-up companies to provide longer-term replacements for core competencies. It is a question of risk adjusted capital investment.

At the same time, start-up companies struggle to attract significant venture capital funding until they have established the commercial viability of their technologies. As a result, much of nanotechnology's potential remains locked in the translational phase of its life cycle. We have solid fundamental research but inadequate effort is being made to translate that fundamental science to specifically address important societal and economic problems. Nanoscience needs to be directionally focused to enable fundamental improvements in a number of industries ranging from energy to health care to telecommunications and computing technology.

With that as context for my testimony, l would like to share with you my thoughts on the Transfer of NNI Research Outcomes for Commercial and Public Benefit, specifically addressing four questions:

1. What are the hurdles to the commercialization of nanotechnology?

   a. First and foremost, lack of early stage capital for cutting-edge, translational research. To go from lab to product, a nanoscience concept must first find capital to develop the core science into a "platform technology." Such platform technologies are usually novel materials or material combinations that have the ability to generate multiple products. It takes extensive capital to develop the platform and demonstrate its potential and commercial viability. This includes being able to reliably and cheaply produce the platform, integrating the platform into a specific application, tailoring it to improve the application's efficiency and then scaling the manufacturing of the platform. Only at this point can commercial efforts generate revenue and profits to reinvest for commercialization of additional applications. The significant amount of capital required and the early-stage, high-risk nature of translating technology from lab to market makes it difficult to raise capital for emerging nanotech businesses. Many great nanotech scientific discoveries fail to attract the extensive capital required for commercialization and for this reason the gap between the lab and product prototype is often called the "valley of death."

   b. Second, lack of a good mechanism to balance focus on multiple, high-potential technologies. The government should focus more spending on translational work or goal-oriented development programs with an appropriate balance on scientific research. To realize the societal and economic benefits of nanotech, government and private sector funds need to focus on the nanotechnologies with the greatest potential applications. Quite often capital is redundantly spread across too many organizations each of which is aiming for the same target. As an example, we still see requests from the military for the development of a biosecurity testing platform that Nanosphere has already developed and provided under contract. The government needs to develop methods to address a broader spectrum of nanotechnologies and control redundant spending. Spending should factor in the existing investment in an area and the potential of the technology to lead to an important product.

   c. A third hurdle to commercialization of nanotechnology is difficulty in finding technical talent. Nanotechnology is unique in its need for highly-trained scientists from multiple disciplines. Since a given nanotechnology can enable multiple applications, nanotech companies find themselves needing Ph.D.s in both the underlying nanotechnology and in the specific area of application. These highly-paid, high-quality jobs are difficult to fill because of the well-documented decline in STEM graduates. In addition to Ph.D.s, nanotech companies also need trained and skilled laboratory technicians. There are currently very few technical training programs producing workers that fill this need. We can address both issues by developing vocational curricula and deploying them in community colleges and encouraging internships by high school and college students that expose them to nanotech as a career.

2. What federal programs or activities can help to bridge the "valley of death" successfully? How effective have the SBIR/STTR and ATP programs been in this regard?

   a. We must find a way for government funds to bridge the "valley of death" where promising science is unable to attract sufficient capital to bridge the gap to corporate sponsorship. This gap is in part a result of the fact that corporate America is more interested in developing and improving already proven technology platforms and the government is largely focused on fundamental research rather than goal-oriented research. Countries such as Taiwan, Korea and China regularly leverage America's investment in fundamental research by using government sponsored programs to directly fund companies to commercialize that research and develop products. America's position in the global market may rest on retaining leadership in nanotechnology. To close the "valley of death," we must invest more in goal-oriented research and in helping translate research from the lab into the marketplace.

      Conceptually programs such as SBIR/STTR and ATP have helped in this process, but often these grants fail to provide a sufficiently significant amount of capital. Up to the point of the first product launch of our nanotechnology-based diagnostic platform Nanosphere had spent approximately $110M in "high risk" capital, with only ~$7M coming from government funding sources including TSWG, SBIR/STTR grants and others. However, if I subtract the biosecurity contract funding, the total government support has been less than $2M.

      While much of the early work on the science was funded through NIH and NSF in a university research setting, those expenses are minor in comparison to the cost of platform development and commercialization. What SBIR/STTR and TSWG funding did do was provide a certain element of validation for private sector investors. To some degree the competitive process of grant review and award provides third party verification of the potential value of the science, especially in early development phases where capital is at the highest risk.

      What the government can do to provide additional incentive for private sector investment is to develop a program of tax and investment credits which will help mitigate risk for early capital and provide additional incentive for investments directed at goal oriented research and development programs. Focusing programs at specific problems enables the government to broadly direct investment while placing the onus of efficiency and effectiveness of investment on the private sector. Since investors use a competitive, market-driven mechanism to select companies, these tax and investment credits will benefit those companies with the most potential to produce meaningful applications.

3. Are there areas of focus for commercialization that will position the Nation for leadership in nanotechnology?

   a. While there are areas of focus that will position the U.S. for leadership, it also makes sense to support goal oriented research and development more broadly beyond today's primary focus on basic science and discovery. Such goal oriented development programs will translate much of this new science into platform technologies that will likely impact several industries.

   b. Clearly there are two areas of focus where the U.S. has strong potential, energy and health care. Our growing energy needs are evident and in health care we are both the largest provider and largest consumer in the world. Historically, health care has not scaled the way other industries have, driven by innovations in technology. Where is the leverage? Nanotechnology holds promise for impacting every aspect of medical care from research to diagnostics to imaging to therapeutics.

      In my own company we have taken basic science from Northwestern University's Nanotechnology Institute and converted it into a diagnostics platform that delivers three distinct value propositions: 1) the ability to move complex genetic testing into mainstream medicine, 2) the prospect of earlier detection of diseases such as cardiovascular disease and cancer as nanoparticle probes improve detection sensitivity by orders of magnitude and 3) the prospect for developing tests for diseases where none exist today as biomarkers of active disease are undetectable by current technologies. Imagine a future where economical, widely available genetic testing provides the architectural game plan for personalized medicine and a panel of ultra-sensitive biomarker tests specifically tailored to an individual monitor for the earliest on-set of disease, a timeframe when therapies are most effective.

4. Are there any barriers to commercialization imposed by current intellectual property policies at NNI supported user facilities, and if so, what are your recommendations for mitigating these barriers?

   a. The issues for user facilities are:

      i. Availability and proximity—Although the user facilities are geographically dispersed, they are not always proximate to business users. Furthermore, there is no single source of data on the services these facilities provide or the equipment they have, making it difficult for many companies to access them efficiently. An effort should be made to create a central database where potential users can see all facilities and their available services and equipment and to create new facilities in locations where nanotechnology centers of excellence are emerging and translational development can be most effectively developed. As an example Chicago does not have a user facility in the National Nanotechnology Infrastructure Network (NNIN) in sufficiently close proximity even though the surrounding area has many nanotech companies.

      ii. Cost and intellectual property—These facilities charge "full cost recovery" which means a significant overhead burden (not related to the facility or service itself) is layered onto the direct cost of the service provided, typically making the cost of use significantly higher than the value of the service provided. In addition, the facilities need strong assurances that protect companies with regard to IP and trade secret information that may develop.

      iii. Support services—Most start-ups do not have personnel that are trained and proficient in using these facilities. Users need support personnel to make use of the facilities or must invest significant time and effort into educating facility personnel prior to engaging for what may ultimately be short-term projects. This may also add to the concern for protection of confidential information and intellectual property, especially in circumstances where the facility sponsor may try to claim joint ownership of IP generated during the use of the facility. These issues make the use of these facilities cost-inefficient for most businesses.

Conclusion

The U.S. must retain its leadership position in this industry-changing technology which has the potential to realign global competitiveness. The U.S. government must set the "gold standard" in supporting an efficient and productive climate, not only for discovery, but also for commercializing nanotechnology innovation. Not only will such an initiative enhance American competitiveness, but it will also help us address significant issues that will impact generations to come.

Thank you for the opportunity to voice my concern and share my perspective with the Committee.

BIOGRAPHY FOR WILLIAM P. MOFFITT

William Moffitt became President, Chief Executive Officer and a Director of Nanosphere, Inc. in July 2004. Nanosphere (NSPH) is developing and commercializing a nanotechnology-based molecular diagnostics platform for earlier detection of disease and economical decentralization of complex genetic testing. Mr. Moffitt has 35 years of experience in the diagnostics and medical device industry, and has spent the last 20 years developing novel technologies into products and solutions that have helped shape the industry.

Prior to joining Nanosphere, he served as President and CEO of i-STAT Corporation, a developer, manufacturer and marketer of diagnostic products that pioneered the point-of-care blood analysis market. Mr. Moffitt led i-STAT from its early research stage to commercialization and through its initial public offering in 1992 to its acquisition by Abbott Laboratories in 2003. Prior to i-STAT, Mr. Moffitt held increasingly responsible executive positions from 1973 through 1989 with Baxter Healthcare Corporation, a manufacturer and distributor of health care products, and American Hospital Supply Corporation, a diversified manufacturer and distributor of health care products, which Baxter acquired in 1985. Prior to entering the medical device and diagnostics field, Mr. Moffitt was director of an experimental education program in science funded under Title III of ESEA in the city school system in Washington, N.C.

Mr. Moffitt is also active on the boards of other companies and industry associations. He is Non-executive Chairman of the board of Glysure, Ltd., a privately held U.K.-based company developing continuous intravascular blood glucose measuring devices for monitoring insulin therapy in critical care settings; he is a Director of Nevro, Inc., a privately-held company developing therapeutic pain management devices; he is a Director of Rapid MicroBiosystems, a privately-held company commercializing systems for rapid detection of contamination in pharmaceutical manufacturing; and, he is a Director and a member of the Executive Committee of the Illinois Biotechnology Association ("iBIO") where he also serves as an entrepreneurial coach for start-up companies.

Moffitt earned a B.S. in Zoology from Duke University.

Chairman BAIRD. Dr. Melliar-Smith.

STATEMENT OF DR. C. MARK MELLIAR–SMITH, CHIEF EXECUTIVE OFFICER, MOLECULAR IMPRINTS, AUSTIN, TEXAS

Dr. MELLIAR-SMITH. Good morning. My name is Mark Melliar-Smith, and I am the Chief Executive Officer of Molecular Imprints. I am please to be able to provide testimony today in support of the Nation's efforts in nanotechnology. My company is but one example of the successful support of new technology by the U.S. Government, and I am happy to talk about this success.

Molecular Imprints is a start-up company which was spun off the University of Texas at Austin in 2001. The company was created to commercialize a newly invented technology called step-and-flash imprint lithography, which has demonstrated the capability to pattern features down as small as the diameter of a DNA molecule.

Nano-lithography is the method used in creating very small patterns on a substrate. The technology is critically important, especially in the production of electronic devices such as computer chips. Today, the technology used to do this is an optical technique, much like making photographic prints, where the patterns are projected onto a light-sensitive resist on the substrate using a very sophisticated and expensive camera.

Chairman BAIRD. Could you make sure you mic is on, Dr. Smith?

Dr. MELLIAR-SMITH. It began to be limited by the wavelength of light. It is a very difficult to make a 50 nanometer feature with a 20 nanometer light source.

Molecular Imprints has developed a superior alternative technique called nano-printing. We make a very accurate master using an electron beam tool of almost unlimited resolution and then use the master to simply print, using a special ink, the features on the substrate.

[Graph.]

Dr. MELLIAR-SMITH. As you can see from this graph, the quality of the images are much better, and the simplicity of the tool makes it much less expensive. The analogy to photography can be extended here. We don't make prints photographically anymore; we simply print them.

The step-and-flash imprint development will have significant impact on the United States economy. The original optical photographic techniques were invented in the United States in the late '50s and early '60s and build up into a billion-dollar industry. However, in the '80s and '90s, the U.S. lost this capability to superior products from Europe and Japan, and now this $10 billion industry is almost entirely sourced from outside of the United States, as shown in this chart.

[Chart.]

Dr. MELLIAR-SMITH. At Molecular Imprints, we intend to turn this around and bring the business back to the U.S. through the use of new and superior nano-printing technology.

However, the economic impact extends well beyond the $10 billion annual market for the litho tools themselves. This technology enables multiple industries. The largest is a $250 billion computer chip industry, with companies such as Intel and Texas Instruments, which itself enables the $1.5 trillion electronics industry and much of our advanced weapons systems. This industry has been built over the past 50 years on our ability to make smaller transistors every year.

The disk drive industry, with companies such as Seagate and Western Digital is also moving into nanotechnology. To increase the density of their drives, they will soon have to start patenting the magnetic disks themselves, and I have shown an example of this in this particular chart here.

[Chart.]

Dr. MELLIAR-SMITH. What you can see are 20 nanometer magnetic pillars on a magnetic disk drive, and a large disk drive in the future will have ten trillion—yes, that is trillion with a t—on each drive. We are also working with the LED industry to place nanofeatures on high-brightness light emitting diodes to increase the efficiency and brightness. The objective is to make the LED a replacement for all forms of architectural lighting, which if completed, would serve a significant fraction of all of the electricity used in the United States, and would remove about 50 million tons of carbon from the air each year. Finally, looking further out, there is growing interest in the use of nano-medicines. By making the drugs into small particles, typically less than 50 nanometers, and of a particular shape, there is evidence that they can be made much more effective and much more specific.

