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Committee on Science and Technology
Subcommittee on Research and Science Education

Hearing on:

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

Testimony of:

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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,

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[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)

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]. 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.

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[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://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 US Manufacturing Industry," full report available on http://www.ncms.org/publications/PDF/05NCMSNanoFinalReport.pdf (accessed March 3, 2008)

Of the respondents in the 2006 survey, 45% felt that the federal government should take the lead in fostering R&D and providing commercialization incentives, while an additional 43% favored participation, but in a limited fashion. These results mirrored those of the 2005 survey, where over 90% 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% of the respondents, with the second highest area (basic, long-term research) coming in much lower at 15%. 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%) 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%). 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 represented 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 3 to 5 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.

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[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)

- **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 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 nano-products – 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% rated access to unique equipment and facilities as very important. Although almost 60% 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 1/3 or ½ 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 of 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 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 (US, 2001, US-Germany, 2005, and Indo-US, 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 PhD, 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.

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[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.