TESTIMONY

of

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to the

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Introduction

On behalf of Northwestern University, I would like to thank Chairman Buchson, Ranking Member Lipinski, and the entire Subcommittee on Research and Technology for the opportunity to participate in today's hearing entitled "Nanotechnology: From Laboratories to Commercial Products." I am currently the Bette and Neison Harris Chair in Teaching Excellence, Professor of Materials Science and Engineering, Chemistry, and Medicine, and Director of the Materials Research Center at Northwestern University. My research group studies and develops nanomaterials for use in a wide range of technologies including electronics, optoelectronics, photovoltaics, batteries, catalysis, and bioimaging. A significant portion of our research has been or is in the process of being patented and commercialized, including our work on carbon nanomaterials that has served as the basis of a startup company that I cofounded called NanoIntegris. I have also been deeply involved in the development of education and outreach activities based on nanoscience and nanotechnology. I greatly appreciate the opportunity today to share my experiences and perspectives on several topics related to nanotechnology policy including fundamental research, application development, commercialization, intellectual property, education, and global competitiveness.

Importance of Fundamental Research

In many ways, I am a product of the National Nanotechnology Initiative. When I entered college in the mid-1990s, I initially intended to pursue an undergraduate degree in engineering as a stepping stone to an MBA and a career on Wall Street. However, these plans abruptly changed following a fundamental research seminar where I was introduced to the scanning tunneling microscope. Not only does the scanning tunneling microscope allow the atomic structure of matter to be visualized, but it can also be used as a tool to manipulate materials with atomic precision. I was immediately enthralled by the possibilities for nanofabrication at the nanometer-length scale, including the evidently attainable goal of constructing electronic devices and circuits with unprecedented computational power. Foreseeing a future that included ubiquitous portable electronics that would revolutionize how individuals would interact with each other and technology, I decided to abandon the MBA plan and instead enroll in graduate school where I could pursue fundamental research on nanoelectronic materials. Since countless other practicing scientists and engineers have similar stories, I am confident that one of the most significant benefits of federally funded fundamental research is its ability to inspire and motivate young people to pursue careers in science and engineering and thus become the drivers of technological and economic growth.

My career decision was subsequently validated when President Bill Clinton announced the National Nanotechnology Initiative during the final year of my PhD studies. In my independent faculty career at Northwestern University, the vast majority of my research has been funded by the National Nanotechnology Initiative. While much of this research has become increasingly applied as elements of the nanotechnology field have matured, these systematic application developments have been punctuated by discontinuous, unanticipated breakthroughs. For example, when the National Nanotechnology Initiative was announced in 2000, no one was talking about the material graphene (a one-atom thick sheet of carbon). However, this material was later discovered in 2004, rapidly advanced over the next 5 years, and ultimately won the Nobel Prize in Physics by the year 2010. More recently, a diverse range of additional atomically thin materials have emerged out of fundamental research laboratories. These nanomaterials are now poised to impact high value applications in information technology, energy technology, and biotechnology. Therefore, while I strongly support the emergence of applied nanotechnology research funding in recent years such as the Nanosystems Engineering Research Centers from the National Science Foundation, nanoscience remains an extremely fertile ground for discovery and therefore a diversified federal funding portfolio that includes sustained support for fundamental research is critical to realize the full potential of nanotechnology. For example, an expansion of the National Science Foundation Nanoscale Science and Engineering Centers, which have a significant focus on fundamental research, would effectively complement the more applied Nanosystems Engineering Research Centers.

Sustained Commitment to Application Development

Over the past decade, nanotechnology has proven to have broad, interdisciplinary impact in virtually all fields of science and engineering. As the co-chair of the National Science Foundation sanctioned global study entitled "Nanotechnology Research Directions for Societal Needs in 2020: Retrospective and Outlook," I had the opportunity to meet with global nanotechnology leaders and observe diverse prototype nanotechnologies that positively address problems in medicine, health, environment, water, energy conversion/storage, catalysis, electronics, photonics, magnetics, and structural materials.[1-3] While some of these prototypes have begun the transition to the marketplace, others remain at a nascent stage. It should also be noted that most of the early nanotechnology application developments have exploited one specific nanoscale device or material, which suggests that significantly more innovation will emerge as multiple materials and functions are integrated into unified platforms.

In this regard, the historical development of related technologies can provide insight into the likely future for nanotechnology application development. Since nanotechnology by definition focuses on short length scales, it is particularly relevant to look at the historical development of other technologies that gained performance through miniaturization. Specifically, the microelectronics revolution is a poignant example of how the relentless reduction in size of the solid-state transistor has driven ever-improving performance of integrated circuits, computers, and portable electronics. While the invention of the transistor was immediately recognized as a means of replacing the vacuum tube and thus could dramatically reduce the size and improve the effectiveness of computer technology, it took another 14 years of sustained effort to solve all of the materials compatibility and systems-level issues before the first integrated circuit was realized. Similarly, many of the early successes of nanotechnology are now in the midst of analogous sustained efforts to solve the reliability, reproducibility, integration, and systems-level problems that will maximize their potential. Consequently, sustained federal support in these areas will ensure that the full technological and economic impact of nanotechnology applications will be achieved.