[Slide.]

Dr. MELLIAR-SMITH. To create this opportunity, we received a large amount of help from many different government agencies, shown in this slide here, and the purpose of my testimony today is to mention that.

As you can see—and I won't read through them—we have received support in significant amount from several different government agencies and also from the University of Texas. In all of the cases, the programs and project management of these funding agencies has, in my mind, been impeccable, maintaining fiscal responsibility for the taxpayer without overly micro-managing the technical efforts.

We have also received extensive help from government-funded facilities. Recently, especially useful has been our access to state-of-the-art electron beam tools at the molecular foundry at Lawrence-Berkeley National Laboratory in California, to make the very fine imprint marks required for our technology.

The government funding has been supplemented by over $60 million of venture capital and industry investment, and in fact, in my experience, I found no dichotomy between the two sources of funding. They seem to be synergistic and collaborative. We are grateful for all of this support. Our company has already grown to 90 people, and I might add, with an average salary of $95,000 a year, so they are really good jobs. And we expect to get $25 million in revenue this year, twice that of 2007. And essentially, we see an almost unlimited future for ourselves and our customers. None of this would have been possible without the various forms of support I have described.

Now, I think we all know that one swallow does not a summer make, but if you will grant me an example of one, I would say that the programs have been very successful. Thank you.

[The prepared statement of Dr. Melliar-Smith follows:]

PREPARED STATEMENT OF C. MARK MELLIAR-SMITH

Good morning. My name is Mark Melliar-Smith and I am the Chief Executive officer of Molecular Imprints. I am pleased to be able to provide testimony today is support of the Nation's efforts in nanotechnology. My company is but one example of the successful support of new technology by the U.S. Government, and I am happy to talk about this success.

Molecular Imprints is a start-up company, which was spun out of the University of Texas at Austin in 2001. The company was created to commercialize a newly invented technology called "Step and Flash Imprint Lithography," which has demonstrated capability to pattern features down as small as 3nm, or about the diameter of a DNA molecule.

Nano-lithography is the method of creating very small patterns on a substrate. The technology is critically important, especially to the production of electronic devices such as computer chips. Today, the technology used to do this is an optical technique, much like making photographic prints, where the patterns are projected onto a light sensitive resist on the substrate using a very sophisticated and expensive camera. However this technology has begun to be limited by the wavelength of light. It is very difficult to make a 50nm feature with a 200nm light source.

Molecular Imprints offers a superior alternative based on nano-printing. We make a very accurate master using an electron beam tool of almost unlimited resolution and then use the master to simply print, using a special ink, the features on to the substrate. As you can see the quality of the images are much better and the simplicity of the tool makes it much cheaper. The analogy to photography can be extended here. You don't make prints photographically any more—you simply print them.

The Step and Flash Imprint development will have a significant economic impact on the United States. The original optical photolithographic techniques were invented in the United States in the late fifties and early sixties and build up into a billion dollar industry. However, in the eighties and nineties the U.S. lost this capability to superior products from Europe and Japan, and now this $10B industry is almost entirely sourced from outside the United States as shown on this chart. At Molecular Imprints we intend to turn this around and bring the business back to the U.S. trough the use of a new and superior nano printing technology.

However, the economic impact extends well beyond the $10B of litho tools themselves. This technology enables multiple industries. The largest is the $250B computer chip industry with companies such as Intel and Texas Instruments—which itself enables the $1.5T electronics industry and much of our advanced weapons systems. This industry has been built over the past fifty years on our ability to make smaller transistors every year. The disk drive industry, with companies such as Seagate and Western Digital, is also moving into nanotechnology. To increase the density of their drives, they will soon have to pattern the spinning magnetic disks—an example of which is shown here. These are 20nm magnetic pillars and a large disk drive in the future would have 10 trillion—yes, trillion with a T, on each drive. We are working with the LED industry, to place nano features on high brightness LEDs to increase their efficiency and brightness. The objective to is make LEDs a replacement for all architectural lighting which if completed would save a significant fraction of all the electricity used in the United States and remove 50M tons of carbon from the air each year. Finally, looking further out, there is a growing interest in the use of nano medicines. By making the drugs into very small particles—less than 50nm, and of a particular shape, there is evidence that they can be made much more effective and much more specific.

So our technology has multiple applications from semiconductors to drugs to energy saving device for clean technology.

To create this opportunity—we have received a large amount of help from many different government agencies—and that is the purpose of my testimony today. Chronologically we have been supported by:

- The University of Texas where the basic invention was created in the mid nineties and I would be remiss if I did not put in a word for the large research Universities in the country—they have become a great resource especially as the large corporate labs like Bell Laboratories are less available, and a resource that is hard to duplicate/outsource.
- Some of the early funding to the University of Texas in the late nineties came through the joint activities of my colleague from SRC and Defense Advanced Research Projects Agency DARPA.
- Our first funding for Molecular Imprints in 2001 came from the DARPA to the tune of $3.5M.
- We also won a major Advanced Technology Program grant of $9M in 2004 from the Department of Commerce.
- And finally a $2.6M contract from the Office of Naval Research to help make the process more production worthy.

In all cases the program and project management from these funding agencies has been impeccable, maintaining fiscal responsibility without overly micro-managing the technical efforts.

We have also received extensive help from government funded facilities. Especially useful has been our access to state-of-the-art electron beam tools at the Molecular Foundry at Lawrence Berkeley National Laboratory in California to make the very fine imprint masks required for our technology.

The government funding has been supplemented by over $60M worth of ventures capital and industry investment—and I have found no dichotomy between the two sources of funding. They are synergistic and collaborative.

We are grateful for all of this support. Our company has already grown to 90 people, and I might add with an average salary in excess of $95K per year, so these are really good jobs, and we expect $25M in revenue this year, twice that of 2007, and essentially we see an almost unlimited future for ourselves and our customers. None of this would have been possible without the various forms of support I have described.

Now I think we all know that one swallow does not make a summer, but if you will grant me an example of one—I would say the programs can be very successful.

Molecular Imprints

Enabling Nano-Scale Manufacturing

Mark Melliar-Smith CEO
(mark@molecularimprints.com)

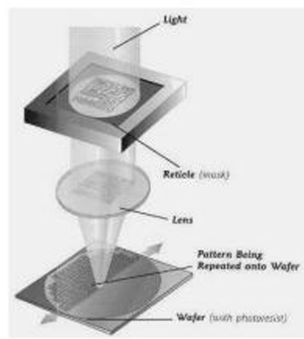
Presentation for House Committee on Science and Technology – Subcommittee on Research and Education
March 11, 2008

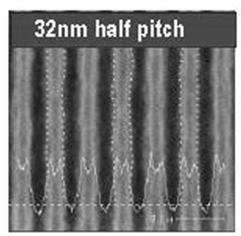
Molecular Imprints

- Founded in 2001 (spin out from U. Texas)
- 90 employees
- Estimated Revenue 2008 $25M
  - 100% growth over 2007
  - Sales to US, Asia, Europe

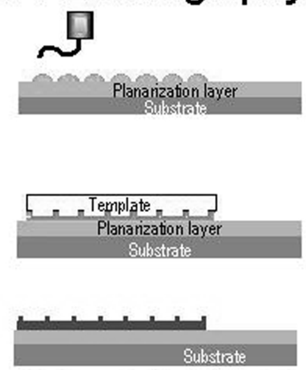
Nano Lithography

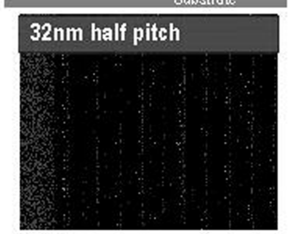
Optical Lithography





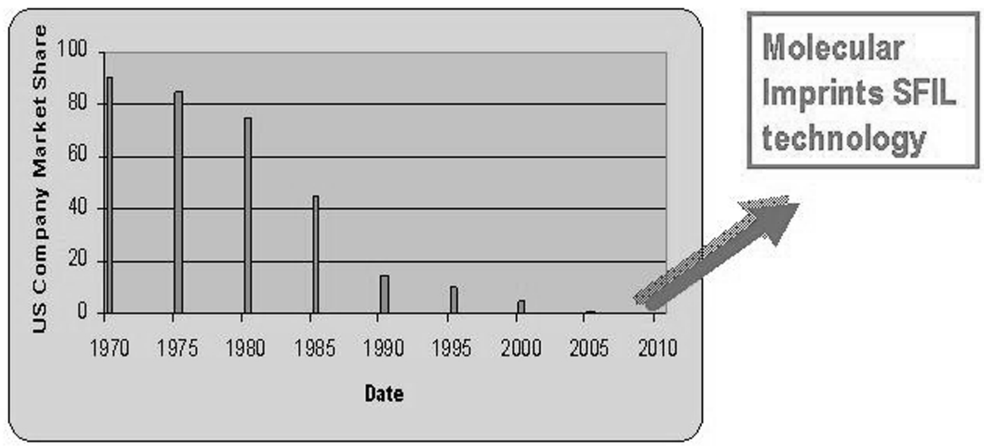
S-FIL Lithography





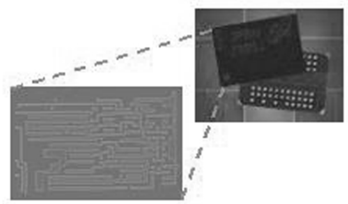
Estimated US Market Share in Lithography

A $10B/year industry to recover!



Nano Lithography Opportunities

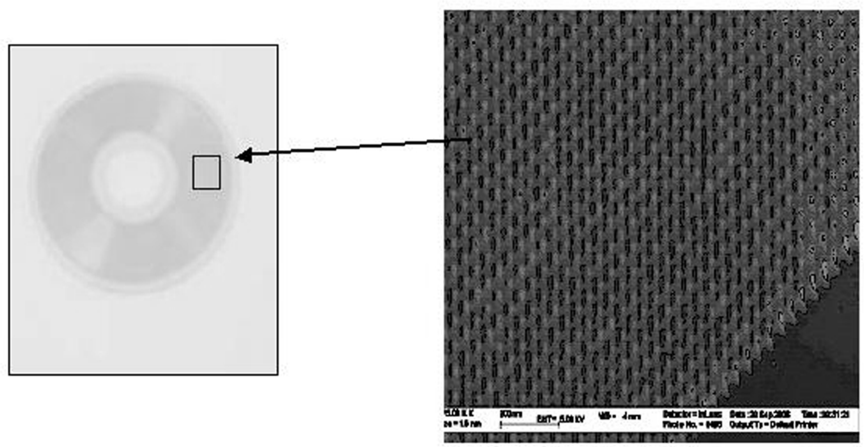
Semiconductors - $250B



Disk Drives - $40B

Molecular Imprints

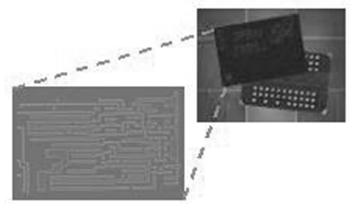
Patterned Media for Disk Drives



Molecular Imprints

Nano Lithography Opportunities

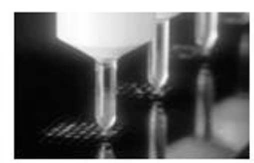
Semiconductors - $250B



High Brightness LEDs - $5B

Disk Drives - $40B

Nano Drug Delivery - TBD



Government Support for S-FIL Technology

- **1995-2000** University of Texas Research Funding from SRC/DARPA for basic lithography research
- **2001-2004** $3.5M from DARPA
- **2004-2008** $9M from ATP (Dept of Commerce)
- **2006-2008** $2.6M from Naval Research

- **2006-present** Access to high resolution electron beam tools at the LBNL Molecular Foundry and other tools from the NSF NNI Network

- Plus $60M in Venture Capital funding (2002-present)

Molecular Imprints

Thank you for your valuable time!

BIOGRAPHY FOR C. MARK MELLIAR-SMITH

Experience Summary:

- General management (President and CEO of SEMATECH, CEO Molecular Imprints, CTO for Lucent Microelectronics)
- Managing a start up operation (GM of AT&T Microelectonics Lightwave Business Unit; CEO Molecular Imprints)
- Extensive R&D and manufacturing experience in integrated circuits, photonics, fiber optics (Executive Director at Bell Labs; managed large electronic component factory for AT&T Technology Systems)
- Venture capital—selection and support of start-up companies (Venture Partner, Austin Ventures; President MSC)
- Managing a large collaborative program (CEO of SEMATECH)

2004–Present—COO and then CEO (from October 2005); Molecular Imprints

Molecular Imprints, located in Austin, Texas, was founded in 2001 with the objective of developing a totally new form of lithography for the semiconductor industry. Founded by two Professors at UT–Austin, it has been very successful both in terms of product development and sales, and also in raising venture funding. The company is growing rapidly and has 80 employees.

2003–Present—President; Multi-Strategies Consulting (MSC)

Consulting and investment company focused on high tech, early stage start-ups in Central Texas.

2002–2003—Venture Partner; Austin Ventures

Austin Ventures is one of the largest venture capital companies in the southwest, focusing on software, telecommunications and semiconductors. With several billions in investment and some 40+ companies in its portfolio, the organization focuses not only on finding and funding innovative new high tech companies, but also supporting and nurturing them through the first five years of their existence. My responsibilities focused on semiconductors, photonics and components.

1997–2001—President and CEO of SEMATECH

Responsible for all aspects of a $160M, 600 person semiconductor R&D consortium, reporting to a board of 13 member companies which represent about 50% of all integrated circuit production in the world. Lead a direction change from the original mission for SEMATECH (restoring U.S. preeminence in manufacturing) to one of driving the technology roadmap acceleration from three to two year development cycles. Expanded membership to include the major semiconductor companies in Europe, Taiwan and Korea.

1990–1997—Chief Technical Officer, Lucent Technologies Microelectronics

Responsible for R&D and Technology for Lucent Microelectronics Business Units including silicon integrated circuits, photonics, gallium arsenide, power supplies and printed wiring boards. Reported to the President of Lucent Microelectronics and was a member of Executive Committee. Greatest challenge was to not only maintain state of the art R&D, but also to help transition an historically vertically integrated cost center (AT&T Western Electric) to an independent, market based entity with profitable P&L and $4B in revenue, 80% of which came from outside the company. Member of the 12 person Bell Labs Council advising President of Bell Labs.

1988–1990—Vice President and General Manager—AT&T Microelectronics, Lightwave Business Unit

1987–1988—Executive Director, Bell Laboratories Photonics and Microelectronics Division

1984–1987—Director of Engineering and Operations, AT&T Kansas City Works, Western Electric.

1970–1984—Various engineering and management responsibilities in Bell Laboratories

Various pre-1970 employment in Canada (technical sales), Australia (chemical engineering), Europe (technician, manufacturing tech)

Board Memberships

Power-One Inc., Camarillo, CA; Chair of Governance Committee, Member of Audit Committee

Technitrol Inc., Trevose, PA; Chair of Audit Committee

Molecular Imprints Inc., Austin, TX

Metrosol, Austin, TX

Education

1967—BS Chemistry, Southampton University, England

1970—Ph.D. Chemistry, Southampton University, England

1986—MBA, Rockhurst College, Kansas City, MO

Community activities:

1998–present: Member of the Engineering Advisory Board at the University of Texas.

Drawn from around the United Sates, this group meets several times per year to advise the Dean and faculty of the College of Engineering on a wide variety of policy issues such as intellectual property strategies, fund raising, government and funding agency relations etc. In addition, members of the EFAC also provide resources for students as needed in special cases.

2006–present: Member of Board of Trustees for Huston-Tillotson University

HTU is a Historically Black University located in Austin. The Board of Trustees meets on a regular basis to advise the President of the University and to provide expensive support in the area of business affairs, fund raising, community relations, student internships, etc.

1998–present: Board of Capital IDEA (Board Chair 2002–2004)

Capital IDEA is a non-profit organization devoted to adult education in Central Texas. Using government and private funding, it provides financial assistance, mentoring, books and tuition for under-employed adults to allow them to build their skills to achieve a position with a living wage and benefits; graduating approximately 100 people each year.

DISCUSSION

Chairman BAIRD. Outstanding testimony, and we appreciate very much your insights and expertise. I want to focus on two things as we look to reauthorize the bill. Give us, if you use—and I am going to rule out one option. You can't just say more money. We hear that enough on Capitol Hill. We have a $400 billion deficit this year, a multi-trillion-dollar debt, as you know, and so the more money thing I will take off the table. Apart from that, if you could each pick one thing to do and one thing not to do as we look towards reauthorizing this bill, what would be? And I will go with you, Mr. Rung, and work across from you.

Mr. RUNG. The one thing to do would be to have some intentional and accountable with measures funding for commercialization associated with multi-year, large award so that might take the form as a gap fund such as ours that provides an incentive and some specific funding. In our case, it is grants to university projects in collaboration with entrepreneurial startups with the goal being that the startups raise funds.

In terms of the one thing not to do, I wasn't prepared for that question, so I guess I will just say "more of the same" without thinking through——

Chairman BAIRD. We have yet to repeal the law of unintended consequences. That is the one law that doesn't sunset here, so I am always cognizant. I ask this very often whatever the topic, because I just want to not make mistakes that set you back in our effort to move things forward.

Dr. Chen.

Dr. CHEN. The one thing to do, I think I would mirror what Mr. Rung said, which is to take a portion of it and have it targeted to help and support university-industry partnership on a few specific areas and projects.

In terms of things not to do, I think the flip side is for the basic research funding. You don't want to target that too much. You want to leave that open, because that is where you don't want to pick and choose what the winners are because then you prevent the unexpected discovery from happening.

Dr. WELSER. Because they already took my university-industry partnerships, the other thing I would say is do look to what the states are doing as well in this. I mean the states are being very responsive to the NRI, in particular, in terms of finding it as an opportunity to build up new economies. And they are willing to invest money in buildings and facilities around the universities. They can't necessarily afford all of the equipment and things that are going to go into that or the types of infrastructures costs that go along with it, but they are ready to catch a lot of this stuff as it comes out and will be more than willing to fund startups as well on that, so I think leveraging that capability with federal funds is very important.

Mr. MOFFITT. I would like to see the initiative balance spending between basic research and bridging the gap to commercialization of products. Historically, we focused a tremendous amount of money and effort at developing the science. It is not time to bring some of that through to fruition so that those industries profit and jobs can being to fuel and repay back in to the cycle, if you will.

The thing I wouldn't do is ignore the need for funding to develop human resources. To all of us that are in the commercial side of this, this is extremely critical.

Dr. MELLIAR-SMITH. I think the point that I would like to focus on are the utilization of the national laboratories. They have been built up over 50 year or longer in the country, and they are an enormous resource for the economy and the well being of the Nation. I think anything that we can use to try to draw the national labs more into the world of innovation and commercialization would be enormously beneficial.

After the Second World War, this nation and a lot of its industries were built on the basis of large, corporate laboratories, which now, unfortunately, have fallen, generally, onto harder times, so it is rare that you can find a really talented group of multi-disciplinary world-class scientists. And those are located in the national labs now, but somehow we need to find a way to get them more involved.

And the thing that we don't want to do, it is always difficult for me to say stop doing something, because I have only dealt with mostly successful activities with the government, so if I might be excused from straying a little bit of, perhaps, this committee, I would like to see us not deny immigrants the chance to work in this country. Many of the universities have got large numbers of graduate students who were not born in the United States. They are another enormous beneficial aspect of our university system which we ought to be able to exploit. Thank you.

Chairman BAIRD. Outstanding comments. My time will shortly expire, so on the second round I will be asking you about education issues. Expensive infrastructure may be better said that it costs to do nanotech work, how do we export that? Can we use web-based instruction or remote access to help, for example, community college students, et cetera, along the lines of something Mr. Moffitt said, but I hear it from nanotech folks as well that that pipeline of students that would get this great gee-whiz development, great economic potential, but we don't have the pipeline, and that is on of our risks in terms of where we lose the technology, is another country has the human resources to exploit the developments that we make here. We have seen this in other fields in the past. So I will yield to Dr. Ehlers or recognize Dr. Ehlers for five minutes, but I will get back to that question in a moment.

Mr. EHLERS. Thank you, Mr. Chairman. And first, I would just like to make an observation. Looking around the room, you will notice that this hearing is fairly lightly attended, both in the audience and by Members, and I don't even know if members of the press are here. But yet I think this particular hearing, and certainly this topic, will have much greater impact on the future of this nation and its economy than most anything, certainly more so than whether or not Roger Clemens took steroids, which has preoccupied the press and part of the Congress for some time.

Chairman BAIRD. If we had the proper chips, we could have assessed whether he took steroids—a plug for Mr. Moffitt.

Mr. EHLERS. Right. It is just striking to me, and it shows me the importance of this committee and the lack of understanding of the public and occasionally our colleagues of the importance of the issues that we deal with.

I thank the panel for being here. Your testimony has been outstanding and very helpful to me. In some cases, you have answered the questions I was going to ask, but let me just try to get a cross section. A few of you have answered this already, but I want a broader and more complete response.

For example, Mr. Moffitt and I think Dr. Chen, as well, mentioned that the U.S. currently leads in the science of nanotechnology but could lose the commercialization race. Now, the question is how can we turn that around? It is not just a matter of money, you know as well as I. Education comes in here and a lot of other factors. You also mentioned immigration. I think I would refer you to John McCain's campaign. Maybe you could help in that process because he seems to be the only one supporting proper immigration.

But what is the answer, or what can we do in the Federal Government to help with the commercialization, given our current budget situation, not a lot of money. What do you need? Do you need more encouragement? Do you need more security to be able to raise money, et cetera? What is your response?

Dr. Chen, why don't you kick it off?

Dr. CHEN. I would say that actually one of the things goes back to what you referred to which is why people aren't interested. And it is the technology demonstration projects, actually, is something that can address both issues because if you have a few examples of things where we have taken things from the lab and turned it into a commercial success, it starts to feed the pipeline. People see that you can succeed, that you can accelerate progress in a particular area, and the success there makes people realize that you can have success in other directions, so I think these technology demonstration projects where university and industry work together is one area where you don't need a huge amount of investment because you are not going to invest in hundreds of them, but if you invest in a few as a starting point, you can make things move forward.

And in terms of the education and immigration, I totally agree. I think that this country needs to recognize that we are going to lose a lot of knowledge if we make it difficult for people to stay here. My parents came here as graduate students. I was born here, and so that is an example of how encouraging the people we train to stay here is going to help this country.

Mr. EHLERS. Mr. Moffitt.

Mr. MOFFITT. The single greatest hindrance to commercialization, I think, today, and keeping it in this country is at the root of that education. We simply lack the workforce. This requires a highly skilled, very technical labor organization, not dissimilar from what the semiconductor industry required 15, 25 years ago. So this, again, is against a falling tide of graduates, STEM graduates, if you will, so I think education is certainly one yet to the answer here.

And I think the second is the ability to provide validation for the private sector investments in a given nanoscience. Now, one of the greatest difficulties is that extremely high risk capital that is used to start a small venture, and then have the ability to cover the gap, if you will, and prove out the commercial viability or value of the product and that, I think, is where if the government would focus spending—I won't say more—but spending on the gap, if you will, that serves to validate, and validation brings in private-sector money, of which there is an abundance in this country.

Mr. EHLERS. Okay, I appreciate those comments because I've spent about 40 years of my life trying to improve math and science education in the elementary and secondary schools, including during my time in Congress.

Just a quick follow-up, Mr. Moffitt, and then there will be a quick question for Dr. Melliar-Smith. Are you having trouble filling spots in your company? Are you having trouble hiring qualified people?

Mr. MOFFITT. Most definitely. In fact, I would tell you very quickly that yesterday, in a staff meeting, we discussed the potential to move manufacturing of our products offshore to get access to a labor force that would be sufficient to supply our needs.

Mr. EHLERS. Okay, and a quick follow-up from Dr. Melliar-Smith. You commented about use of the National Labs. How about the university centers?

Dr. MELLIAR-SMITH. I believe the universities also fall into the same category of being a national resource for research and development. And what I might add, that is very hard to duplicate or outsource. It takes several generations to build a great research university, and we need to support those activities.

The only comment I would make in the form of sort of constructive criticism, if I may, is that I think that the universities could provide an increasing reference toward commercialization in their tenure decisions for professors. We have been very fortunate in having a professor at the university who spent a lot of time at Molecular Imprints as our chief technical officer. I am not sure that it has helped his tenure track to a full professor position, and I think in some universities such activities are, in fact, almost frowned on. So any encouragement we can give to universities that commercialization of the inventions of which they act as a wellspring for could be used further the academic career of the professor.

Mr. EHLERS. In my experience in universities, the answer has been that the professors go off and form their own companies and take care of the commercialization that way, which is not healthy for the universities. With that, I yield back.

Chairman BAIRD. But it makes tenure a whole lot less relevant if you are successful.

Mr. EHLERS. Go back and donate a building.

Chairman BAIRD. Dr. Lipinski.

Mr. LIPINSKI. Thank you, Mr. Chairman, and I want to try not to repeat the same questions. I think all three of us doctors up here think alike on these questions, but I want to echo a little bit what Dr. Ehlers said about that is apparently here on this issue. Tomorrow, we are going to have Bill Gates in this room, and I am sure that everyone will be packed out the doors and media will be here, and Bill Gates is going to come and address, talk to the Democratic Caucus. I really think what we should have, what would probably be more helpful to our country is to have the five of you come and speak to the Democratic Caucus and see if you could really raise the interest.

I have been discussing this. I don't know if it is because people hear nanotechnology, and they just don't understand it, they feel that it is too complicated. But I really think that this is critical to the future economic prosperity of our country. And there is a couple of things sort of around the margins, coming off of the questions before: what have some of the states done that you see as very successful in terms of helping to promote nanotechnology. I know that New York has done a lot, but who else has done things that you think are successful? I will start with Dr. Welser.