As noted above, the National Science Foundation Nanosystems Engineering Research Centers are providing such support in a select number of application areas. However, broader investments of this type across all funding agencies (e.g., Department of Energy, Department of Defense, National Institutes of Health, and National Institutes of Standards and Technology) will be necessary to achieve the full range of nanotechnology applications. In addition, both fundamental and applied research requires universal access to nanotechnology infrastructure. Historically, the National Nanotechnology Infrastructure Network provided such infrastructure, but its future is currently in doubt. Renewal and expansion of this program will undoubtedly accelerate the timescales for nanotechnology innovation. In all cases, researchers will be able to plan and execute their application development most efficiently when funding is sustainable and predictable. Therefore, it is highly desirable for federal budgets to be announced and approved in a timely manner without the uncertainties and unpredictability that result from brinkmanship, government shutdowns, and unanticipated sequestrations.

Commercialization and Intellectual Property

The ultimate judge of the utility of any technology is its ability to succeed as a commercial product in the marketplace. Towards that end, many nanotechnologies that were originally supported by federal research grants have spun out of university research laboratories into startup companies. For example, during its 10 years of funding from the National Science Foundation, the Nanoscale Science and Engineering Center at Northwestern University launched 14 startup companies in diverse technologies ranging from biomedical diagnostics and therapeutics to nanoelectronic materials. The company that spun out of my lab, NanoIntegris, is among those 14 startups. In its early stages, NanoIntegris benefited significantly from federal funding in the form of Small Business Innovation Research grants that supported the scale-up of our carbon nanomaterial purification technology. By accelerating our technical milestones, the Small Business Innovation Research program allowed NanoIntegris to more quickly focus on business development, ultimately growing revenue and creating jobs. Expansion of the Small Business Innovation Research program, especially at the Phase II level, will thus enable more nanotechnology startup companies to negotiate the so-called valley of death, resulting in sustainable economic and job growth. Furthermore, early-stage proof-of-concept funding will enable more research laboratory concepts to reach the prototype level, which is often a prerequisite for successful commercialization.

While the NanoIntegris story is largely positive, its ultimate success was nearly compromised by issues surrounding intellectual property. The key patent application for NanoIntegris, which consisted of both method and composition of matter claims, was filed in early 2005. However, the initial office action response from the United States Patent and Trademark Office did not occur for nearly 4 years, and the initial patent, which only allowed the method claims, was not issued until early 2010. To this date nearly 10 years later, the composition of matter claims remain pending. While the 10 year timeframe on the composition of matter claims is exceptional, a wait of 4 to 5 years for a nanotechnology patent to be issued has been commonplace in my experience. Indeed, I currently have 28 nanotechnology patents pending, which implies that my commercialization attempts have largely occurred without formal patent protection. In the case of NanoIntegris, the absence of issued patents likely contributed to our technology being blatantly copied by multiple companies in Asia, which created stress on our emerging business that could have been minimized with more expeditious patent protection. Therefore, I strongly believe that policies that improve the efficiency of the United States Patent and Trademark Office are critical for advancing and protecting nanotechnology commercialization.

Education and Global Competitiveness

It is well documented that the United States is trailing many other industrialized nations in science, technology, engineering, and math (STEM) education at all levels including K-12, undergraduate, and graduate students.[4] While this problem is multi-faceted with no easy solution, the situation is certainly improved when the most talented American students are inspired to pursue careers in science and engineering. Towards this end, the incorporation of nanotechnology content into education and outreach efforts has been exceeding successful at Northwestern University. For example, under the support of the National Science Foundation, I incorporated nanotechnology into our undergraduate materials science and engineering curriculum, resulting in a doubling of our domestic undergraduate population. Similarly, efforts targeting undergraduate research, such as the Research Experience for Undergraduates program, have been successful at inspiring domestic students to pursue graduate study in this field. From the perspective of entrepreneurship, the Small Business Evaluation and Entrepreneur program and the NUvention program have successfully united science, engineering, and business students in the development of business plans based on nanotechnology research that have helped spawn the aforementioned 14 nanotechnology startup companies from Northwestern University.

At the K-12 level, the Research Experience for Teachers program brings K-12 STEM teachers onto campus in the summer, allowing them to be exposed to the latest nanotechnology research that then inform their curricula and thus impact their K-12 students. Similarly, the Materials World Modules program reaches thousands of K-12 students by developing teaching modules that can be seamlessly incorporated into K-12 STEM curricula. Partnerships with local museums, such as the Chicago Museum of Science and Industry, allow the excitement of nanotechnology innovations to be disseminated to the general public. These education and outreach efforts were pioneered and directed in a coordinated fashion under the support of the National Science Foundation Nanoscale Science and Engineering Center. An expansion of these centers will therefore not only facilitate nanotechnology research but also provide tangible benefits to STEM education and American global competitiveness.