Dr. WELSER. I would say, New York, I think is a great example, so I won't dwell on that one right now. The other things we have seen going on, though, in Texas, they put together an endowment for pulling in new faculty, specifically in the area of nanoelectronics and nanotechnology, when they started the center, which then allowed them to pull in more of a critical mass of people there working on this effort, both for training the students and for doing the research. I think that is extremely useful because getting enough people at a given university center to work on it oftentimes makes the difference between whether you just have a few good products coming out from professor's lab or a whole bunch of ideas building off each other.

The other thing we see is, in one of the Midwestern States we are looking at right now, they are specifically looking to try and build up incubators outside of the university that can catch some of the spin-offs, but have the university professors help them in the design of that and actually be able to utilize those facilities in the early-stage research before it is ready to be, necessarily, a technology that is going to go out for actual R&D. I think this is a somewhat smaller investment than what, say, New York did to build the entire nanotech center there. But by doing that in a targeted way, I think it is still going to have a big impact.

Mr. LIPINSKI. Anyone else have anything on what other states have done?

Dr. MELLIAR-SMITH. If I might mention that Texas has something called Emerging Technology Fund, to the tune of about $100 per year, and that money is passed out to aspiring small startup companies. Many of them are actually pre-venture capital companies, so they are very early stage funding. Some are later-stage funding. And that actually has been very successful in terms of Texas being able to support a wide variety of different startup companies in different industries. I think that program has been pretty successful.

Mr. MOFFITT. I am also aware that in the past, the State of New Jersey has allowed small entrepreneurial companies in certain industries and meeting certain qualifications to sell their State net operating loss carry-forwards to large industries. The large industry buys it and uses it as a credit against their own taxes if you will. The State of Wisconsin has a program of matching grants in certain segments of the industry. The State of Indiana has a program that supplies SSRT grants for the development of science that is invented inside of the state and commercialized inside of the state and the State of Illinois is considering a number of different of these approaches to try to build a greater center, if you will, of nanoscience, and a center of excellence in that area.

Mr. RUNG. Well, the State of Washington, for many years has had an organization called the Washington Technology Center which is a State-funded or initiated user facility that performs work for a large number of companies and also has a twice annual competition for research support grant for companies. They are right adjacent to the University of Washington Nanotechnology Center. They have been a model for us in a lot of what we have done.

In Oregon, we have the Signature Research Program. ONAMI is the signature research center. There are two more now. I think one of the things that has worked very well, maybe better than we thought it would, is to encourage the research universities and the state to collaborate very deeply with one another. That sounded like something that might be difficult at first, but it has gone exceedingly well, and we have ideas, successes in regarding research funds and commercialization that would not have occurred but for that collaboration.

Dr. CHEN. I think one thing that is a little bit of a difficulty in terms of State funding is that, again, because nanotechnology cuts across industry sectors—it can have relevance to biotech; it can have relevance to energy, to automotive—it is not like a sector where you can have whole bunch of companies that come together and go to the State and say we need this. We have that in the state in terms of biotechnology, but there is not really that equivalent cluster of nanotechnology identified in the state, even though many of the companies in the state do benefit from nanotechnology. I think that is one consideration.

Mr. LIPINSKI. Thank you. Let me throw this out. I don't want to get an answer. It will go into the question that the chairman had. In terms of education, what do we really need—I should say are we looking for in a workforce, to work in nanotechnology? What exactly are we trying to do and does that just mean encouraging STEM education across the board, across all students, or are we looking for something more concentrated? But I will turn it over to Chairman Baird for his questions on education.

Chairman BAIRD. Let us take that as a friendly amendment to my question and open that up to what we need to do and how we can better do that and how the nanotechnology initiative might adapt it in some fashion to encourage that or if their another vehicle that might be better to do it.

Mr. RUNG. I guess I will start. One of the panelists mentioned internships or experiences for students. We call this inquiry-based science and think this is extremely important. You know, you can talk to a child and try to push information, but the experience of doing something is very powerful. The Nanoscale Informal Science Network is a great thing. We are very proud of our local Oregon Museum of Science and Industry and for the outreach that they are doing, even in rural parts of the state, also towards those experiences.

The goal, of course, is to have, you know, U.S. citizen student, you know, persist, you know, through graduate degrees. There is an increased demand for graduate degrees, and in the absence of sufficient numbers of those at the time being, I have to agree very strongly with the other panelist that we must keep the immigrant advanced-degree people that we have educated here. Otherwise, in the short-term, they will create jobs overseas.

Chairman BAIRD. Let me follow up on that issue for just a second. My own belief is, and I can tell you in our local community, there are industries who have really stepped up to the plate to better educate the local populous. They take Ph.D. levels and put them into the schools. They bring high school and community college students into their labs to work in an internship, and quite frankly, there are other, comparable high-tech industries that don't. And interestingly enough, it is the latter that tend to be busting down our doors to expand H1–Bs.

And I would much more be inclined to link increased H1–Bs—and we will hear tomorrow, I think, from Mr. Gates, probably, about the need to expand H1–Bs. I would be much more inclined to expand H1–Bs based on a demonstrated effort to educate the domestic populous rather than just ignore the domestic populous. And I am aware that there is this piddling $1,500 fee you get for an H1–B and that goes to an education, and that is being used pretty well. But quite frankly, given some of the data about under-funding and underpayment of H1–B recipients here, how can we do this? How can you folks in the industry reassure the American people that we are going to try to educate our own kids so they can fill these gaps rather than just trying to get folks from overseas, as valuable as they are, and maybe have a synergy there to where every H1–B you get, you have to demonstrate you are educating ten Americans, something like that. I just put that out there.

So I am sympathetic to it, but I hear it far too often when high-tech people come to us and say expand the H1–Bs, and we knock on their door and say what are you doing for mentoring? What are you doing for internships? What are you doing to invest in the local school? Oh, gosh, you know, we are just too busy. The economic climate is just too competitive, blah, blah, blah, and I am kind of tired of it.

Dr. MELLIAR-SMITH. Again, I guess my recommendation would be to identify and speak with the large industry associations that are asking for the H1–B visa and just lay it on the table. They understand a simple partnership as well as anybody. I tend to agree. My biggest goal is in fact to make sure that we provide, you know, a green card to every student that graduates from a large research university with a post-graduate degree in an area this country needs. Now, I know that is difficult to put in place in the present environment, but it is such a simple thing to do, and I think everyone agrees that it would be good thing to do, but it is difficult for us to make it happen.

Chairman BAIRD. I would fully support it, providing that the green card gets revoked if you don't dedicate some of your time after you got the green card to educating American citizens.

Dr. MELLIAR-SMITH. That is fair enough. You can have them do whatever you want.

Dr. WELSER. I guess, just briefly back to question on education, I think the first thing that, obviously, that we would love to see is that the NNI can, in fact, fund all of the stuff that is in the America COMPETES Initiative, and obviously, we weren't successful in getting that through every year. I think there is a lot of really good programs there, both for helping research as well as education.

But the other thing that I think the NNI could do in its reauthorization is try to identify some grand challenges and big initiatives that can capture the public mind. I think the nanotechnology is so large and so vague that sometimes it loses some of its graspability by the general public. Maybe, you know, looking for the next transistor isn't quite as sexy as putting a man on the moon, but we can find some things out there in nanotech that is stuff to grab people's mind, and hopefully encourage students that this is an interesting area to go into.

And lastly to your question on what kinds of education we need. I do think it is much more cross-functional than it used to be. One of the things we have found is we are working a lot more with physicists and chemist and wishing we had more people who knew organic chemistry in the semiconductor side as we are trying to transition into more nanoelectronics sorts of applications. Most of us were trained more in the inorganic side of things and more on the engineering side, so we need people with those skills, but we need them from the very beginning to be talking with engineers and getting an engineering background in their education so they understand how you take organic chemistry and actually make a device or make a product out of it.

Chairman BAIRD. As you may know, the America COMPETES Act specifically addresses cross-disciplinary research and funding for that kind of training. Unfortunately, we didn't get to the appropriation last year. But in the budget, which just passed the Committee last week, we have made space for substantial increases. We'll bring that budget up tomorrow on the floor, and expect the democratic budget will pass, and it has large allowances for substantial increases in funding for America COMPETES related activities.

Other comments on the education issue, especially how we can skill it up to people who are not necessarily located in the centers where you have got your equipment directly available.

Dr. WELSER. We have been involved in a project in the FEI Company with a table-top scanning electron microscope that was actually demonstrated here in Congress last year. I believe there is a Nanotechnology in Schools Act that Congress is considering that would provide funding or an opportunity to place low-cost tools that expose students to hands-on nanoscience, and so that would be one example, looking for placement of those in community colleges or traveling units.

Chairman BAIRD. If I were a kid in rural Southwest Washington, is there a way I could go on the net and tinker, remotely, with some nanotech equipment? Dr. Chen, you seem to have——

Dr. CHEN. Yeah, there are programs where they have set up through the Internet you can access atomic force microscope and get a feel for what sort of images you could get out of it, and so I think those are things that we need to do to excitement in there. I mean a middle-school kid may not end up working in nanotechnology, but if they get excited in science and STEM areas, that is a win for this country. I think you make a very strong point in terms of forward thinking in that we can't just rely on people from overseas over the long-term, because as things get better, they are not going to come. Why are going to leave their country if things are as good there.

We need to get kids in this country excited about science and engineering because if they don't get excited at the middle school level, there is not a lot we can do to recapture them at the undergrad or graduate level.

Dr. WELSER. I am a former middle school science teacher, so I can appreciate a lot of these comments. I think there is tremendous opportunity in dealing with the community colleges in this country. There is a great network of resource there. There is an opportunity there, not to train necessarily Ph.D.s, but the supervisory/managerial technical talent that we require in order to commercialize. And I think a government-industry cooperation to pull together a curriculum that could be broadly disseminated across these community colleges would go long way to solving problems within the next few years as opposed to a generation away.

However, we still need to underwrite the generation away, and that simply is just more math and science teachers. I personally participate in education of math and science teachers with respect to nanotechnology and have done a lot of local work, but the local work alone is not sufficient.

Chairman BAIRD. I appreciate that. We had comprehensive review in my district, and one of the interesting things was I invited a fellow in charge of production management for SEH America, and he listed a number of the thing that he needs employees to be able to do, and it was such things as looking at an array of numbers and trying to get a sense of what the mean and the standard deviation is an what numbers are beyond the bounds, and then trace that through some other charts and figure out what here may have caused the deviation here.

He said they can't find people to do that, and we are talking high-level jobs. We are talking potential billion dollar investment in the community and just a fairly rudimentary mathematical reasoning sequence is difficult. But what was also intriguing was the local educators said that they had been trying for a long time to get the high-tech community to articulate clear-cut defined, achievable goals, and until he had done that at that presentation, they had lacked that. So there is a huge disconnect between the educational community and the consumers of the so-called supposedly educated work force, and we need to close that gap, and your notion of a curriculum may go well along the way towards that.

Dr. Ehlers.

Mr. EHLERS. Thank you, Mr. Chairman. The one surprise so far is that no one has mentioned health and safety issues, and so I feel obligated to raise those issues. Dr. Chen, you mentioned that you have environmental health and safety researchers working side by side with the nanomanufacturing researchers in your center for excellence. I want you to amplify that with Dr. Melliar-Smith and Mr. Moffitt. I am wondering what type of health and safety precautions do you have to take in your facilities to minimize employee exposure to nanoparticles.

Dr. Chen, first, and we will just work down the line.

Dr. CHEN. One of the things that we discovered, actually, in talking to the EHS researchers, they were so happy to be involved at the stage where we were looking at creating new processes because what they said was usually what happens is people call us in after the fact and ask us to clean up the mess. And so the exciting thing there is that they really are side by side. I mean there is someone making product, and there is someone measuring exposure, and so they can, by being right in the lab, they can make suggestions, they can take measurements, they can understand how the manufacturing process might go so that they can also make suggestions as to how that process could be designed to be more environmentally friendly.

And so I think that is a key. The EHS research, a good chunk of it, can't be done in isolation because there is too much to look at. It needs to be focused in terms of what are the issues if we go down a certain pathway for a manufacturing process. What are the issues for a particular type of application? And I think in the near-term, that is going to get us there a little faster. I mean we won't be able to solve all of the problems, but we may be able to address some of the more urgent problems sooner if we get those groups together.

Mr. EHLERS. Would you consider your center to be a green center?

Dr. CHEN. I would. I mean it is a very important piece, and it is a unique part of Lowell that we have this very strong health and environment group as well as the manufacturing.

Mr. EHLERS. Mr. Moffitt.

Mr. MOFFITT. We make a biologically reactive gold nanoparticle, so we must concern ourselves, both with the biological components of what we do, as well as the nanoparticle structure. We start with the premise that gold is inert noble metal, and as such, it is not an active particle if you will. But once we functionalize it, it becomes active, so we do some—I would not call it core research—but we do some basic safeguard measures that you would expect in any biological facility, so we manufacture products in a clean-room environment, in an isolated environment. We have P–2 labs, which are labs that are capable of handling infectious agents and disposing of them properly, and monitor, of course, on a safety basis, every step we take in the handling of these materials.

Mr. EHLERS. Dr. Melliar-Smith.

Dr. MELLIAR-SMITH. Well, I think health and safety goes without saying. It would be incredibly irresponsible for any CEO or any citizen, for that matter, of a country to do something that would risk the health of their employers or their neighbors or what have you.

In our particular case, the nanoparticles that we produce are actually patented onto a substrate so they stick to the substrate. They never come free. They never float in the environment in the way if you were manufacturing carbon nanotubes or something of that sort. So in fact, the product we make does not represent any form of nano- or biohazard to the community, but I strongly agree that the nano-industry has to step to the environmental risks that potentially very small particles do or could create in the environment, and I think it goes without saying we have to do that.

Mr. EHLERS. Thank you very much. I have no further questions.

Chairman BAIRD. Dr. Lipinski.

Mr. LIPINSKI. Very quickly, what can we do in the NNI, if anything, to, first of all, do all we can to make sure the proper work is done so that we do not have these environmental concerns, health concerns with any kind of nanotechnology, and what can we do to convince the public about that? Is there something that should be done in the NNI? I think you univocally talked about what you do where you are at, but is there something more general that the government could help in this area?

Mr. RUNG. If I may, I have written extensively about this in my written testimony. Green nanotechnology is ONAMI's single largest program, and in fact, in about ten minutes, day two of our Greener Nano Conference will be getting underway.

The summary is that you want to link the research on implications with the research on applications, and you need to have a comprehensive program that is multi-disciplinary, unites multiple agencies and objectives together. The best example that I am aware of this, and we are heavily involved in it at the leadership level, is the NIEHS Nano-health Initiative, which is breaking out into three projects, one on characterization of nanoparticles, which is critical—without data, nothing else is going to be achieved—biological assays that are efficient and practical to perform, and then very importantly, a system of federated databases so that data can be shared and be consistent on the interactions of engineered nanomaterials with biological systems.

This three-part project would be a great way to fill the gap between what current EHS funding in the NNI is and the ten percent or so that the Nanobusiness Alliance and other groups have suggested. It brings together multiple federal agencies, industry, academic centers, and I think it is an extremely promising initiative and following exactly the right approach.

Dr. CHEN. I have already made some prior comments, so I may just add one additional thing. I think we want to also recognize that EHS research also will benefit from the creation of tools that will make it easier to measure and understand what is going on, so I think we want to make sure that there is a recognition for that piece of the EHS research aspect.

Mr. LIPINSKI. One other quick question—well, first a plug for my alma mater, Northwestern University. Northwestern has really put a lot into nanotech and has been very successful, and the commercialization has been very successful. It is best to have some centers of excellence rather than to spread the federal funding around? Is it better to do that way? I think maybe someone had suggested that earlier, and I just wanted to put that out there.

Dr. WELSER. Well, I think is a balance. Unfortunately, a lot the tools that we are going to be needing for this sort of work are extremely expensive, so you can't afford to put one in every university, but I think the idea of doing multi-university centers that span across our geographies has worked well. It has worked well with the NNIN that the NSF put in initially for nanofabrication work. It is the same kind of thing we are trying to do with NRI.

I think a balance is then trying to limit your investments to what can be afforded, but also tried to pull in as many universities as you can. And I would note that even though we center these in distinct states, they actually do pull in schools from other states, so actually to your questions earlier, for example, the California center in the proposal that we are just about to announce is pulling in the University of Iowa because there are a couple of professor there who were doing very interesting work. Geographically, we will have to work it out with telecons, but it is a way to get that school, also, very much involved in that work.

So I think that you can work around centers and then expand them out, but you have to give them a mission that they are going after so everyone understands why they are working together on this problem.

Dr. MELLIAR-SMITH. I guess I would like to second that. In my experience in the industry, I think the SRC and the marker centers have done a very good job of balancing individual contributors who can come from anywhere because any good idea can come from anywhere, with the larger organizations which have got the center of gravity they need to actually be successful in commercialization. If you are looking for a model, I think the semiconductor research organization is a good one.

Mr. MOFFITT. I would just echo the comment that I think the center of excellence approach is the right approach simply because it does focus and channel available resources and they are constrained, as we all know, and then I think they do locally and organically grow from that center. As developments are made, companies get spun out for commercial viability and commercial translation to this science, but that just loops right back in to the university and the universities in the area as well as other companies, so you tend to think of it as just dropping a few seeds here an there, and from that will grow, I think, a tremendous industry.

Dr. CHEN. One thing I would say in caution, though, with the center for excellence approach is that we want to make sure that we don't define nanomanufacturing as only one type of process because as we have seen with the predecessor to the NNIN, that was very heavily based in lithography-based processes, because that is the industry that was more actively in the nano-areas. So we don't want to too narrowly define what we mean by nanomanufacturing when we define what type of centers of excellence we should have, so I think that is important.

Dr. WELSER. I think every center of excellence is going to be a center of excellence in nanoscale science because that is the cutting edge of chemistry, condensed-matter physics and molecular biology. Nanotechnology affects every conceivable economic sector, and so we should think of this not as something esoteric or tied to a single industry, but it is very, very broad. So there are going to be many, many centers of excellence, each of them focusing on something they do uniquely well, and so that, I think, might be the appropriate vision to have.

Mr. LIPINSKI. Thank you.

Chairman BAIRD. We will finish shortly, but I wanted to raise two other issues.

The issue of access to federal facilities, particularly Dr. Melliar-Smith, you mentioned the DOE labs. How well is that working? Can we make it better? What are the obstacles that any of you have experienced in terms of access to these federal facilities that provide the infrastructure that allows people to do some of this work? How can we improve it and what are any strengths or weaknesses?

Dr. MELLIAR-SMITH. My experience has been very successful. Inevitably, there is a balance between what a company wants to do in a research facility and what the facility, itself, can let them do. There are obviously, ultimately certain constraints, but our experience at Berkeley has been excellent. They have allowed our research engineer to come in and use the equipment, largely unsupervised after full training.

These are things that we could not afford to put into the infrastructure ourselves and they are crucially important to us. Generally, we have not had a problem with them. At any given point in time, there may be an aggravation over this that or the other, but they are all solvable on both side, so we have been very supportive.

Dr. WELSER. Since we just formed this new partnership with NIST, we are very interested in how we can leverage the labs, and one of the things that the partnership started off with was the idea that NIST was very interested in having people come and utilize the labs, and we were very interested in taking advantage of what was there. But without an actual set of project to further, oftentimes it was difficult to figure out how you start the collaborations off, so one of their goals was funding some of the research at the universities as part of the NRIS to get better insight into what the researchers are doing to understand what they actually needed for future characterization tools.

Measuring the spin of an electron is something that is extremely important to us right now, and that is the kind of grand challenge that NIST can go after extremely well, and probably no individual university can really solve that problem with its own recourses. So I think leveraging the labs on specific projects, particularly for things that require tools or capability that is really beyond what a university can have is very important.

What I think is less effective is if we rely on them to have all of the fabrication and facilities that are needed to do the daily research of the students. I mean it is fine for a student to go to a lab for a week, a month, or whether to go work on a specific aspect of this project, but he really needs to be also back at his university working with his research group and his professor as he goes through. So that is why there needs to be a balance one-of-a-kind sorts of tools and capabilities with the labs with more pervasive investment at university centers to allow students to be able to do work at both places.

Chairman BAIRD. The number of people nodding their heads to that, apparently there is a consensus on that.

One last question, Mr. Moffitt, you talked about the $100 million venture cap or financial investment in bringing it from concept to manufacturing. Obviously, if we took the entire NNI and we would pretty quickly use up our funds. I was thinking of a gentleman named Yosi Verdi who is venture-cap, high-tech entrepreneur in Israel, and he had a very intriguing idea, and I won't articulate as well as he knows it, but an example where the Federal Government somehow indemnifies the venture cap folks, that we share the risks but also share in the profits so that you are able to leverage up-front money.

Any thought about a mechanism like that, versus say just a grant that goes and then we don't' necessarily net anything back from it, but some kind of a collaborative indemnification/repay model wherein we recycle the funds. Any thoughts about that?

Mr. MOFFITT. I hadn't though about the repay part of it yet.

Chairman BAIRD. That would not surprise me. The repay question, oh, you mean we have to pay this back? But that allows us to leverage the money, and you would get it up front. You would get the real startup kick, and then we can give it to somebody else.

Mr. MOFFITT. Of course, the repay comes in the form of us being successful and ultimately paying taxes, in part, but I would say——

Chairman BAIRD. So you are calling for special higher taxes for——

Mr. MOFFITT. No, I do think there is—I would make the point again the programs that exist today, they do serve as validators, and you know, as I said, there is a tremendous amount of private equity out there willing to be invested. The question is where and how do they separate the winners from the loser. They certainly will pick the right industry and industry segments, and I do think that there is a way to develop a program of investment credits so that the government does share in the up-front risk. But I agree. It is appropriate to share in the downstream reward, and perhaps something over and above just paying routine corporate taxes.

Dr. MELLIAR-SMITH. Certainly, in the Texas Emerging Technology Fund I spoke about one of the criteria for that investment is the company receiving the investment provides the state with common stock such that when the company is successful and goes through an IPO, the state essentially gets paid with a lot of profit to boot, assuming the IPO is successful, so I think there are many way. And again, I would encourage Congress to be innovative about asking for what you think you want from industry. It seems to me it is not at all unreasonable that if the government or a state establishment makes a significant investment in the company that there is a way to get the money back, and the venture-capital industry has lots of different ways for you to get your money back. That is why they specialize in it. It is what they do all of the time.

And so it is just a matter of sitting down and saying, okay, I want to try to form a partnership with industry, and where is what I want, and here what you want, and it isn't just a one-way street with checks being cut in Washington, but it is in fact a partnership.

Chairman BAIRD. Other thoughts or additional responses?

Dr. WELSER. An additional though is I strongly agree with that and the Texas model, as it was described to me is excellent.

I contended fairly strongly for gap funds, and I will simply add that I don't think that that is going to take a great deal of money or would be a large percentage of any given grant or the NNI. The needs of our gap grants are about $250,000, maximum, and that can do a great deal to get a company from the proof-of-concept stage to the point where a venture capitalist, you know, can consider it as an investment, so I simply would leave the thought that these don't have to be large amounts.

Chairman BAIRD. We have a bill called the Bridge Act which we introduced a couple of years ago which would allow rapidly growing companies to reinvest their tax liability in building the company, and then later on, once you've built up, you would pay the tax back with modest interest. So you are basically loaning yourself the money. It is one of those Catch 22s. If you had the money, you could expand, and if you could expand, you could pay more taxes, but because you don't have the money, you can't expand. And especially in your kind of industry, we need to find creative ways to not penalize, but in fact reward and incentivize the risk-taking, the expansion, and this Bridge Act, which I introduced on the House side and Senator Kerry is our Senator sponsor, we want to make a run at it.

Interestingly enough, there is some up-front cost to the treasury, but in the long run, our best estimates would generate hundreds of thousands of jobs with a net profit to the Federal Government because we would actually generate revenue. Here is a tax reform, not a tax cut at all, just a change in how and when we collect the tax and what is done with the money in the interim, and if anyone wants information on that, we would happy to share that with you.

Dr. Ehlers, any closing comments or questions?

Mr. EHLERS. Not really. I was just going to say that is the same rationale for the Bush tax cuts.

Chairman BAIRD. No, it is actually much different than that.

Mr. EHLERS. But I won't say that.

Chairman BAIRD. It is actually completely different. It is not a cut. You are paying it back. The point is you are still paying the same rates on it. You are paying it back over time, but only on the proviso that you reinvest the money. But you actually have to pay it back. It is a much, much different structure.

Mr. EHLERS. Thank you. I didn't intend to start that discussion, but I couldn't resist that.

Chairman BAIRD. I would let you pass on the John McCain seems to be the only person that is dealing with immigration in a responsible way, but I just couldn't let the tax cuts go by. If President Bush would actually support the Bridge Act, I would support—I want to thank our witnesses. We have digressed to much less pleasant topics, but this has actually been very, very fascinating, highly informative. I hope we will use your information well enough to justify the red-eye and the time away from your most important research. We look forward to great things, and we may well follow up. Also, if there are suggestions that you feel you want to add—sometimes these interactions stimulate further thought. You may go back and say here is a creative way. The reason we do these hearings is so that the legislation that comes out in a few months will actually be the best we could possibly make on this round. And it is an interactive process, as you know, so if there are further thoughts, we would welcome those.

And thank you. With the gratitude of the Committee, this hearing stands adjourned. We are grateful for your presence. Thank you.

[Whereupon, at 11:38 a.m., the Subcommittee was adjourned.]

Appendix:

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Robert D. "Skip" Rung, President and Executive Director, Oregon Nanoscience and Microtechnologies Institute (ONAMI)

Questions submitted by Chairman Brian Baird

Q1. Both Dr. Chen and Mr. Moffitt remark that user facilities require technical support, particularly for small company users. This raises the issue of how to safeguard the companies' intellectual property. Do you have suggestions on ways to reduce these concerns that now appear to inhibit use of the facilities by industry?