At the graduate level, the National Science Foundation and National Defense Science and Engineering Graduate Fellowship programs have been exceedingly successful in recruiting and retaining the top domestic science and engineering talent. While these fellowships do provide a modest financial incentive to prospective graduate students, their true value is in the intellectual freedom that is provided to fellowship recipients. By combining the top talent with the freedom to pursue creative research solutions, federally funded graduate fellowship programs consistently produce significant discoveries, innovation, and domestic graduate students with a high propensity to remain in science and engineering in their subsequent careers. Consequently, an expansion of the National Science Foundation and National Defense Science and Engineering Graduate Fellowship programs would have immediate impact on graduate education and American global competitiveness.

Conclusions

In conclusion, the National Nanotechnology Initiative has successfully fueled fundamental discoveries, application development, commercialized technologies, educational innovation, and global competitiveness over the past 14 years. With its ability to impact diverse and interdisciplinary problems in medicine, health, environment, water, energy conversion/storage, catalysis, electronics, photonics, magnetics, and structural materials, nanotechnology touches essentially all technological sectors and will continue to impact economic and job growth for the foreseeable future. This opinion is now widely held globally, leading to substantial investments in nanotechnology by governments throughout the industrialized world. Consequently, coordinated, predictable, and sustained federal funding by the United States in both applied technology development and fundamental research will be critical to maintaining our global competitive advantage. In addition to continued growth of the National Nanotechnology Initiative, specific recommendations include expansion of the Nanoscale Science and Engineering Centers and Nanosystems Engineering Research Centers, reinstatement of the National Nanotechnology Infrastructure Network, expanded support of the Small Business Innovation Research program, reforms targeting improved efficiency of the United States Patent and Trademark Office, and growth of the National Science Foundation and National Defense Science and Engineering Graduate Fellowship programs.

References

[1] M. C. Roco, C. A. Mirkin, and M. C. Hersam, "Nanotechnology research directions for societal needs in 2020: Summary of international study," *Journal of Nanoparticle Research*, **13**, 897 (2011).

[2] *Nanotechnology Research Directions for Societal Needs in 2020*, M. C. Roco, C. A. Mirkin, and M. C. Hersam, eds., Springer, 2011, ISBN: 978-94-007-1167-9.

[3] http://www.wtec.org/nano2/Nanotechnology_Research_Directions_to_2020/

[4] E. T. Foley and M. C. Hersam, "Assessing the need for nanotechnology education reform in the United States," *Nanotechnology Law and Business*, **3**, 467 (2006).

Executive Summary of Testimony

The National Nanotechnology Initiative has successfully fueled fundamental discoveries, application development, commercialized technologies, educational innovation, and global competitiveness over the past 14 years. With its ability to impact diverse and interdisciplinary problems in medicine, health, environment, water, energy conversion/storage, catalysis, electronics, photonics, magnetics, and structural materials, nanotechnology touches essentially all technological sectors and will continue to impact economic and job growth for the foreseeable future. This opinion is now widely held globally, leading to substantial investments in nanotechnology by governments throughout the industrialized world. Consequently, coordinated, predictable, and sustained federal funding by the United States in both applied technology development and fundamental research will be critical to maintaining our global competitive advantage. In addition to continued growth of the National Nanotechnology Initiative, specific recommendations include:

(1) Expansion of the National Science Foundation Nanoscale Science and Engineering Centers due to their success in fostering fundamental research, breeding new discoveries, and accelerating innovation in nanotechnology education and outreach.

(2) Sustained support of the National Science Foundation Nanosystems Engineering Research Centers and related applied research centers across all funding agencies (e.g., Department of Energy, Department of Defense, National Institutes of Health, and National Institutes of Standards and Technology) to ensure that the full range of nanotechnology applications are realized.

(3) Reinstatement of the National Nanotechnology Infrastructure Network to provide regional hubs and ultimately universal access to nanotechnology infrastructure for fundamental research, applied technology development, and commercialization activities.

(4) Expanded support of the Small Business Innovation Research program both at Phase I for proof-of-concept demonstrations and at Phase II to help nanotechnology startup companies negotiate the so-called valley of death, resulting in sustainable economic and job growth.

(5) Reforms targeting improved efficiency of the United States Patent and Trademark Office so that valuable nanotechnology intellectual property can be secured quickly, thereby reducing commercialization risks and improving American global competitiveness.

(6) Growth of the National Science Foundation and National Defense Science and Engineering Graduate Fellowship programs due to their proven success at producing significant discoveries, fostering innovation, and attracting the top domestic students with a high propensity to remain in science and engineering in their subsequent careers.