A1. Although I am not familiar with the user policies at all of the NNIN facilities, I do not believe there should be any fundamental or terribly difficult issues related to intellectual property. The remainder of this response is based on experience and practice at ONAMI-affiliated user facilities.

We distinguish between two types of usage that we believe are both valid and important roles for publicly supported nanoscience and microtechnology facilities: (a) research—including industry-sponsored or collaborative R&D involving industry partners, and (b) fee-for-service, i.e., access to sophisticated equipment and expert staff assistance. In the former case, research contracts with the university are in place, and these contracts will normally contain provisions related to intellectual property. Contracts with businesses typically include some kind of preferred right to negotiate a license (but see note at end regarding complexities created by federal private-use restrictions). In the fee-for-service case, no new IP is created by university or facility personnel, but there may be concerns about disclosure of client IP (unpatented inventions, trade secrets) that need to be dealt with by means of a non-disclosure agreement (NDA). When the actual work is done, the client specifies a measurement or fabrication task to be performed, and provides as much or little information to facility personnel as desired. The facility collects the data or performs fabrication steps as requested and provides the results to the client. Market rates (as best they can be determined) are charged for this type of service, and it is often best if the service is performed by professional staff rather than students (who may not be compelled to sign an NDA and have, by their nature, high turnover rates). Data is given to the client (e.g., on CD or thumb drive) and not retained by the facility unless the client desires it to be, and no attempt is made to publish the work unless the client wants to do so. State law and university system administrative rules can have an important influence on how these matters are handled.

Regarding private use restrictions (please note that I am not a professional bond counsel): Many research buildings and facilities—especially at State-supported institutions—have been financed with tax-exempt bonds. This results in a (federal) limitation (e.g., 10 percent) on the fraction of structure capacity that may be engaged in "private use" activities without jeopardizing the tax-exempt status of the bonds. It is the responsibility of State and university officials to ensure compliance with related law, which in Oregon's case is done system-wide. "Private use" can include such things as street-level retail (which is sometimes required of urban campus buildings by city councils) and valuation/sale of IP before it is created under the auspices of industry-sponsored research (e.g., advance grant of exclusive license or non-exclusive royalty-free license) For these reasons, much of the industry-sponsored research in the U.S. is long-range and "pre-competitive," funded by large industry consortia such as the Semiconductor Industry Association. All new ONAMI-affiliated facilities are being financed with taxable bonds, but this does not help us with the many existing buildings in which many of our researchers have their labs. A suggestion to consider that might make universities freer to engage in nearer-term commercialization is to create a way to "reimburse" the Federal Government for the value of foregone taxes related to capacity used for "excess" private use.

Q2. Relative to your comments on establishing a "gap" fund under NNI analogous to the fund your organization has, how would this work on a national level? Do you see it as a fund the Federal Government could use to support projects that would meet defined federal needs or requirements?

A2. My comments ("the suggested concept here is to have some portion of NNI funds—perhaps in association with large multi-year awards—tied to commercialization, perhaps in the form of a gap fund, with a short-term outcome measure of leveraged private capital investment") were not sufficiently clear on this point. I do not advocate creation of a national gap fund, which already exists to an extent in the SBIR, STTR and TIP programs. What I do suggest is that NNI funding encourage (and possibly help fund) local gap fund efforts similar to ours—which engage the business and investor communities closest to the researchers and facilities. I believe this could be very beneficial for technology entrepreneurship growth outside the most familiar venture "hot spots" such as Silicon Valley and the Boston and Austin areas. One possible form this could take would be requiring that a modest portion (perhaps five percent) of "center-sized" awards be managed as a gap fund, with incentives (e.g., cost-share) to augment these funds with state, campus and private resources. In addition to their nanoscience investors and commercialization partners having access to the ONAMI gap fund, Oregon research universities are now able to offer tax credits (up to a cap) for donor investments in "university venture funds" which may be used for proof-of-concept work and entrepreneurship development. Again, the purpose behind all of these programs is accelerated commercialization in partnership with small businesses and spin-out/start-up companies, which are often the best places to develop and introduce disruptive technology. As I will say in answer to Ranking Member Ehlers' first question, clear measures of success for this type of activity will be important.

Q3. One of the examples you give for a project supported with your gap funding (drinking water purification) also received a Phase II SBIR award. Were the two sources of funds used to fund different aspects of the project and did the SBIR award precede the gap funding award?

A3. Crystal Clear Technologies received its $500K NSF Phase II SBIR award in 2006, using those funds for technology development. The ONAMI gap award—made in 2007 to the University of Oregon to work with CCT—is being used for fabrication and laboratory scale-up of material samples for customers and certification testing.

Questions submitted by Representative Ralph M. Hall

Q1. Do you think that tax and investment credits for nanotechnology investment is a good idea? Do you have any thoughts as to what would be eligible for such a credit?

A1. I am no expert on tax policy, and in fact somewhat hesitant to suggest anything that further complicates federal and state tax codes, but the fact is that the tax codes are extensively used to encourage desired activity, and therefore they should prioritize incentives for those things which are most strongly in the national interest. Accordingly, I believe that an investment tax credit for investors in research-based businesses that can create high-wage R&D and advanced manufacturing jobs in the U.S. is worthy of serious consideration. This is because, except in cases where shipping costs dominate, research-based intellectual property is going to be the only durable basis for retaining manufacturing (physical activity-based) high-wage jobs in the U.S. and other affluent countries. We cannot simultaneously complete mainly on cost and maintain the world's highest standard of living.

The reason for making this an investor, rather than corporate, tax credit is that startup and growth stage companies are usually not profitable, and in fact should not be profitable until they reach a size commensurate with their targeted market share range. A venture-backed company, for example, is better off investing generated cash in growing the company than in distributing profits and paying taxes. Those things are the ultimate/mature objectives, of course, but it is a mistake to do them too soon and fail to realize the company's potential. A good example of this principle is Amazon—one of the successful dot.com companies. Their investors' and shareowners' patience with years of losses and negative cash flow has been rewarded, and it can be argued that if they had not "bought" market share with their large IPO proceeds, they could even have lost their position to competitors who did. The key point is that corporate tax credits and tax relief don't help innovative companies at their most critical stage. But investor tax credits can make them more attractive investments, so that is where any tax incentive for nanotechnology commercialization needs to be targeted.

As for determination of eligibility, it seems likely that law writing and rule-making in support of this idea will be complex. The things that should be emphasized are some of the same things emphasized in SBIR, STTR and TIP awards: high research content and technical risk, a preponderance of high-wage activity conducted in the U.S., potential for high economic impact and contribution to areas of high national economic and security interest.

Questions submitted by Representative Vernon J. Ehlers

Q1. You mention in your testimony that "accountability measures" are as important as the research itself—could you elaborate?

A1. My comment in testimony ("Intentional federal investment in, and accountability measures for entrepreneurial startup company-driven commercialization of NNI research are just as necessary and important as the research itself. . .") meant to suggest that there be (a) funding for the purpose of accelerating commercialization of NNI research along the lines described in my answer to Chairman Baird's second question above, (b) clear goals for what this funding is intended to achieve. In ONAMI's case, the ultimate goal of our commercialization "gap" funding is to create high-wage jobs in new traded sector companies. Since it typically takes several years before startup companies employ dozens, let alone hundreds, of people, a meaningful proxy metric that can show results much more quickly was chosen: private capital investment in the new company, with the expectation that this would happen within 12–18 months of the start of the gap project. Such capital investment is usually spent on staff salaries and locally purchased services and materials. It also indicates that professional investors have confidence that the company represents a growth opportunity.

Q2. How is "gap-funding" defined and identified? Since this type of funding seems to be a need unique to this industry, is there a point where the cost-benefit tradeoff will not be worth it? How do you know when the hurdles to commercialization are insurmountable?

A2. This "gap," by no means limited to the field of nanotechnology, is between what research agency funding will support and what private investors need to see before advancing capital to a company. Gap projects are alternatively referred to as "proof of concept demonstration" or "translational research," and their typical goal is to produce one or more product prototypes sufficient to convince customers to enter into supply agreements. Investors need to see reduced technical risk (i.e., something can be done repeatably) and customer "traction" (there is a demonstrated willingness to buy on the part of significant customers in a large market). Even with these things achieved, there still remain significant management team and execution (e.g., manufacturing and supply chain scale-up) risks, but investors are used to judging and managing these things. They just don't want to be surprised by unexpected technology or market risk.

Nanotechnology and other manufacturing businesses typically need this type of pre-investor R&D funding more than software, information technology and retail businesses because of their much greater technical risk and higher cost/longer cycle time of experiments and prototype builds. "Pulling the plug" on an investment is always a difficult decision to make. In our case, we will invest a maximum of $250K in a gap project, and we administer the award in three or four "tranches," with each tranche contingent upon meeting specific project and business development milestones. This is quite different than a one-time grant where all funds are committed up front. We follow all of our gap projects closely, and often take an active role in business plan improvement and introduction to investors. We are intensely focused on the one goal—and only success measure for the program—of securing private capital investment in the new company.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Julie Chen, Professor of Mechanical Engineering; Co-Director, Nanomanufacturing Center of Excellence, University of Massachusetts Lowell

Questions submitted by Chairman Brian Baird

Q1. Both you and Mr. Moffitt remark that user facilities require technical support, particularly for small company users. This raises the issue of how to safeguard the companies' intellectual property. Do you have suggestions on ways to reduce these concerns that now appear to inhibit use of the facilities by industry?

A1. Chairman Baird is correct in identifying IP concerns as a major hindrance to collaborations between industry and universities. Many universities have been wrestling with this issue. The IP issue may not be as difficult for user facilities as it is for funded research contracts for a large percentage of the cases. Perhaps in terms of overall numbers, the IP issue may be significant due to the greater number of industry interactions with the user facilities. There are three types of interactions:

- Type 1—the company is only interested in using standard characterization and processing equipment available in the user facility. The testing or processing is according to an established standard method or protocol, or the company is providing their own people to use the equipment, and no new IP is being contributed by the university. In this case, the company clearly retains all rights to the IP. I believe many user facilities have policies that work this way.
- Type 2—new R&D must be conducted by the university personnel to help address a design or processing problem, or to develop a new characterization method for the technology brought by the company. Here the university is clearly contributing IP, and the overall IP is thus shared.
- Type 3—this is where things get murky. There is no anticipated IP, as the effort starts out appearing to be a Type 1 effort. In the course of running some standard characterization or processing, however, university personnel discover a new idea. Here is where most of the IP negotiation problems reside and this small possibility also causes problems with negotiations for the Type 1 cases.

I believe what might help reduce these concerns is to have a group representing industry, federal funding agencies, and universities look at developing template agreements addressing these three cases. If the majority of companies and universities come up with an approach that seems reasonable to all parties, then such a template will help to reduce the time and effort required to come to an agreement for each individual case. Obviously, special cases will occur, but a template would help to speed up the process for the majority.

Q2. You indicate in your testimony that there would be value in federal support for technology demonstration partnerships between industry and academia that could be carried out using a modified form of the Small Business Technology Transfer Research (STTR) program. How would this program work; how would it differ from the STTR?

A2. Currently, the STTR program has two limitations that would hinder its utilization to encourage industry-university collaboration:

(1) only small business is eligible—in the case of nanotechnology, much of the R&D activity is still quite entrepreneurial in nature; even within the large companies, the nanotechnology group is typically a relatively new, relatively small group. Thus, allowing these groups within large companies to participate in the modified nano-STTR's would support some of the exciting opportunities

(2) most STTR topics are defined by the funding agency in terms of identified needs (e.g., Army, Navy, NASA, . . .)—for the nano-STTR's the topic should be identified by the industry-university partners.

The Phase I and II structures of the STTR program would be beneficial to supporting university-industry partnerships. The amount of funding and the timeframe would need to be looked at to determine if it is sufficient to lead to successful technology demonstration efforts.

Questions submitted by Representative Ralph M. Hall

Q1. Do you think that tax and investment credits for nanotechnology investment is a good idea? Do you have any thoughts as to what would be eligible for such a credit?

A1. I am not an expert when it comes to tax and investment credits, so I cannot answer this question with respect to the economic aspects; however, I will try to answer with respect to the impact on R&D.

Cash flow is constantly a concern for small companies and large public companies also have to worry about quarterly outcomes. Thus, any company investment in R&D typically has to have a very short time of return. This can be very ineffective in developing and/or transferring new technology. Tax and investment credits for R&D conducted as part of a partnership with a university could be one example that would encourage efforts on bridging the "valley of death." Also, even without a university involved, I like the idea of having credits that companies could "borrow" to reinvest, but then would "pay back" after successful product development. Yes, they do this in terms of paying taxes on earnings, but having some portion directed funneled back into the credit program would lead to a more direct connection (albeit, some complicated bookkeeping) between the objective of the fund and its success in achieving that objective. I am not sure the best mechanism, but we need a way to encourage U.S. companies to support some longer-term R&D.

Questions submitted by Representative Vernon J. Ehlers

Q1. How is "gap-funding" defined and identified? Since this type of funding seems to be a need unique to this industry, is there a point where the cost-benefit trade-off will not be worth it? How do you know when the hurdles to commercialization are insurmountable?

A1. I view "gap-funding" as the funds that bridge between the current R&D funding for universities and venture capital. For example, federal R&D funding will address the creation and understanding of a sensing method (e.g., functionalized nanoparticle sensor for chemical agents), but it will not typically fund the effort required to figure out how to connect the nanoparticles to the power, input/output, and packaging needed to make a working sensor.

The reason why this gap-funding is needed for the nanotechnology industry, is because many of the potential new products (beyond the "1st generation" products, which represent relatively minor modifications to existing processes) require major changes to the manufacturing process, and are thus viewed as risky by VCs. In addition, VCs are quite cautious these days due to recent history; until we have more examples of successes, there is a need to provide some gap-funding.

Cost-benefit analysis is crucial to deciding where to invest the gap-funding. Clearly, if significant funding is required for just an incremental improvement with little societal impact, this is not a useful investment. On the other hand, if significant funding is required for a huge advancement of major societal impact, but there is concern about "insurmountable hurdles," I think the requesters of such gap-funding have to make a case that is plausible to experts in the field. There will still be risk, but I think we need to pick a few examples, learn from them, and continue to push forward.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Jeffrey Welser, Director, Nanoelectronics Research Initiative

Questions submitted by Chairman Brian Baird

Q1. Both Dr. Chen and Mr. Moffitt remark that user facilities require technical support, particularly for small company users. This raises the issue of how to safeguard the companies' intellectual property. Do you have suggestions on ways to reduce these concerns that now appear to inhibit use of the facilities by industry?

A1. NRI is focused on basic research undertaken largely by university professors and students. Virtually all of this research is destined for public disclosure. To the extent confidentiality is needed, it is for only the short time necessary to decide whether to seek intellectual property protection. For these purposes, the confidentiality measures within the university community have proven to be quite sufficient.

Q2. NIST recently awarded the Nanoelectronics Research Initiative a grant of just under $3 million. What was NRI's level of funding before the NIST award? Did industry members of NRI contribute new funds to the project because of the NIST grant? If so, how much extra industry funding was leveraged by the NIST grant?

A2. From the beginning, the model for funding the NRI research has been to create centers where industry and state funding could be combined with federal supported university research, so it is important to consider all contributions. The industry funding directly to the NRI consortium has been about $5 million a year. In addition, individual companies have been contributing approximately $1.5 million a year to some of the NRI university centers, as well as in-kind donations of tools and equipment. The largest of these donations has been a $10 million commitment of equipment to the Western Institute of Nanoelectronics (WIN). The states have been contributing approximately $15 million a year in cash, equipment, and endowments for recruiting new Nanoelectronics faculty, in addition to major investments in new buildings, such as the expansion of the College of Nanoscale Science and Engineering's Albany Nanotech Complex in Albany, N.Y. to house the NRI's Institute for Nanoelectronics Discovery and EXploration (INDEX), estimated at over $200 million.

While NIST has just joined a few months ago, we have already successfully completed a new round of proposal awards, expanding the work at both the existing centers, including the addition of new universities and projects submitted independently, and opening a new center, the Midwest Academy for Nanoelectronics and Architectures (MANA) centered at Notre Dame in Indiana. The base industry contributions to the NRI directly have remained constant, but as a result of this expansion, industry is contributing approximately $2 million a year in additional support between the Midwest center and the expanded INDEX center in New York; New York state has committed an additional $1.5 million a year to the INDEX center; and Indiana and the City of South Bend have committed approximately $5 million a year to support the new MANA center, in addition to a $40 million investment in nanoelectronics buildings for both research on the campus and eventual commercialization in a new Innovation Park adjacent to the campus. Finally, the NIST partnership was instrumental in convincing the NRI sponsor companies to commit to additional years of industry funding for the program beyond 2008. This is exactly the kind of increased support we hoped the NIST partnership would foster, and we are very excited to see it happening in such a short period of time.

Q3. What is NIST's role in determining where NRI funds will be awarded? Do NIST scientists participate in the NRI application review process? If NIST does not feel a particular application merits an award, are there cases in which NRI would still grant that award?

A3. NIST participates directly in the full proposal and review process, as an equal member on the NRI Technical Program Group (TPG) and Governing Council (GC). NIST also receives a variety of rights and benefits with respect to the research results. For the process we just completed, NIST helped to write the initial call for proposals; helped to insure the open call was distributed broadly across all U.S. universities; and helped review, rank, and choose all of the proposals that were submitted. The successful proposals all were chosen by consensus between NIST and industry participants, and it is our goal in this process to have everyone agree with the final decisions that are made. However, if NIST felt strongly that a certain proposal did not merit funding, it would be possible that NRI could still choose to fund that award using industry funds alone.

Q4. You indicate that the NNI should develop a research plan for nanoelectronics. At present, what mechanisms are available for industry to influence the prioritization process for NNI-supported research? Do your member companies interact with the President's Council of Advisors for Science and Technology (PCAST), which currently serves as the advisory committee for the NNI?

A4. Our primary mechanism for influencing NNI prioritization is through informal interaction with the agencies. We have advisory members from NSF, NIST, and DARPA who attend our NRI monthly meetings, and industry members participate on some of the NSF review panels. At the PCAST level, I have presented the NRI work as a model for public-private partnership to one of the subcommittees in August, 2007, and George Scalise, the president of SIA, is on the PCAST.

While these mechanisms are valuable, it is not the equivalent of having a national research plan for nanoelectronics. What is needed is a more formal effort that can identify key technology challenges, such as discovering a new logic switch and the milestones that need to be achieved to meet the challenge. This type of effort can provide the basis for a focused and integrated national technology program.

Q5. You have stated in your testimony that there is a need for both large scale user facilities such as the NIST Center for Nanoscale Science and Technology user facility and smaller, university-based facilities where researchers can work directly with students and other researchers daily. Do you think that the current user facility infrastructure for nanotechnology at universities is sufficient to meet the needs of the research under the NNI?

A5. Many of our U.S. universities have excellent facilities for doing *micro*-electronics research, and this has served them well for both finding the new discoveries and training their graduate students to drive the semiconductor so effectively over the last 10–15 years. Much of this infrastructure was enabled by a combination of universities and states investing in the brick and mortar infrastructure, and the Federal Government supporting much of the specialized equipment through the NSF's National Nanotechnology Infrastructure Network (NNIN). However, as we move forward into the *nano*-electronics era—where it is not just about making things smaller, but rather about exploiting new effects and materials that exhibit entirely new behavior when less than 10nm in size—more specialized tools for fabricating and characterizing these structures are needed. And there needs to be increased focus on the right level of equipment to move beyond the initial single device lab demonstrations to doing small scale prototypes, in order to help expedite the process of commercializing these new discoveries.

The SIA, after multiple consultations with university and government experts, is suggesting a program be included as part of the NNI re-authorization to create a National NanoElectronics Research and Manufacturing Infrastructure Network [(N2)ERMIN] at U.S. universities based on the NRI model of centers of excellence. Note that the entire idea presented here is for strengthening the U.S. university infrastructure—no funding would go to the industry itself. This network will operate in the field of nanoelectronics, somewhat similarly to the way the NNIN operates in the field of nanotechnology in providing users' access to facilities, but with additional significant focus on both fundamental research and manufacturing components. This approach will place a major emphasis on the areas with the greatest potential for future economic development and societal impact for Nanoelectronics applications. In order to assure success, there is the need for a visionary and fully integrated approach that cannot be addressed by fragmented and less coherent activities. This program will establish the U.S. as the world leader in the field of nanotechnology, and especially nanoelectronics.

The (N2)ERMIN would operate as a virtual organization, utilizing and building upon the facilities and infrastructure of the U.S. universities focused on nanoscience and technology and sponsored in large part by NSF. It should be noted that the states and universities at the NRI centers, as well as at other locations, are already investing hundreds of millions of dollars in the necessary buildings and infrastructure, so the federal investment in tools, equipment, and operating costs will be well-leveraged. In considering the appropriate budget for (N2)ERMIN, it should be noted that many of the individual tools for nanoelectronic fabrication and characterization can cost between $3–10 million each. And based on experience from the existing university nodes of the NNIN, purchasing the equipment solves only half the problem. One needs to budget monies for long-term (~10 years) warranty/maintenance and personnel support. Typical warranty costs are 10 percent of the tool cost per year.

A typical operating staff member with appropriate overheads costs about $150,000 per year.

In addition to the academic facilities and infrastructure, a close partnership for conducting research should be formed between industry and the national labs, such as those owned by NIST, DOE and NASA. Similar to the current partnership between NIST and NRI, this collaboration should not only include government and industrial co-funding and technical guidance of the university research, but also leverage the key assets in the national labs for advancing the research program. (N2)ERMIN will provide nanoelectronics researchers a key advantage in conducting cutting-edge research, and through the partnership with industry, a rapid path for developing commercial technologies ahead of competitors in other countries is assured. And while the SIA focus is largely on Nanoelectronics, this same infrastructure can also be utilized for many other areas of nanotechnology, including bio-technology and new energy source research.

To realize the maximum benefit from the investments in Nanoelectronics, we propose a three-pronged approach to setting up (N2)ERMIN:

First, an agency, such as the NSF, should be charged with funding the large investments for the nanomanufacturing equipment and infrastructure at the universities, similar to what they have done with NNIN. To create a network of these facilities across the United States, they should target funding 4–6 multi-university centers using a budget of $100 million a year for the next five years. Such funding should be awarded based on merit peer review, including inputs from academia and industry on the review panels, following the usual approach well demonstrated by NSF. Preference should be given to universities that are working closely with industry, states, and multiple (at least two) government agencies on specific NNI objectives with high impact, such as finding a new switch. It should be noted that the states currently involved in the NRI centers are already investing hundreds of millions of dollars into new buildings and centers for Nanoelectronics research and product commercialization, so a ready infrastructure is emerging to house this new equipment, offering good leverage for the NSF investments.

Second, additional funding for "one-of-a-kind" tools should be allocated to the national labs, such as those owned by NIST and DOE, to support the university research efforts. This not only accelerates the pace of the research, by enabling capabilities beyond the scope of a university facility, but also increases the impact of the work in the national labs on research that can lead to new commercial applications.

Third, additional government funding on the order of $20 million a year should be directed through the agencies to be used for funding and managing the university research in collaboration with industry partners, similar to the NRI model with NIST currently. Involving industry early will help guide even the initial science research in directions that offer the most potential for future commercialization, and will insure that new breakthroughs can be validated and rapidly translated into product innovations.

Questions submitted by Representative Ralph M. Hall

Q1. Do you think that tax and investment credits for nanotechnology investment are a good idea? Do you have any thoughts as to what would be eligible for such a credit?

A1. The industry does not have a position with regard to specific tax credits for nanotechnology. We do strongly believe, however, that the Congress can best support nanotechnology research by expanding and making permanent the research and experimentation tax credit, which expired in December 2007. It is worth noting that, according to a study by the Information Technology and Innovation Foundation, the United States now provides one of the weakest R&D incentives, below our neighbors Canada and Mexico, and other nations including Japan, Korea, and France.

Questions submitted by Representative Vernon J. Ehlers

Q1. How does industry measure how much basic nanoresearch is the "right" amount?

Q2. How is "gap-funding" defined and identified? Since this type of funding seems to be a need unique to this industry, is there a point where the cost-benefit trade-off will not be worth it? How do you know when the hurdles to commercialization are insurmountable?

A1, 2. The answers to both questions follow. The semiconductor industry is somewhat unique in its approach to research, due to the basic science which governs the scaling of the transistors (currently CMOS) on our integrated circuit chips. For the past 30 years, scaling has enabled us to double the number of devices on a chip on predictable basis, allowing us to build a plan for growth. The increased devices not only mean that existing products and application will run faster and cheaper, but also means that whole new applications and products are enabled. For example, personal GPS units were enabled once we had scaled the key components for them to be small enough to fit on just a couple of chips in a portable, affordable unit. This is what has allowed the industry to grow exponentially—and hence has justified the subsequent increases in R&D funding to continue the cycle.

The nature of scaling also allows us to more accurately assess how much research will be needed to reach the next node, based on an understanding of the current challenges we see in front of us. In the case of CMOS technology, there exists the International Technology Roadmap for Semiconductors (ITRS), developed by a worldwide group of domain experts, that provides a fifteen year forecast for technology advancements required to advance or scale integrated circuit technology during this period. Basic research needs are identified using this ITRS forecast data. Estimates of existing annual research funding are obtained from contacts in international and domestic industry and governments and from publicly available data. Projections of funding required to address the basic research needs are developed based on the collective research management experience of the SRC staff and several industry advisors. The 'research gap' is the difference between annual research funding needs and the actual annual expenditures and was estimated to be on the order of two billion dollars in 2007.

Undoubtedly, we will eventually reach a point where the projections for the required research to advance forward may seem to be too large. However, the semiconductor industry, which was founded on innovation, has learned that its growth is tightly linked to its ability to continue to provide exponential increases in time of functionality per unit cost. Worldwide spending from all sources for basic semiconductor research that would sustain industry growth is less than one percent of the aggregate semiconductor sales and we think that the 'breaking point' for cost-benefits from research is not very near.

If research results point to the need for capital and human investments that are far outside the norm for the industry and/or if the projected performance per unit cost doesn't offer the potential for order-of-magnitude improvements over conventional technology, then it is likely that the new technology will not be implemented. A proviso is that the new technology could offer or open new market opportunities or distinct advantages in defense applications that might justify its commercialization.

It should be noted that as we approach the current challenge of finding a "new switch" to replace the CMOS transistor in the next 10–15 years, we do anticipate a need for much larger investments in basic science and research. And similar to when we made the last major transition—from the vacuum tube to the solid state diode—it will require joint work between industry and universities, with substantial investment from the Federal Government. In the 1940's, the Department of Defense made most of these investments, working with both university and industry labs, and it is estimated that the total investment over a 10-year period was approximately $5 billion (in today's dollars) to do the first prototypes of the solid state diode that went into their weapons systems. Leveraging this investment, Bell Labs created the first solid state transistor which launched the entire semiconductor industry. This is now a $250 billion industry, enabling a much larger electronic products industry and driving much of our Information Technology based economy today.

ANSWERS TO POST-HEARING QUESTIONS

Responses by William P. Moffitt, Chief Executive Officer, Nanosphere, Incorporated

Questions submitted by Chairman Brian Baird

Q1. Both you and Dr. Chen remark that user facilities require technical support, particularly for small company users. This raises the issue of how to safeguard the companies' intellectual property. Do you have suggestions on ways to reduce these concerns that now appear to inhibit use of the facilities by industry?

A1. Given that early stage development companies are typically still in the "exploratory" phase of technology development (even though they may have specific commercialization targets), investors expect discoveries made to be the property of the company, which adds to the value and provides some measure of liquidation risk mitigation. Therefore, discoveries made while using such facilities require significant negotiation for the company to retain sole ownership of those rights. At the same time, there is always a certain amount of "trade secret" information developed, which the company would like to hold as proprietary, but how does one keep learned knowledge in the minds of the facility staff from spreading? This becomes a question of value gained from use of the facilities versus risk of loss of important proprietary information. Add to this perhaps the requirement to disclose confidential information to educate facility personnel in order to perform projects and the risk can often outweigh the value gained by using such a facility. The only recommendation I can make is to ensure that all proprietary information (whether jointly developed or not) remains exclusive property of the company using the facility. How to prevent spread of learned knowledge is another matter and one that does not have an immediate solution other than non-disclosure agreements.

Q2. You comment in your testimony on the need of nanotechnology companies for trained and skilled lab technicians, as well as Ph.D.s. What is the experience of your company in finding the skilled workers you need and is this a widespread problem among the companies in the NanoBusiness Alliance?

A2. Nanosphere has had a difficult time finding highly skilled technicians who are necessary to build both R&D and production staffs. We continually have open job requisitions. Some training in nanotechnology is important to understanding why and how certain important processes are dissimilar from other highly technical industries (chemical, semiconductor, etc.). We have not had as great a problem finding Ph.D.s as we are located in close proximity to the International Institute for Nanotechnology at Northwestern University in Evanston, IL. I believe you would find other nanotech companies in the NanoBusiness Alliance struggling with the same issue.

Q3. Please expand on your comment regarding cost of use of NNI supported facilities by businesses. Is there a difference in the level of user costs for facilities supported by NSF versus DOE? Is there much variation in the quality of user support or the administrative burden associated with different facilities? And, what specific recommendations do you have to make these facilities friendlier for industry users?

A3. My company has no direct interaction with such facilities, therefore, my remarks are confined to information I have gathered from other members of the NanoBusiness Alliance. Recommendations for improving use of such facilities include:

1. Resolve IP issues (see above).
2. Develop and disseminate a single, national resource listing of all facilities and the equipment and capabilities/services they offer. To my knowledge this does not exist in one place today.
3. Price services on a direct cost basis for time and resource usage, without inclusion of overhead burden and administrative fees. While these latter costs are real, inclusion of unabsorbed overhead burden in the cost of use diminishes value received and can be a deterrent to usage.

Questions submitted by Representative Ralph M. Hall

Q1. You mention in your testimony that it would be good for the Federal Government to create an additional incentive for private sector investment by developing "a program of tax and investment credits which will help mitigate risk *for early capital and provide additional incentive for investments directed at goal oriented research and development programs." What form do you think these tax and investment credits should take?*

A1. First, I believe the government can direct resources by funding selected industries, those with the likely greatest payback to society (health care and energy). There are a few ways to construct such programs:

1. Within certain guidelines and certain qualifications, permit small companies who are still cash flow negative to sell federal net operating loss carry-forwards ("NOLs") to larger companies who can then apply them to their taxes. This has the effect of reinvesting tax revenue in entrepreneurial efforts that will create jobs and drive product development in a given area, not just research. The net effect is the small company raises capital at the government's cost of capital, not that of a small, high risk start-up.
2. Tax credits for investors in specific nanotech sectors. Deductions for qualified losses of high risk capital, not just offsets to gains.

Q2. You state in your testimony that the U.S. currently leads the science in nanotechnology, but could lose the commercialization race. How would an early regulatory regime affect the growth of the nanotechnology commercial industry?

A2. Assuming I have correctly understood the question, my comments were originally directed at the need to more evenly balance funding for commercialization efforts with basic scientific research. It is incumbent upon all in the nanotechnology space to ensure safety of their products and practices and to that end a question is whether current regulations suffice to ensure public safety. More regulations specifically directed toward nanotechnology may be required or appropriate. I do not have sufficient visibility to data outside my own company to have an opinion. However, greater regulatory requirements in the absence of data to support the need would risk unnecessarily adding to the burden, cost and timeline for commercialization. Those companies in health care (as is Nanosphere) already come under regulatory oversight of the FDA, which, while history will show has protected public health, has added to the burden and cost of product commercialization. An additional layer of regulations applied to nanotechnology would further hinder commercialization. If data prove such regulations necessary, I would strongly support implementation, but in the absence of data, added regulations make no sense.

Questions submitted by Representative Vernon J. Ehlers

Q1. How does industry measure how much basic nanoresearch is the "right" amount?

A1. At the highest level, it becomes an understanding of whether there is a backlog of discovery in the absence of advancing discoveries to commercialization and the solutions to problems where nanotech holds promise. At some point (how to define?), nanotech must provide society with a return on investment by contributing to or providing solutions for key problems in society or we run the risk of funding science for the sake of interesting science. It is always easy to make the "undiscovered breakthrough" argument in favor of continued heavy investment in basic science, but that must be tempered with practical application of discoveries.

Whether the government and we as a society back one technology or another should be measured by the ability to convert science to solutions. In the case of nanotechnology, the science is early, so the risk for commercialization is still very high. This creates the "gap" referenced in the second question below. Venture capital needs to see some early successes to underwrite confidence and/or see the commercial promise of a given technology before committing significant funding. It is this early stage gap between science and building a portfolio of commercial successes for a new technology that is difficult to fund. Government support can help bridge this gap. Once nanotechnology begins to build a portfolio of successes, gap funding requirements will diminish, if not disappear. Moreover, one would think that continued funding of basic science in the absence of meaningful practical applications would underwrite the likely false pretense that nanotech holds no value (as measured by society).

As for a quantitative measurement of the "right" amount of basic nanoresearch, do data exist to compare invention disclosures (NSF, NIH, DOD, etc.) with commercialization or licensing activity? How does the current status of nanotech compare with other platform technologies? How often do government-funded development contracts result in products with sustained usage? These measures of productivity may be part of a formula to balance basic science with development of applications.

Q2. How is "gap-funding" defined and identified? Since this type of funding seems to be a need unique to this industry, is there a point where the cost-benefit tradeoff will not be worth it? How do you know when the hurdles to commercialization are insurmountable?

A2. (Reference the answer to the question above as well.) I am not certain that "gap funding" is unique to the nanotechnology industry. Rather, I would submit that such fundamental breakthroughs in science are not that common and we happen to be in the midst of one now, creating the appearance that this is the only industry with such requirement. Moreover, because nanoscience has the potential to significantly impact virtually every industry we know, there is significant inertia. Did not the semi-conductor industry require significant government funding in the earliest of days? What about the human genome project? However, the question concerns time and cost for a return on the investment in nanoscience and recognition of whether and when challenges are insurmountable. It strikes me that this is not dissimilar from resolving whether the microprocessor has actually improved productivity in society. There have been arguments to the contrary.

No question that it is difficult to objectively measure the return (or lack thereof) on scientific discovery that unfolds over decades. One source of data would be government funded nanoscience programs seeking to develop applications and whether those have been successful. At a higher level, an analysis of the percentage of any given industry now represented by nano-enabled technology would also provide both an understanding of the success of nanotech development and an opportunity to understand return on investment.

ANSWERS TO POST-HEARING QUESTIONS

Responses by C. Mark Melliar–Smith, Chief Executive Officer, Molecular Imprints, Austin, Texas

Questions submitted by Chairman Brian Baird

Q1. Both Dr. Chen and Mr. Moffitt remark that user facilities require technical support, particularly for small company users. This raises the issue of how to safeguard the companies' intellectual property. Do you have suggestions on ways to reduce these concerns that now appear to inhibit use of the facilities by industry?

A1. In my mind, the issue is less about protecting a company's IP than it is about how the two organizations (the company and the national facility) seek to protect their own IP as they work together. Every company has the responsibility to protect its IP and should do this through patent applications before the begin working with any other entity—be it commercial or national. The real issue in my experience has been that the national facility, which also wants to protect its own IP on behalf of the taxpayers, will often get into overly legal battles with the companies seeking to do business with the national facility. In this respect they are no different than any other enterprise.

Congress should send a clear directive to the DOE as to what role they want the National Labs to play. If the purpose is to enhance the U.S. economy by working with U.S. companies, then the directive can be towards a laxer protection approach to existing and new IP generated by the National Labs. Congress should also ask the DOE to measure the success of this activity and report back to the Congress on these objectives on a regular basis.

Squabbles over IP are not a new item. They are a regular occurrence. They are usually solved through negotiation. Small companies also need to understand that they cannot simply use all the IP at the National Labs without charge, and the National Labs should view the small companies as customers.

Q2. Is the research now being supported under the nanomanufacturing component of the NNI meeting the needs of industry? Do you believe industry has a voice in determining research priorities for these activities?

A2. My company has not been that involved with NNI programs and funding—most of our funding has come from DARPA, ATP and the U.S. Navy. I would say that this support has been excellent.

Question submitted by Representative Vernon J. Ehlers

Q1. How does industry measure how much basic nanoresearch is the "right" amount?

A1. This can be a somewhat different answer if the question is related to either companies or the government. For companies the answer is relatively straight forward. It is what the management and the board of directors feel is appropriate. This can range from 50 percent plus of revenues for small start up companies to a more typical 15 percent for established high tech companies.

For governments, I think the answer should be more focused on the value and outcome of the research rather than the absolute amount of money. There is certainly a place for fundamental research to expand the frontiers of knowledge, but even in this case it should be structured around the eventual objective or benefit. The best research is always done in this context.

I believe that the total funding being spent by the U.S. Government on research is adequate at present. Congress should make it a point to measure the value of the research outcomes on a regular basis.

The National Labs and also the large research universities are a very valuable, and probably under utilized resource, for the Nation. Such entities are hard to duplicate and take many years to build up to their full potential. Funding for these institutions should be predicated on the expectation that over time, they serve the needs of the Nation.

Questions submitted by Representative Ralph M. Hall

Q1. You mention in your testimony that you are working with the LED industry to place nano features on high brightness LED's to increase their efficiency. How *exactly will nano features increase efficiency? What properties of nanoparticles allow for an increase in efficiency?*

A1. High brightness light emitting diodes are built from high refractive index semiconductors such as gallium nitride. As a result a significant fraction of the light photons emitted by the semiconductors are trapped inside the LED by total internal reflection. By adding an array of specially designed nano features, called a photonic crystal, to the surface of the LED, it is possible to breakdown the total internal reflection at the semiconductor/air interface and let the photons escape. This enhances the efficiency of the LED—light out per watt of electrical energy used by the LED.

In addition, photonic crystals can be used to coalesce the light into a sharper beam as it is emitted from the LED. This is important for some applications where a focused light source is required—for example automobile headlights. This improvement is referred to as an increase in brightness.

Q2. You mention an ATP grant that your company received in 2004. Would you say that this award helped bring in venture capital? Has your company benefited from the SBIR program and, if so, how?

A2. Our ATP grant was a great value to the company. It helped us fund the evolution of our capability well into manufacturing and to build strong customer relationships. It was a very important facilitation to help move Molecular Imprints to the next level. It was not directly related to our venture capital funding in that no VC actually came to us and said "we will not invest unless you have ATP money." However, as we have approached later stage funding from the VCs it is clear that the contribution made by the ATP grant has helped as make a stronger company and hence a stronger case for additional VC funding. We have not used SBIR funding.

Q3. Do you think that tax and investment credits for nanotechnology investment is a good idea? Do you have any thoughts as to what would be eligible for such a credit?

A3. Generally not. Most small companies do not pay any federal taxes and so tax credits are irrelevant in the early stages where cash flow is critical. Once the companies become profitable they should pay taxes like anyone else.

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